

Water use and yield of sugar beet (*Beta vulgaris* L.) under drip irrigation at different water regimes



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ABSTRACT

This study examines the effects of different irrigation regimes on water use and root yield of sugar beet, irrigated with a drip system under field conditions in the 2012–2013 seasons at Cukurcayir in the Kirsehir Centrum of the Central Anatolian region of Turkey. Experiments were carried out in split plots in randomized blocks with three replications.

The application of irrigation water was based on cumulative class A pan evaporation within irrigation intervals. Study treatments consisted of one irrigation interval (7 days); the two sugar beet varieties (C_1 : Esperanza and C_2 : Calixta) and three different irrigation levels (I_1 , I_2 , and I_3) adjusted according to the class A pan evaporation (E_{pan}) using three different plant-pan coefficients (K_{cp1} : 0.5; K_{cp2} : 0.75; and K_{cp3} : 1.00).

The lowest and the highest values of irrigation water and plant water consumption (Et) were observed in the I_1 and I_3 treatments in both years, respectively. In 2012, the lowest and the highest root yields were observed in the I_3C_1 (85.38 t ha⁻¹) and I_2C_2 (75.10 t ha⁻¹) treatments. In the second experimental year, the lowest and the highest root yields were achieved with the I_3C_1 (66.13 t ha⁻¹) and I_1C_2 (47.57 t ha⁻¹) treatments, respectively.

The impact on the examined parameters of irrigation programs in the C_2 treatment had not significant. On the other hand, in the C_1 treatment of irrigation programs had a significant effect on sugar rate, sugar yield, and other parameters. If the economic yield and quality are desired, the I_1C_1 treatment can be suggested for sugar beet production under the similar soil and climatic conditions.

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1. Introduction

Today, about 144 million tons of sugar is produced each year in as many as 127 countries around the world (Thelen, 2004). Worldwide, 80% of the world's sugar supply comes from sugar-cane, cultivated in tropical climates in developing countries, while the remaining 20% comes from sugar beet that is mainly cultivated in industrialized countries. The largest producing countries are Brazil (25%), India (10%), China (10%) and the 27 European countries (9%), followed far behind by the United States, the Russian Federation, Turkey, Ukraine and Food and Agriculture Organization of the United Nations (FAO, 2009).

Sugar beet (*Beta vulgaris* L.), grown mostly under irrigated conditions, is a major commercial field crop in Turkey, and Turkey's share in world production of beet sugar in 2010/11 was 2.27 million tons, accounting for 8% of the world total. Sugar beet takes an important

place among the field crops grown in the Kirsehir Province, given its economic importance as the raw material for the production of sugar. In the Kirsehir Province, the average sugar beet production was 58.2 t ha⁻¹ in 2012 on 49,113 ha of sugar beet growing area (TSFGD, 2013).

A common irrigation method in sugar beet production in this region is sprinkler irrigation, and crop yield may increase if proper irrigation methods are followed. Drip irrigation has been shown to reduce irrigation water requirements for a variety of crops under certain circumstances when compared to sprinkler or furrow systems (Kruse et al., 1990), among which can be counted sugar beet (Tognetti et al., 2002). The cost of drip irrigation systems has been declining with the advent of new concepts and materials, and if sugar beet can be proved to be well suited to drip irrigation, farmers with established drip systems may consider including sugar beet in their crop rotations.

The appropriate management of irrigation is of vital importance for the preservation of water resources, quantitatively and qualitatively, and to maximize food production with the available water resources. Irrigation scheduling is one of the most important tools

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in the development of best management practices for irrigated areas (Al-Jamal et al., 1999), and this is especially the case in semi-arid areas that are prone to frequent droughts and with limited water resources. In short, irrigation water plays an essential role in agricultural practices, and particularly in sugar beet cultivation.

Deficit irrigation is one optimized solution for the cultivation of products under water scarcity conditions, with product reduced in unite level and its increase with develop (Sepaskhah et al., 2006). Deficit irrigation involves plants receiving less water than requested (English et al., 1990), and its effects on sugar beet yield and on yield components have been examined in relation to different water levels and irrigation methods. For example, Sharifi et al. (2002) made a study of the effect of various levels of irrigation on sugar beet. They considered white sugar yield by reducing the water consumption from 1000 to 725 and to 655 mm decreased 16.6% and 39.7%, respectively. It showed reduced in high stress condition is high. Vazifedousta et al. (2008) reported that we can get to economic yield in deficit irrigation by the limitation in water resources and they reported that it was obtained 1.1 kg dry material per 1 m³ water for sugarbeet.

The objectives of this study are to investigate the effects of deficit irrigation on sugar beet root yield, sugar rate and the quality parameters of sugar beet, and to evaluate the water use efficiency of sugar beet (*Beta vulgaris* L.) in the Kırsehir Centrum of the Anatolian region of Turkey, and to suggest a suitable irrigation program to farmers in the region using the drip irrigation system.

2. Materials and methods

2.1. Experimental site, soil and climate

The experiment was conducted in 2012 and 2013 under the field conditions at the Cukurcayir in Kırsehir Centrum, Turkey. The experimental site is 1017 m above sea level and has a 36°42' and 39°16' N latitude, 31°14' and 34° 26' E longitude.

According to the Thornthwaite climate classification, Kırsehir has a semi-arid climate type and total annual precipitation of 384.4 mm. It has also continental climate prevails. In general, summers are warm and dry, and winters are cold. The most significant meteorological data and the long term averages were obtained from weather stations of Kırsehir's Region Meteorology Station (2014). The monthly average meteorological data of the trial years and the long years in the experimental region are shown in Table 1. The long years (1970–2012) annual mean temperature, relative humidity, total annual precipitation, wind speed and sunshine duration per day in the area were 11.4 °C, 55%, 384.4 mm, 2.7 m s⁻¹ and 7.2 h, respectively. During the growing periods (from the sowing to harvesting dates) of the years 2012 and 2013, an average temperature of 20.1 and 18.2 °C, total precipitation of 53.2 and 70.5 mm, and an average relative humidity of 45.2% and 47.6% were recorded, respectively. The average temperature and relative humidity data of sugar beet growing seasons were similar to long year's meteorological data. The precipitation in the growing season of the second year was 70.5 mm, which was greater than the first growing season (53.2 mm). However, 2 years' precipitations were lower than long year's averages.

Soil at a depth of 90 cm was sampled before the experiments began and subjected to a physicochemical analysis. Some physical and chemical characteristics of soils in the experimental area are given in Table 2. As seen in Table 2, the texture is silty-clay-loam, alkaline pH, and with a high limy and potassium content. In the experimental area, water content at field capacity varied from 24.4% to 30.6% and wilting point varied from 13.4% to 15.7% on a dry weight basis. The soil contained high percentages of sand (42.6–49.2%), followed by silt (25.4–28.5%) and clay (24.6–30.3%).

The bulk density ranged from 1.2 to 1.4 g cm⁻³ throughout the 90 cm deep profiles. The organic matter contents for different soil layers range from 0.73% to 2.13%.

Chemical characteristics of the applied well water are presented in Table 3. Water is obtained from a well using a pump in the experimental area, and good quality irrigation water, and the mean pH is 7.22, and the average electrical conductivity is 91.20 dS m⁻¹.

2.2. Sowing and fertilization

In the study, the two sugar beet varieties of Calixta and Esperanza were used as the plant material and the seeds that are widely used by farmers in the region. Sowing was conducted on April 14 and 2 in 2012 and 2013, respectively. There was 2.0 m separation between each plot in order to minimize water movement among treatments. Each experimental plot was a total of 18 plots, with each plot measuring 9 m in length and 2.25 m in width and had a total area of 20.25 m² with five rows. Sugar beet seeds were sown at 1.5–2 cm depths using a 5-row mechanic beet seeder. The experimental design was carried out in split plots in randomized blocks with three replicates. Study treatments consisted of one irrigation interval (7 days); two sugar beet varieties (C₁: Esperanza and C₂: Calixta) and three different irrigation levels or three plant-pan coefficients (K_{cp1}: 0.5; K_{cp2}: 0.75 and K_{cp3}: 1.00). Three different irrigation levels (I₁, I₂, and I₃) were adjusted according to the class A pan evaporation using three different plant-pan coefficients.

Fertilizer applications were given according to the soil analysis results. A compound fertilizer of (12–30–12% N, P₂O₅, K₂O) and nitrogen were applied at the rate of 50 kg ha⁻¹ and 160 kg ha⁻¹ prior to planting on April 14, 2012, and on April 2, 2013; the rest of nitrogen dose was applied to all experimental plots in the form of ammonium sulfate (21% N) at a rate of 50 kg ha⁻¹ on June 28 and July 25 in 2012 and 2013.

2.3. Irrigation and evapotranspiration

Irrigation water was supplied from a well using a pump. The water was classified as C₃S₁ with a low sodium risk and a high electrical conductance (USSL, 1954). The 16 mm diameter lateral pipes carrying 4 l h⁻¹ water had inline drippers with 20 cm spacing. Soil water contents were measured by the gravimetric method from the soil samples taken from soil depths at 30–60 and 90 cm increments in each plot at sowing, pre-irrigations, and at the final harvesting date. Experimental plots were irrigated by precipitation at the beginning for a uniform plant establishment. After the emergence of sugar beet seedlings, the plants were irrigated by drip irrigation for a soil profile of 0–90 cm to field capacity. Subsequent irrigations were applied according to the prescribed irrigation rates at 7 day intervals.

Irrigation scheduling methods based on pan evaporation are widely used because of their easy applications (Elliades, 1988). Cumulative evaporation between the irrigations was measured with a class A pan located near the plots. In calculating irrigation water volume, class A pan evaporation, whose fundamentals were described by Doorenbos and Pruitt (1977) and Ertek et al. (2012), was used, as follows:

$$I = E_{\text{pan}} \times K_{\text{cp}} \times A \quad (1)$$

where I : the volume of irrigation water applied (liter), E_{pan} : the cumulative evaporation at class A pan in the irrigation intervals (mm), K_{cp} : the plant-pan coefficient and A : the plot area (m²). Thus, treatments occurred from three different irrigation levels ($I_1 = E_{\text{pan}} \times K_{\text{cp1}}$, $I_2 = E_{\text{pan}} \times K_{\text{cp2}}$ and $I_3 = E_{\text{pan}} \times K_{\text{cp3}}$).

Soil water measurements were taken throughout the crop growth season. The soil water, up to the 90 cm depth in 30 cm increments, was measured gravimetrically (oven dry basis) at sowing,

Table 1
The monthly mean meteorological data of the 2012–2013 growing seasons and the long years in the experimental region.

Climatic factors	Years	Months							Average
		April	May	June	July	August	Sept.	Oct.	
The highest mean temperature (°C)	14 April–1 Oct. 2012	19.6	22.2	28.8	32.3	30.1	28.9	30.8	27.5
	2 April–12 Oct. 2013	22.2	25.4	29.5	29.5	30.3	24.8	18.2	25.7
	Long years ^a	16.8	21.5	26.0	29.8	29.8	25.8	19.6	24.2
The lowest mean temperature (°C)	14 April–1 Oct. 2012	3.9	9.5	13.7	17.7	15.5	12.4	14.5	12.5
	2 April–12 Oct. 2013	4.6	9.9	15.9	15.9	16.2	8.9	3.2	10.7
	Long years	4.7	8.7	12.6	15.9	15.8	11.4	6.6	10.8
Mean temperature (°C)	14 April–1 Oct. 2012	11.6	15.6	21.4	25.0	22.9	20.6	23.3	20.1
	2 April–12 Oct. 2013	13.4	18.0	22.7	22.7	23.2	16.9	10.5	18.2
	Long years	10.6	15.2	19.6	23.2	22.9	18.4	12.5	17.5
Relative humidity (%)	14 April–1 Oct. 2012	55.1	67.2	49.1	40.1	43.3	39.9	22.0	45.2
	2 April–12 Oct. 2013	58.0	50.7	41.3	41.3	39.7	50.1	52.1	47.6
	Long years	63.8	61.0	54.3	48.4	48.8	53.2	63.7	56.2
Precipitation (mm)	14 April–1 Oct. 2012	11.5	27.2	11.9	1.4	0.0	1.2	0.0	53.2
	2 April–12 Oct. 2013	1.0	15.1	1.0	6.6	0.2	32.0	14.6	70.5
	Long years	46.5	44.7	32.0	3.2	0.3	6.8	28.1	161.6

^a Values of 1970–2012 in Regional Meteorology Station, Kirsehir.

Table 2
Some physical and chemical characteristics of soils in the experimental area.

Physical characteristics								
Years	Soil layers (cm)	Particle size distribution (%)			Texture	Field capacity (% of weight)	Wilting point (% of weight)	Bulk density (g cm ⁻³)
		Sand	Silt	Clay				
2012	0–30	42.6	27.1	30.3	CL	30.6	15.7	1.2
	30–60	46.4	25.8	27.8	SCL	26.6	13.4	1.3
	60–90	46.4	25.4	28.2	SCL	26.6	13.4	1.3
2013	0–30	44.0	28.5	27.5	CL	28.5	14.3	1.3
	30–60	46.4	26.9	26.7	SCL	24.4	13.8	1.3
	60–90	49.2	26.2	24.6	SCL	26.2	13.4	1.4
Chemical characteristics								
Years	Soil layers (cm)	pH	Total salt (%)	EC (dS m ⁻¹)	CaCO ₃ (%)	Available nutrients (kg ha ⁻¹)		Organic matter (%)
						P ₂ O ₅	K ₂ O	
2012	0–30	7.71	0.012	0.331	54.69	127.3	1022	1.86
	30–60	7.83	0.013	0.370	60.34	48.1	430.1	1.08
	60–90	7.76	0.017	0.454	59.61	31.0	281.3	0.73
2013	0–30	7.32	0.032	0.844	53.09	209.4	1090	2.13
	30–60	7.38	0.025	0.664	58.46	116.3	630.0	1.76
	60–90	7.36	0.028	0.813	62.52	73.0	385.1	1.46

CL: clay loam; SCL: silty-clay loam.

Table 3
Chemical characteristics of the applied well water.

Years	pH (25 °C)	EC (25 °C), dS m ⁻¹	Cations (meq l ⁻¹)				Anions (meq l ⁻¹)				Na %	SAR	IWC (EC-SAR)
			Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	CO ₃	HCO ₃	Cl ⁻	SO ₄ ⁻²			
2012	7.21	90.40	1.49	0.10	6.43	2.33	0.00	9.20	0.30	0.41	14.41	0.71	C ₃ -S ₁
2013	7.22	92.00	1.51	0.11	6.09	2.32	0.00	7.15	1.19	1.33	15.05	0.72	C ₃ -S ₁
Mean	7.22	91.20	1.50	0.11	6.26	2.33	0.00	8.18	0.75	0.87	14.73	0.72	–

SAR: sodium adsorption ratio; EC: electrical conductivity; IWC: irrigation water class.

pre-irrigation, and at final harvest. Evapotranspiration was calculated for each treatment by the water balance method (Eq. (2)) (James, 1988):

$$Et = I + P + Cr - Dp - Rf - Ds \quad (2)$$

where *Et*: the evapotranspiration (mm), *I*: the irrigation water (mm), *P*: the precipitation (mm), *Cr*: the capillary rise (mm), *Dp*: the water loss by deep percolation (mm), *Rf*: the surface run-off (mm) and *Ds*: the change in profile soil water content (mm).

Precipitation was measured daily at a nearby weather station, placed about 3 km from the experimental area. *Cr* was considered to be zero because there was no high underground water problem in the area. If available water in the root zone (90 cm) and total volume of applied irrigation water were above the field capacity, it was assumed that any water leakage would be the deep percolation value (Kanber et al., 1993; Ertek et al., 2006a). On the other hand, due to the fact that irrigation water volume was calculated and applied according to pan evaporation, there was no surface runoff (Ertek et al., 2006b).

Irrigation water use efficiency (IWUE) and water use efficiency (WUE) was calculated using Eqs. (3) and (4) (Howell et al., 1990; Ertek et al., 2007):

$$IWUE = \frac{Ey}{I} \quad (3)$$

$$WUE = \frac{Ey}{Et} \quad (4)$$

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

Moreover, Eq. (5) was used to determine the contribution of different irrigation levels on plant water consumption (Howell et al., 1990):

$$I_{rc} = \frac{I}{Et} \times 100 \quad (5)$$

where I_{rc} is the irrigation water compensation for plant water consumption (Et) (%).

Yield response factor (ky) is a relative value, which indicates yield sensitivity under per unit water deficit (Ertek et al., 2006a). To determine yield response factor (ky), Eq. (4) was used, as advised by Stewart et al. (1977) and Doorenbos and Kassam (1986). Therefore, using Eq. (6), the relative yield decrease per unit relative evapotranspiration deficit can be predicted:

$$ky = \frac{1 - (Ya/Ym)}{1 - (Eta/Etm)} \quad (6)$$

where Ya : the actual sugar beet yield (t ha^{-1}), Ym : the maximum sugar beet yield (t ha^{-1}), Eta : the actual plant water consumption (mm), Etm : the maximum plant water consumption (mm), and ky : the yield response factor.

2.4. Harvest and measured parameters

At the harvest, the size of the area sampled for yields from each replication was $1.35 \times 8.2 = 11.07 \text{ m}^2$. The harvests in the first year and the second year were conducted by hand after about 3 and 2 weeks from the last irrigation, respectively. A total of 70 sugar beet recommended by the Ankara Sugar Beet Factory selected randomly from each plot for sugar beet (root) yield, sugar rate, and yield components analysis were determined by the Ankara Sugar Institute Laboratory within the Sugar Factories Corporation following the method of the International Commission of Uniform Methods of Sugar Analysis (ICUMSA, 1958). In addition, the values of refined digestion rate and refined sugar yield obtained from the analysis data calculated as mentioned by Reinefeld et al. (1974) method.

In addition to this, 15 plants were randomly selected from each plot to measure root length, root diameter, and mean root weight of five sugar beet randomly selected per treatment.

2.5. Statistical analysis

All data were subjected to ANOVA using the Statistical Package Program (SAS); the significant differences between the group means ($P < 0.01$ and $P < 0.05$) were separated by a least significant difference (LSD) test according to the method of Steel and Torrie (1980).

3. Results and discussion

3.1. Irrigation water (I_r), plant water consumption (Et) and root yield

Table 4 presents a summary of the amount of water applied and total precipitation (from snowing dates to final irrigation dates)

for the two growing seasons. Irrigation treatments in both years started on June 20 and were completed on October 20 and 19. The plants in the first and the second year were irrigated 14 times at 7 day intervals, respectively. A total of 97.05 mm and 108.56 mm of water was applied to all treatments prior to the scheduled irrigations in both the first and second years. The soil water deficit in all plots was replenished to a field capacity at 0–90 cm soil depth, after which scheduled irrigation, based on 7 days of cumulative evaporation, was initiated. The total amount of water applied for I_1 , I_2 , and I_3 treatments was 353.95, 482.40, and 610.85 mm in 2012 and 361.06, 487.31 and 613.56 mm in 2013, respectively. Irrigation water levels applied for same treatments were found close together in both years.

The lowest and the highest values of irrigation water and plant water consumption (Et) were observed in the I_1 and I_3 treatments, respectively in both growing seasons. The Et values increased with increasing irrigation levels. The amount of precipitation (from snowing to harvest) in 2013 was higher than in 2012. Therefore, the water consumption in 2013 was higher than in 2012.

Table 5 presents the sugar beet yields, irrigation amounts, evapotranspiration, irrigation water use (IWUE) and water use efficiency (WUE), as well as I_{rc} data. The highest root yield, averaging 85.73 t ha^{-1} , was obtained with the I_2C_1 treatment, followed by the I_3C_1 and I_3C_2 treatments with 85.38 and 82.37 t ha^{-1} , respectively in 2012. The lowest root yield was achieved with the I_2C_2 treatments, at 75.10 t ha^{-1} for the first experimental year. In 2013, the maximum root yield was achieved with the I_3C_1 treatment plots, at 66.13 t ha^{-1} , followed by the I_1C_1 and I_2C_1 plots with root yields of 63.87 t ha^{-1} and 62.93 t ha^{-1} , respectively. The lowest root yield was obtained with I_1C_2 treatments with 47.57 t ha^{-1} for the second experimental year.

Yildirim (1990) determined a largest root yield of 65.1 t ha^{-1} using the drip irrigation in Ankara in Central Anatolia, Turkey. The sugar beet yields were the highest using irrigation level I_1 at 57.4 t ha^{-1} and 62.4 t ha^{-1} , and the lowest root yield was I_6 at 9.63 t ha^{-1} and 11.21 t ha^{-1} in the corresponding years, respectively (Ucan and Gencoglan, 2004). Baigy et al. (2012) recorded a largest root yield of $119.178 \text{ t ha}^{-1}$ from complete irrigation using the drip tape system, and the lowest root yield was 74.752 t ha^{-1} for 50% deficit irrigation. The results of our experiments are similar with those reported by Yildirim (1990), Ucan and Gencoglan, 2004, and Baigy et al. (2012). Jahad Akbar and Ebrahimian (2003) reported a reduction in sugar yield of 20% with deficit irrigation at the beginning of the sugar beet growing season. Many studies also indicate that sugar yields are affected significantly by irrigation regimes.

In the first year, the highest and lowest WUE values were achieved with the I_1C_1 and I_3C_2 treatments, with $0.231 \text{ t ha}^{-1} \text{mm}^{-1}$ and $0.135 \text{ t ha}^{-1} \text{mm}^{-1}$, respectively. In the second year, the highest and the lowest WUE values were achieved with the I_1C_1 and I_3C_2 treatments, at $0.180 \text{ t ha}^{-1} \text{mm}^{-1}$ and $0.088 \text{ t ha}^{-1} \text{mm}^{-1}$, respectively. The highest IWUE was $0.138 \text{ t ha}^{-1} \text{mm}^{-1}$, using I_1C_1 , while the lowest was observed with I_3C_2 treatments, at $0.090 \text{ t ha}^{-1} \text{mm}^{-1}$ in the first year. In the second year, the highest and the lowest IWUEs were determined as $0.103 \text{ t ha}^{-1} \text{mm}^{-1}$ with I_1C_1 and $0.061 \text{ t ha}^{-1} \text{mm}^{-1}$ with I_3C_2 treatments, respectively. WUE was higher than IWUE in all treatments across the entire growing season because crop water consumption was higher than the amount of applied water. The IWUE and WUE values decreased in levels from I_1 to I_3 in 2012 and 2013 due to a decrease in the amount of applied water and the yield. Ucan and Gencoglan (2004) also found that the greatest values for WUE and IWUE were observed in the treatments with the highest yields, depending upon the irrigation water. Water-use efficiency (WUE) relates to the amount the yield increases per unit of applied water, which can be represented as an incremental gain in dry matter per unit of water taken up and transpired by the plant

Table 4
Amounts of irrigation water applied and total precipitation.

Irrigation dates	2012-Treatments			Irrigation dates	2013-Treatments		
	I ₁	I ₂	I ₃		I ₁	I ₂	I ₃
20/06/2012	97.05 ^a	97.05	97.05	20/06/2013	108.56 ^a	108.56	108.56
27/06/2012	11.4	17.1	22.8	27/06/2013	23	34.5	46
05/07/2012	16.5	24.75	33	04/07/2013	21	31.5	42
12/07/2012	22.5	33.75	45	11/07/2013	26	39	52
19/07/2012	21.5	32.25	43	18/07/2013	19	28.5	38
26/07/2012	26	39	52	25/07/2013	21	31.5	42
02/08/2012	22.5	33.75	45	01/08/2013	25	37.5	50
09/08/2012	18.5	27.75	37	06/08/2013	18.5	27.5	37
16/08/2012	19	28.5	38	15/08/2013	24.5	36.75	49
23/08/2012	21	31.5	42	22/08/2013	20	30	40
30/08/2012	21	31.5	42	29/08/2013	16	24	32
06/09/2012	16	24	32	05/09/2013	11	16.5	22
13/09/2012	17	25.5	34	12/09/2013	14	21	28
20/09/2012	24	36	48	19/09/2013	13.5	20.25	27
01/10/2012		Harvest		12/10/2013		Harvest	
Total irrigation, mm	353.95	482.4	610.85		361.06	487.31	613.56
Total precipitation, mm	132.6	132.6	132.6		91.5	91.5	91.5

^a Soil water content in 0–90 cm soil depth of all plots was increased up to field capacity.

(Draycott, 2006; Hassanli et al., 2010). Howell (2003) stated that IWUE can be increased through the practice of deficit irrigation, improvements in irrigation technologies, irrigation scheduling and improved agronomic practices, leading to an increase in yield.

Mengistu et al. (2014) reported WUE values of 9.44 and 3.91 kg m⁻³ for sugar beet using drip irrigation at the Ukulinga research farm, University of KwaZulu-Natal, Pietermaritzburg, South Africa, while Cassel Sharmasarkar et al. (2001) reported a WUE range of 9.60–10.60 kg m⁻³, and Fabeiro et al. (2003) reported a WUE range of 13.3–17.5 kg m⁻³. In a study conducted by Winter (1980) in Texas, United States, the values for WUE and IWUE were 51.4 and 58.7 kg ha⁻¹ mm⁻¹, and 44.0 and 63.0 kg ha⁻¹ mm⁻¹ for basin irrigation with different amounts of applied water. The results of our study are shown similarity with findings reported by some researchers above mentioned.

I_{rc} values ranged from 54.5% to 67.8% with I₁C₂ and I₃C₁ treatment plots in the first year; while in the second year, similar to the previous year, the compensation rate of *Et* through applied irrigation water (I_{rc}) varied from 56.9% to 70.1% in the I₁C₂ and I₃C₁ treatment plots.

The values of the compensation rate of *Et* of applied water were a higher increase in higher levels of water application and in the C₁ treatment. Considering the yield and water use efficiency values of treatments, better use of water and higher yields were obtained with treatments of C₁. As a result, cultivation of the C₁ variety is important for saving water in similar climates and soil conditions. Treatments of I₁C₁ resulted in the highest yield of water per unit, and so are also suggested as the most appropriate treatment in regions where irrigation water is scarce.

3.2. Water–yield relationships

Tables 6a and 6b present the results of the analysis of variance related to the studied parameters. In the first year of experiment were not significant the impact of irrigation levels, varieties and interactions on the root yield. In the second year, varieties and interactions were determined at the 0.1% and 5% levels of significance, respectively, while irrigation levels were not significant. The root yield values varied from a minimum of 75.10 t ha⁻¹ (I₂C₂) to a maximum of 85.73 t ha⁻¹ (I₂C₁) in the first year; this rate varied from 47.57 t ha⁻¹ (I₁C₂) to 66.13 t ha⁻¹ (I₃C₁) in the second year. In both years, the highest root yields were determined for C₂ variety. Jahad Akbar et al. (2003) also pointed to the fact that deficit irrigation causes a significant decrease in root yield, impure sugar and root sodium, but increases harmful nitrogen significantly. In addition, Rahimian and Asadi (2000) studied the effects of deficit irrigation on the quality and quantity of sugar beet, showing that deficit irrigation increases the root yield of sugar beet growing, that deficient irrigation increased water use efficiency and increasing on rate of water consumption and irrigation level reduce pure sugar toward impure sugar (Mehrandish et al., 2012).

In both years, effects of varieties and interactions on the sugar rate (%) were determined at the 0.1% and 5% levels of significance, respectively, while irrigation levels were not significant. The sugar rates varied from a minimum of 15.29% (I₂C₁) to a maximum of 17.43% (I₃C₂) in the first year; this rate varied from 15.19% (I₃C₁) to 17.04% (I₂C₂) in the second year. In both years, the highest sugar rate was determined for C₂ variety. Baigy et al. (2012) also reported that percentages of sugar from 100%, 75% and 50% drip

Table 5
The values related to water and yield parameters of the treatments.

Year	Treatments	I, mm	Et, mm	Root yield, t ha ⁻¹	WUE, t ha ⁻¹ mm ⁻¹	IWUE, t ha ⁻¹ mm ⁻¹	I _{rc} , %
2012	I ₁ C ₁	353.95	592.2	81.93	0.231	0.138	59.8
	I ₁ C ₂	353.95	650.0	77.02	0.218	0.118	54.5
	I ₂ C ₁	482.40	745.9	85.73	0.178	0.115	64.7
	I ₂ C ₂	482.40	788.8	75.10	0.156	0.095	61.3
	I ₃ C ₁	610.85	900.5	85.38	0.140	0.095	67.8
	I ₃ C ₂	610.85	919.4	82.37	0.135	0.090	66.4
2013	I ₁ C ₁	361.1	617.4	63.87	0.180	0.103	57.3
	I ₁ C ₂	361.1	622.6	47.57	0.134	0.076	56.9
	I ₂ C ₁	487.3	731.8	62.93	0.130	0.086	65.9
	I ₂ C ₂	487.3	749.4	53.75	0.111	0.072	64.4
	I ₃ C ₁	613.6	871.6	66.13	0.108	0.076	70.1
	I ₃ C ₂	613.6	887.7	53.77	0.088	0.061	68.8

Table 6a
Results of the variance analysis of yield and quality parameters in different treatments.

Treatments	V	Root yield (t ha ⁻¹)	Sugar rate (%)	Refined digestion rate (%)	Refined sugar yield (t ha ⁻¹)	Na (mmol 100 g ⁻¹ beet)	K (mmol 100 g ⁻¹ beet)	Alpha-amino nitrogen (mmol 100 g ⁻¹ beet)	Dry matter rate (%)
2012									
I ₁	C ₁	81.93a ns	15.44b*	12.54b*	10.28a ns	2.14abc*	4.39c*	3.97a*	19.03b*
	C ₂	77.02a	16.72b	13.75a	10.57a	1.86c	4.63bc	4.84ab	19.14b
I ₂	C ₁	85.73a	15.29b	12.31b	10.62a	2.12abc	4.55bc	4.25bc	20.96a
	C ₂	75.10a	16.79a	13.65a	10.25a	2.01bc	4.89ab	5.18a	21.11a
I ₃	C ₁	85.37a	15.43b	12.31b	10.40a	2.35a	4.69bc	4.47bc	19.26b
	C ₂	82.37a	17.43a	14.09a	11.59a	2.21ab	5.22a	5.30a	21.77a
Irrigation level	I ₁	79.48a ns	16.09a ns	13.15a ns	10.42a ns	1.99b*	4.50b*	4.40a ns	19.99a
	I ₂	80.42a	16.04a	12.98a	10.43a	2.06ab	4.72ab	4.71a	20.13a
	I ₃	83.87a	16.43a	13.19a	11.00a	2.28a	4.95a	4.89a	20.51a
Varieties	C ₁	84.34a ns	15.39b***	12.39b***	10.44a ns	2.20a*	4.54b**	4.23b***	19.14b***
	C ₂	78.16a	16.98a	13.83a	10.81a	2.02a	4.91a	5.11a	21.28a
C.V. (%)		9.41	2.92	3.13	10.37	8.55	5.11	8.12	3.26
2013									
I ₁	C ₁	63.87a*	16.08bc*	13.12ab*	8.38a*	1.95a ns	4.59a ns	4.50c*	20.83c*
	C ₂	47.57b	16.95a	13.73a	6.53b	2.00a	4.86a	6.17a	21.36bc
I ₂	C ₁	62.93a	15.72 cd	12.72bc	8.02a	2.02a	4.64a	4.41c	22.66a
	C ₂	53.75b	17.04a	13.87a	7.47ab	1.91a	4.95a	5.55b	22.39ab
I ₃	C ₁	66.13a	15.19d	12.10c	7.99a	2.18a	4.75a	4.47c	20.73c
	C ₂	53.76b	16.92ab	13.81a	7.40ab	2.04a	4.78a	5.08b	22.22ab
Irrigation level	I ₁	55.72a ns	16.51a ns	13.43a ns	7.46a	1.97a ns	4.72a	5.33a*	21.75a
	I ₂	58.34a	16.38a	13.30a	7.74a	1.96a	4.80a	4.98ab	21.87a
	I ₃	59.95a	16.06a	12.95a	7.70a	2.11a	4.76a	4.77b	21.48a
Varieties	C ₁	64.31a***	15.67b***	12.65b***	8.13a**	2.05a ns	4.66a	4.46b***	20.98b***
	C ₂	51.69b	16.97a	13.80a	7.13b	1.98a	4.86a	5.60a	22.42a
C.V. (%)		7.37	2.82	3.13	8.87	8.97	5.99	6.02	3.01

Means in the same columns followed by the same letters are not significantly different as statistically.

C.V.: coefficient of variation (%); V: varieties; C₁: Esperanza; C₂: Calixta.

* Significant at $P < 0.05$.

** Significant at $P < 0.01$.

*** Significant at $P < 0.001$.

ns: not significant.

Table 6b
Results of the variance analysis of some quality parameters in different treatments.

Treatments	V	Root length (cm)	Root diameter (cm)	Weight of five sugar beet per unit plot (kg)	Root length (cm)	Root diameter (cm)	Mean weight of five sugar beet per unit plot (kg)
2012							
I ₁	C ₁	28.37a ns	28.01a ns	2.17a ns	25.41a ns	25.15ab*	2.00a ns
	C ₂	26.51a	27.97a	1.97a	26.33a	26.33a	2.00a
I ₂	C ₁	28.13a	26.97a	1.80a	26.75a	26.33a	2.00a
	C ₂	28.45a	28.67a	1.83a	26.17a	26.95a	1.80a
I ₃	C ₁	25.65a	26.28a	2.03a	24.28a	23.77b	2.13a
	C ₂	27.02a	27.28a	1.93a	26.73a	25.97a	1.97a
Irrigation levels	I ₁	27.44a ns	27.99a ns	2.07a ns	25.87a ns	25.74ab*	2.00a ns
	I ₂	28.32a	27.82a	1.82a	26.45a	26.64a	1.90a
	I ₃	26.33a	26.78a	1.98a	25.50a	24.87b	2.05a
Varieties	C ₁	27.40a ns	27.09a ns	2.00a ns	25.48a ns	25.08b*	2.04a ns
	C ₂	27.32a	27.97a	1.91a	26.41a	26.42a	1.92a
C.V. (%)		5.66	6.28	11.50	5.57	3.88	10.46

Means in the same columns followed by the same letters are not significantly different as statistically.

C.V.: coefficient of variation (%); V: varieties; C₁: Esperanza; C₂: Calixta.

* Significant at $P < 0.05$.

ns: not significant.

irrigation treatments were 15.48%, 17.7% and 18.01%, respectively, which indicates the sugar rate with the water stress is increased. Tsialtas and Maslaris (2013) stated that the highest sugar rate was recorded in 2004 (15.85%), the lowest in 2002 and 2006 (12.42%

and 12.90%, respectively), while in 2005 sugar rate was moderate (14.93%). The results in our study coincide with those reported by Ucan and Gencoglan (2004), Baigy et al. (2012), and Tsialtas and Maslaris (2013).

In both years, effects of varieties and interactions on the refined digestion rate (%) were determined at the 0.1% and 5% levels of significance, respectively, while irrigation levels were not significant. The refined digestion rates varied from a minimum of 12.31% (I_2C_1 and I_3C_1) to a maximum of 14.09% (I_3C_2) in the first year; this rate varied from 12.10% (I_3C_1) to 13.87% (I_2C_2) in the second year. In both years, the highest refined digestion rate was determined for C_2 variety. Çakmakçı and Oral (1998) reported that the refined digestion rates were reduced from 11.08% to 6.16% due to the dependence on the reduction in plant density.

In the first year, the impact of irrigation levels, varieties and interactions on the refined sugar yield was not significant. In the second year, varieties and interactions were determined at the 1% and 5% levels of significance, respectively, while irrigation levels were not significant. The refined sugar yield varied from a minimum of 10.25 t ha⁻¹ in I_2C_2 to a maximum of 11.59 t ha⁻¹ in I_3C_2 , in the treatment plots in the first year; the refined sugar yield varied from 6.53 t ha⁻¹ in I_1C_2 to 8.38 t ha⁻¹ in the I_3N_3 treatments in the second year. Okut and Yıldırım (2004) reported that a mean refined sugar yield varied from a minimum of 2.26 t ha⁻¹ to a maximum of 10.69 t ha⁻¹. Çakmakçı and Oral (1998) reported that refined sugar yield ranged from 8.75 t ha⁻¹ to 6.18 t ha⁻¹. Reported that refined sugar yield from 90%, 75%, 50%, and 25% levels of deficit irrigation treatments was 3.88, 5.23, 7.15, and 5.97 t ha⁻¹ respectively. The results in our study were higher than the values obtained by Çakmakçı and Oral (1998), Okut and Yıldırım (2004). The reason for this may be due to the different planting time, emergence rates, irrigation and fertilizer levels and climatic conditions.

The effect of irrigation level, variety and interaction (irrigation level × variety) on Na was determined at the 5% level of significance. In the second year were not significant the impact of irrigation levels, varieties and interactions on the Na. In the first year, Na values changed between 1.86 and 2.35 mmol 100 g⁻¹ beet; the second year, Na values changed between 1.91 and 2.18 mmol 100 g⁻¹ beet.

The impacts of variety on the K value have a significance at 1% of the level, and irrigation level and interaction effects on K were significant at 5% of the level. In the second year were not significant the impact of irrigation levels, varieties and interactions on the K. The first year, K values of treatments ranged from 4.39 to 5.22 mmol 100 g⁻¹ beet; K values in the second year ranged from 4.59 to 4.95 mmol 100 g⁻¹ beet.

The effect on alpha-amino nitrogen of variety and interaction was found to have 0.1% and 5% significance level, respectively, while irrigation levels were not significant. In the second year, the effects of irrigation level, variety and interaction on the alpha-amino nitrogen were significant at 5%, 0.1% and 5%, respectively. In the first year, the values of alpha-nitrogen in the first year ranged from (I_1C_1) 3.97 to (I_3C_2) 5.30 mmol 100 g⁻¹ beet; in the second year, the values of alpha-nitrogen ranged from (I_2C_1) 4.41 to (I_1C_2) 6.17 mmol 100 g⁻¹ beet.

Fathy et al. (2009) reported that a mean K ranged from 5.00 to 5.22 mmol 100 g⁻¹ beet; Na ranged between 1.30 and 1.72 mmol 100 g⁻¹ beet; alpha-amino nitrogen ranged from 3.48 to 4.18 mmol 100 g⁻¹ beet in sandy calcareous soil. Tsialtas and Maslaris (2013) reported that a K ranged from 9.25 to 7.86 mg g⁻¹; Na ranged between 2.36 and 6.66 mg g⁻¹ beet; alpha-amino nitrogen ranged from 1.17 to 2.82 mg g⁻¹ beet in clays under irrigated, Mediterranean conditions. The findings obtained in our study were found higher than these results, except Na values. These differences may be due to the planting time, different rates and time of the nitrogen fertilization application, varieties, irrigation applications, and environmental effects in different regions.

The dry matter rate varied from a minimum of 19.03% in I_2C_1 to a maximum of 21.28% in I_3C_2 , in the treatment plots in the first

year; this rate varied from 20.73% in I_3C_1 to 22.66% in the I_2C_2 treatments in the second year. Salarian et al. (2014) reported that a dry matter rate was maximum for the sugar beet cultivars 004 (30.29%), Zarhgan (30.21%), and Bomirang (30.12%); and dry matter rate was minimum for cultivars Merak (27.45%) and Rizofort (27.09%). Okut and Yıldırım (2004) reported that a dry matter rate was maximum for the sugar beet cultivar evita (24.06%) and dry matter rate was minimum for cultivar sonja (22.14%). The results in the present study were found lower than that obtained by Salarian et al. (2014). These differences among the results may be affected by root performance among the genotypes under soil and climatic conditions. Also it is well known that nitrogen and potassium fertilizers increase dry matter accumulation as reported by Badawi et al. (1995) and Kandil et al. (2002).

A comparison of the 2 years reveals that the alpha-amino nitrogen, dry matter rate, sugar rate and refined digestion rate values similarly affected irrigation levels, varieties and interactions (levels of irrigation × variety) in both years.

As the results of the statistical analysis show, for the first year, the irrigation level, variety and interaction effects were not significant on the values of root length, root diameter and mean root weight of five sugar beet randomly selected per treatment. In the second year, the irrigation level, variety and interaction effects were not significant on the values of root length and mean root weight of five sugar beet randomly selected per treatment, while the effects on root diameter were determined significant at a 5% significance level (Table 6b). In addition, the high values of root length, root diameter and mean root weight of five sugar beet randomly selected per treatment were effective in increasing yield in 2012. Despite the above-mentioned differences between years, this difference is reflected approximately equally to experiments.

In the first year, root length ranged between 25.65 (I_3C_1) and 28.45 cm (I_2C_2); in the second year, root length ranged between 24.28 (I_3C_1) and 26.75 cm (I_2C_1); the heaviest mean root weight ranged from 1.80 (I_2C_1) to 2.17 kg (I_1C_1) in the first year; the lowest root weight ranged from 1.80 (I_2C_2) to 2.13 kg (I_3C_1) in the second year; root diameter ranged from 26.28 (I_3C_1) to 28.67 kg (I_2C_2) in the first year; root diameter ranged from 23.77 (I_3C_1) to 26.95 kg (I_2C_2) in the second year. Hozayn et al. (2013) reported that root length ranged from 30.50 (DS-9004 and Heliospoly cultivars) to 41.00 cm (Monte Rosa cultivar) average 34.12 cm; the heaviest root weight (1.43 and 1.33 kg) was reported by DS-9004 and Heliospoly cultivars, respectively; root diameter ranged between

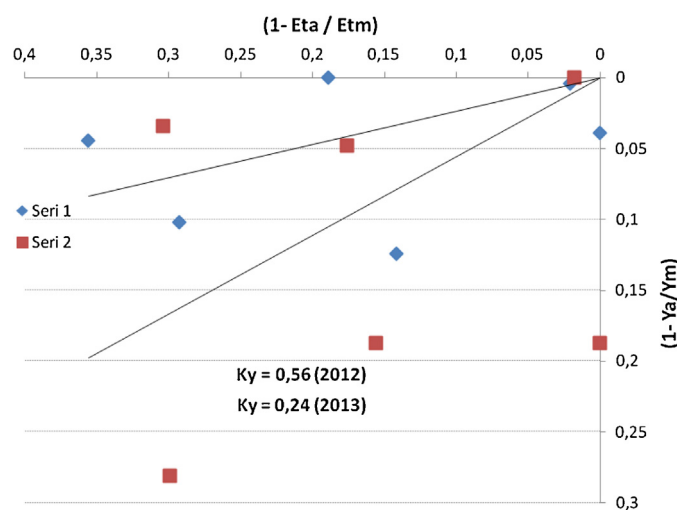


Fig. 1. The relationship between relative yield decrease and relative evapotranspiration deficit for sugar beets in the total growing period.

Table 7
The coefficients of correlation among examined parameters..

Year	Yield components	<i>Et</i>	<i>I</i>	WUE	IWUE	<i>I_{rc}</i>	Root length	Root diameter	Weight
2012	<i>Et</i>			$R^2 = \mathbf{0.96}$	$R^2 = \mathbf{0.87}^{**}$	$R^2 = \mathbf{0.67}^{**}$			
	<i>I</i>			$R^2 = \mathbf{0.93}$	$R^2 = \mathbf{0.74}^{**}$	$R^2 = \mathbf{0.82}^{**}$			
	WUE				$R^2 = \mathbf{0.90}^{**}$				
	IWUE								
	<i>I_{rc}</i>			$R^2 = \mathbf{0.66}$	$R^2 = \mathbf{0.35}^*$				
	Root length	$R^2 = \mathbf{0.22}$	$R^2 = \mathbf{0.18}$	$R^2 = \mathbf{0.10}$	$R^2 = \mathbf{0.15}$	$R^2 = \mathbf{0.04}$			
	Root yield	$R^2 = \mathbf{0.09}$	$R^2 = \mathbf{0.20}$	$R^2 = \mathbf{0.05}$	$R^2 = \mathbf{0.002}$	$R^2 = \mathbf{0.50}^*$	$R^2 = \mathbf{0.06}$	$R^2 = \mathbf{0.79}^{**}$	$R^2 = \mathbf{0.02}$
	Sugar rate								
	Refined digestion rate								
	Refined sugar yield								
	Na								
	K								
	Alpha-amino nitrogen								
	Root diameter	$R^2 = \mathbf{0.29}$	$R^2 = \mathbf{0.40}^*$	$R^2 = \mathbf{0.19}^*$	$R^2 = \mathbf{0.07}$	$R^2 = \mathbf{0.51}^*$	$R^2 = \mathbf{0.40}^*$		
Weight	$R^2 = \mathbf{0.13}$	$R^2 = \mathbf{0.09}$	$R^2 = \mathbf{0.87}^{**}$	$R^2 = \mathbf{0.28}^*$	$R^2 = \mathbf{0.03}$	$R^2 = \mathbf{0.05}$	$R^2 = \mathbf{0.003}$		
2013	<i>Et</i>			$R^2 = \mathbf{0.73}$	$R^2 = 0.48^*$	$R^2 = 0.92^{**}$			
	<i>I</i>			$R^2 = \mathbf{0.70}$	$R^2 = 0.43^*$	$R^2 = 0.96^{**}$			
	WUE				$R^2 = 0.91^{**}$				
	IWUE								
	<i>I_{rc}</i>			$R^2 = \mathbf{0.63}$	$R^2 = 0.34^*$				
	Root length	$R^2 = \mathbf{0.03}$	$R^2 = \mathbf{0.03}$	$R^2 = \mathbf{0.03}$	$R^2 = 0.08$	$R^2 = 0.02$			
	Root yield	$R^2 = \mathbf{0.04}$	$R^2 = \mathbf{0.07}$	$R^2 = \mathbf{0.08}$	$R^2 = 0.30^*$	$R^2 = 0.12$	$R^2 = 0.36^*$	$R^2 = \mathbf{0.48}^*$	$R^2 = \mathbf{0.27}$
	Sugar rate %								
	Refined digestion rate %								
	Refined sugar yield								
	Na								
	K								
	Alpha-amino nitrogen								
	Root diameter	$R^2 = \mathbf{0.11}$	$R^2 = \mathbf{0.12}$	$R^2 = \mathbf{0.01}$	$R^2 = 0.05$	$R^2 = 0.09$	$R^2 = 0.87^{**}$		
Weight	$R^2 = \mathbf{0.04}$	$R^2 = \mathbf{0.05}$	$R^2 = \mathbf{0.01}$	$R^2 = 0.04$	$R^2 = 0.04$	$R^2 = 0.32^*$	$R^2 = \mathbf{0.70}^{**}$		
Year	Yield components	Sugar rate	Refined digestion rate	Refined sugar yield	Na	K	Alpha-amino nitrogen	Dry matter rate	
2012	<i>Et</i>	$R^2 = \mathbf{0.09}$	$R^2 = \mathbf{0.03}$	$R^2 = \mathbf{0.39}^*$	$R^2 = \mathbf{0.40}^*$	$R^2 = \mathbf{0.59}$	$R^2 = \mathbf{0.30}$	$R^2 = \mathbf{0.12}$	
	<i>I</i>	$R^2 = \mathbf{0.03}$	$R^2 = \mathbf{0.001}$	$R^2 = \mathbf{0.35}^*$	$R^2 = \mathbf{0.57}^*$	$R^2 = \mathbf{0.46}$	$R^2 = \mathbf{0.16}$	$R^2 = \mathbf{0.04}$	
	WUE	$R^2 = \mathbf{0.09}$	$R^2 = \mathbf{0.03}$	$R^2 = \mathbf{0.21}$	$R^2 = \mathbf{0.34}^*$	$R^2 = \mathbf{0.58}$	$R^2 = \mathbf{0.33}$	$R^2 = \mathbf{0.12}$	
	IWUE	$R^2 = \mathbf{0.26}$	$R^2 = \mathbf{0.16}$	$R^2 = \mathbf{0.20}$	$R^2 = \mathbf{0.12}$	$R^2 = \mathbf{0.72}$	$R^2 = \mathbf{0.59}$	$R^2 = \mathbf{0.32}^*$	
	<i>I_{rc}</i>	$R^2 = \mathbf{0.04}$	$R^2 = \mathbf{0.11}$	$R^2 = \mathbf{0.13}$	$R^2 = \mathbf{0.82}^{**}$	$R^2 = \mathbf{0.15}$	$R^2 = \mathbf{0.001}$	$R^2 = \mathbf{0.01}$	
	Root length	$R^2 = \mathbf{0.004}$	$R^2 = \mathbf{0.001}$	$R^2 = \mathbf{0.05}$	$R^2 = \mathbf{0.10}$	$R^2 = \mathbf{0.04}$	$R^2 = \mathbf{0.03}$	$R^2 = \mathbf{0.01}$	
	Root yield	$R^2 = \mathbf{0.39}^*$	$R^2 = \mathbf{0.98}^{**}$	$R^2 = \mathbf{0.05}$	$R^2 = \mathbf{0.60}^{**}$	$R^2 = \mathbf{0.04}$	$R^2 = \mathbf{0.31}^*$	$R^2 = \mathbf{0.40}^*$	
	Sugar rate		$R^2 = \mathbf{0.98}^{**}$	$R^2 = \mathbf{0.37}^*$	$R^2 = \mathbf{0.12}$	$R^2 = \mathbf{0.68}^{**}$	$R^2 = \mathbf{0.86}^{**}$	$R^2 = \mathbf{0.98}^{**}$	
	Refined digestion rate			$R^2 = \mathbf{0.94}^{**}$	$R^2 = \mathbf{0.23}$	$R^2 = \mathbf{0.55}^*$	$R^2 = \mathbf{0.79}^{**}$	$R^2 = \mathbf{0.97}^{**}$	
	Refined sugar yield				$R^2 = \mathbf{0.05}$	$R^2 = \mathbf{0.56}$	$R^2 = \mathbf{0.28}$	$R^2 = \mathbf{0.34}^*$	
	Na					$R^2 = \mathbf{0.03}$	$R^2 = \mathbf{0.05}$	$R^2 = \mathbf{0.14}$	
	K						$R^2 = \mathbf{0.82}^{**}$	$R^2 = \mathbf{0.70}^{**}$	
	Alpha-amino nitrogen							$R^2 = \mathbf{0.92}^{**}$	
	Root diameter	$R^2 = \mathbf{0.20}$	$R^2 = \mathbf{0.88}^{**}$	$R^2 = \mathbf{0.07}$	$R^2 = \mathbf{0.56}^*$	$R^2 = \mathbf{1E-04}$	$R^2 = \mathbf{0.09}$	$R^2 = \mathbf{0.18}$	
Weight	$R^2 = \mathbf{0.07}$	$R^2 = \mathbf{0.07}$	$R^2 = \mathbf{0.04}$	$R^2 = \mathbf{0.06}$	$R^2 = \mathbf{0.17}^*$	$R^2 = \mathbf{0.24}^*$	$R^2 = \mathbf{0.13}$		
2013	<i>Et</i>	$R^2 = \mathbf{0.04}$	$R^2 = 0.06$	$R^2 = 0.12$	$R^2 = 0.40^*$	$R^2 = 0.03$	$R^2 = 0.09$	$R^2 = 0.01$	
	<i>I</i>	$R^2 = \mathbf{0.07}$	$R^2 = 0.09$	$R^2 = 0.13$	$R^2 = 0.43^*$	$R^2 = 0.02$	$R^2 = 0.13$	$R^2 = 0.02$	
	WUE	$R^2 = \mathbf{0.04}$	$R^2 = 0.02$	$R^2 = 0.09$	$R^2 = 0.15$	$R^2 = 0.34$	$R^2 = 0.04$	$R^2 = 0.16$	
	IWUE	$R^2 = \mathbf{0.20}$	$R^2 = 0.14$	$R^2 = 0.28$	$R^2 = 0.06$	$R^2 = 0.53$	$R^2 = 0.21$	$R^2 = 0.40^*$	
	<i>I_{rc}</i>	$R^2 = \mathbf{0.13}$	$R^2 = 0.14$	$R^2 = 0.06$	$R^2 = 0.86^{**}$	$R^2 = 0.001$	$R^2 = 0.19$	$R^2 = 0.04$	
	Root length	$R^2 = \mathbf{0.43}^*$	$R^2 = 0.47^*$	$R^2 = 0.16$	$R^2 = 0.73^{**}$	$R^2 = 0.03$	$R^2 = 0.15^*$	$R^2 = 0.86^{**}$	
	Root yield	$R^2 = \mathbf{0.83}^{**}$	$R^2 = 0.80^{**}$	$R^2 = 0.70$	$R^2 = 0.21$	$R^2 = 0.55$	$R^2 = 0.91^{**}$	$R^2 = 0.95^{**}$	
	Sugar rate %		$R^2 = 0.99^{**}$	$R^2 = 0.31^*$	$R^2 = 0.48^*$	$R^2 = 0.45$	$R^2 = 0.87^{**}$	$R^2 = 0.83^{**}$	
	Refined digestion rate %			$R^2 = 0.32^*$	$R^2 = 0.54^*$	$R^2 = 0.43^*$	$R^2 = 0.58^*$	$R^2 = 0.76^{**}$	
	Refined sugar yield					$R^2 = 0.27$	$R^2 = 0.66^{**}$	$R^2 = 0.57^*$	
	Na					$R^2 = 0.0004$	$R^2 = 0.19$	$R^2 = 0.23$	
	K						$R^2 = 0.65^{**}$	$R^2 = 0.81^{**}$	
	Alpha-amino nitrogen							$R^2 = 0.62^{**}$	
	Root diameter	$R^2 = \mathbf{0.60}^{**}$	$R^2 = 0.63^{**}$	$R^2 = 0.11$	$R^2 = 0.62^{**}$	$R^2 = 0.21$	$R^2 = 0.34^*$	$R^2 = 0.80^{**}$	
Weight	$R^2 = \mathbf{0.57}^*$	$R^2 = 0.60^{**}$	$R^2 = 0.0001$	$R^2 = 0.74^{**}$	$R^2 = 0.79^{**}$	$R^2 = 0.23$	$R^2 = 0.40^*$		

Bold denotes it is 5% level between 0.30–0.59 (*) and 1% between 0.60–1.00 (**).

* Significant at $P < 0.05$.

** Significant at $P < 0.01$.

ns: not significant.

30.50 cm and 39.17 cm for Disk 01–99 and Heliospoly cultivars. The differences among cultivars in these traits might be attributed to the differences in genetics constituents for each cultivar and growing conditions (Hozayn et al., 2013).

The yield response factors (ky) of treatments in the first and the second years were determined as 0.56 and 0.24, respectively (Fig. 1), indicating that the first and second year unit yields per unit of water deficiency may be decreased to 0.56 and 0.24, respectively.

The k_y value in the first year was higher than in the second year. This situation reveals may change the value of k_y depending on the climatic conditions. Also, the slope of the water–yield relationship in the graphic determines the k_y . Therefore, the ratio between the maximum and minimum water deficit is not important. Also, irrigation level has not effective on yield. In addition, k_y values were low that the impact on the beet yield of irrigation water level is due to unimportant in both years. In the second year, k_y was low, which may be attributed to lower water use efficiency. Pejić et al. (2011) determined that the k_y value (0.45) could be used as a good platform for sugar beet growers in the climatic conditions of the Vojvodina Province in Northern Serbia. Doorenbos and Kassam (1979) stated the average k_y values for sugar beet at 0.6–1.0. The results in our study are different from the results given above by some researchers. In addition, the researchers reported that k_y may be affected by other factors besides soil water deficiency, namely soil properties, climatic conditions, growing season length, irrigation methods and programs, and inadequacies of production technology (Vaux and Pruitt, 1983; Petcu et al., 2009; Ucan and Gencoglan, 2004; Pejić et al., 2011).

3.3. Relationship between examined parameters

The relationship between the examined parameters was evaluated graphically and the correlation coefficients are presented in Table 7. The table shows that in the first year of the study, the relationships between root length and E_t , and I and IWUE were determined be significant at a 5% level. In the second year, the relationships between root length, sugar rate, refined digestion rate, refined sugar yield and alpha-amino nitrogen and between root length, Na and dry matter rate were determined at 5% and 1% significance level, respectively.

In the first year, the relationships between refined sugar yield with I , I_{rc} , sugar rate, alpha-amino nitrogen and dry matter rate, and with root diameter, refined digestion rate and Na were found to be at 5% and 1% significance level, respectively.

In the first year, between sugar rate with refined digestion rate, K, alpha-amino nitrogen and dry matter; between sugar rate with refined sugar yield was found a significant relationship at the level 1% and 5%, respectively. In the second year, the relationship between sugar rate and refined digestion rate; between alpha-amino nitrogen and dry matter rate; and between refined sugar yield, Na and K was found to be significant at 1%, 1% and 5% levels, respectively.

In the first year, the relationship between the refined digestion rate with the refined sugar yield, the alpha-amino nitrogen and dry matter rate; and between Na and K was determined to be significant at 1% and 5% levels, respectively. In the second year, the relationships between refined digestion rate and refined sugar yield, and between Na, K and alpha-amino nitrogen and dry matter rate were determined to be significant at 5% and 1% levels, respectively.

In the first year, the relationship between refined sugar yield and K, alpha-amino nitrogen and dry matter rate was found to be at a 5% significance level; while in the second year, the relationship between refined sugar yield and K and dry matter rate was also determined at a level of 5%.

In the second year, the relationships between Na and K, and between alpha-amino nitrogen and dry matter rate were determined to be significant at a level of around 1% and 5%, respectively. In both years, the relationship between K and alpha-amino nitrogen and dry matter rate was found to be similar at a 1% level. In both years, alpha-amino nitrogen and dry matter rate were determined to be in a significant relationship at a level of 1%.

In the first year, the relationship between root diameter with E_t , I , WUE, I_{rc} , root length, sugar rate, Na and dry matter rate; with refined digestion rate was determined at a level of 5% and

1%, respectively. In the second year, the relationships between root diameter and root length, sugar rate, refined digestion rate, Na and dry matter rate, and between K and alpha-amino nitrogen were determined at 1% and 5% significance level, respectively.

In the first year, the relationships between the mean weight of five sugar beet per unit plot and IWUE, K and alpha-amino nitrogen, and between WUE were found to be at a level of 5% and 1%, respectively. In the second year, the relationships between the mean weight of five sugar beet per unit plot and root length, sugar rate, dry matter rate; and between root diameter, refined digestion rate, Na and K were determined at a level of 5% and 1% respectively.

The above results reveal that some of the examined parameters do not affect others, while some would appear to affect others significantly. The most important parameters, being sugar rate and refined sugar yield, Na, K, alpha-amino nitrogen, dry matter rate, yield, root diameter, root length, and weight are affected at a significant level, and so the necessary measures should be taken related to these parameters to increase the sugar content and yield.

Jahad Akbar et al. (2003) also pointed to the fact that deficit irrigation causes a significant decrease in root yield, impure sugar and root sodium, but increases harmful nitrogen significantly. In addition, Rahimian and Asadi (2000) studied the effects of deficit irrigation on the quality and quantity of sugar beet, showing that deficit irrigation increases the root yield of sugar beet growing, that deficient irrigation increased water use efficiency and that increasing rate of water consumption and irrigation level reduces pure sugar toward impure sugar (Mehrandish et al., 2012).

Yield and relative yield exhibited a strong linear relationship with E_t . Percent sugar was not significantly affected by irrigation regimes or harvest date, but tended to increase as amount of applied irrigation water increased. Relative yields of root yield, sugar, and total dry matter under full-season irrigation. The relative yield relations of fresh roots, sugar and total dry matter were similar. Where irrigation was terminated in mid-season the model (Plantgro) slightly under predicted yield at high irrigation levels (Davidoff and Hanks, 1989).

Hozayn et al. (2013) reported that significant differences ($P \leq 0.01$) were in sugar beet root length and weight; however the differences were insignificant in root diameter at harvest. Hozayn et al. (2013) also reported that there was a strong and positive correlation among root yield and root weight while a weak and negative correlation was recorded between root yield and root diameter. Shalaby et al. (2010) reported that negative correlation was occurred between root yield and sugar rate.

4. Conclusions

This study has investigated the effects of deficit irrigation on the sugar beet root yield, sugar rate and some quality parameters of sugar beet, while also evaluating the water use efficiency of sugar beet (*Beta vulgaris* L.) in the Central Anatolian region of Turkey. The study goes on to suggest a suitable irrigation program to farmers in the region using the drip irrigation system.

The study has revealed that the best sugar rate and root yield is obtained from the level of I_1 of the lowest water application and the variety of C_1 . Furthermore, the best values of above-mentioned parameters (K, Na, dry matter rate, etc.) that helped to increase sugar rate and root yield were obtained in I_1C_1 treatment. As a result, it can be said that for the best sugar beet yield and quality under the similar climatic and soil conditions should be taken I_1 irrigation water level and C_1 variety.

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