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Yield and quality of sugar beet (*Beta vulgaris* L.) at different water and nitrogen levels under the climatic conditions of Kırsehir, Turkey

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ABSTRACT

The present study was conducted to determine the effect of different irrigation and nitrogen levels on yield, yield components, and sugar rate of the sugar beet (*Beta vulgaris* L.) during the years 2012 and 2013 in the Kırşehir province 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 the irrigation intervals. Treatments consisted of one irrigation interval (7 days) 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) and four nitrogen fertilizer levels (N_1: 30 kg ha^{-1}; N_2: 40 kg ha^{-1}; N_3: 50 kg ha^{-1}; and N_4: 60 kg ha^{-1}).

The highest WUE and IWUE values, the best quality parameters (Na, K, and alpha-amino nitrogen), and economic sugar beet root yield was determined in the treatment of I_1N_1 (K_{cp1}: 0.5 and 30 kg ha^{-1} of N). Therefore, this treatment can be used for sugar beet cultivation under similar climate and soil conditions.

1. Introduction

Recent annual world production of sugar beet has been approximately 227 million tons on 4.2 million hectares area per year, according to the Food and Agriculture Organization of the United Nations (FAO, 2011).

The crop land has been decreasing over the past two decades; total root production, however, remained stable over the same period because of increasing yields. Sugar beets are primarily produced in the following countries: France, United States, Germany, Russian Federation, Turkey, Poland, Ukraine, United Kingdom, and China, respectively (FAO, 2011).

Water shortages, especially in arid and semi-arid climate conditions, are a major barrier in agriculture development. Without optimizing use of water resources, agriculture production is impossible (Kheirabi et al., 1996). Sugar beets can be grown in a wide range of climatic conditions and are noted for tolerance to soil salinity (Tognetti et al., 2003; Sakellariou-Makrantonaki et al., 2002) but drought stress is a major cause of yield loss in sugar beets in arid and semiarid regions (Pidgeon et al., 2001). Therefore, irrigation water plays a significant role in agricultural practices and particularly in sugar beet cultivation (Hassanli et al., 2010). Sugar beets are drought resistant plants that can produce economic yield even with declined irrigation (Winter, 1980; Faberio et al., 2003). The water requirement of sugar beet cultivation is strongly dependent on weather conditions, irrigation management, growth period, plant density, genotype, and nitrogen application (Kuchaki and Soltani, 1995). This crop is one of the highest water consuming plants due to the long growth period and seasonal water consumption of 350–1150 mm in different regions of world (Allen et al., 1998). Low irrigation, in which the plant has undergone water stress in a special growth step or in a whole season, is one of methods to maximize water use efficiency and increase yield per unit of water used (Kirda, 2002).

The application of deficit irrigation is different from full irrigation applications. The main purpose of deficit irrigation is to raise the water use efficiency (WUE) and to obtain the highest yield per unit water (Kirda, 2002). Fertilizer is considered as a limiting factor to obtain high yield and quality. An adequate supply of nitrogen is essential for optimum yield.

However, excessive nitrogen decreases sugar content and increases impurities (Na, K, and amino-N) (Ouda, 2002; Fathy et al., 2009).

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Sugar beet is one of the most important crops among the field crops grown in the Kırsehir Province, Turkey, considering its economic importance as the raw material for the production of sugar. The cultivation area and amount of sugar beet production in Kırşehir region are 8770 ha and 421,000 t, respectively (TSI, 2010). Sugar beet production of Kırşehir province constitutes 2.3% of the sugar beet production of Turkey (TSFGD, 2013). The effects on yield components and yield of sugar beets and other crops under different irrigation regimes and methods have been investigated, especially in arid and semi-arid regions, and presented by many researchers. However, fewer studies have examined what the issues effect efficiency, with the use of different levels of water and fertilizer. However, irrigation practices are not implemented depending on irrigation scheduling; it is completely done according to the conventional irrigation methods under the traditional routines of farmers. This prevents the effective use of our scarce water resources. Thus, there are needed to more scientific research to create of the appropriate irrigation programs in this region.

The objective of the study was to investigate the effects of different water and nitrogen levels on the root yield, sugar rate, and some quality parameters of sugar beets and to suggest suitable irrigation in the Kırsehir, Turkey.

2. Materials and methods

2.1. Experimental site, climate and soil structure

The experiment was conducted during the 2012 and 2013 growing seasons under the field conditions at the Cukurcayir in Kırsehir Centrum, Turkey. Cukurcayır is located at a 36°42′ and 39°16′ N latitude, 31°14′ and 34°26′ E longitude and 1017 m altitude with semi-arid climate characteristics and total annual precipitation of 384.4 mm. The monthly mean meteorological data for the growing seasons and the long years (1970–2012) in the experimental region 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 season (from the sowing to harvesting dates) of the years 2012 and 2013, a mean 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 mean temperature and relative humidity data of sugar beet growing seasons were similar to long-term meteorological data; however, two years' precipitations were lower than long-term averages.

Soil at a depth of 90 cm was sampled before the experiment and subjected to a physicochemical analysis. The mean soil layer (0–30 cm) is clay loam (28.9% clay, 27.8% silt and 43.3% sand), the deeper one (30–60 cm) is of silt-clay loam type (27.8% clay, 26.8% silt, and 45.4% sand) and the deepest one (60–90 cm) is silt-clay loam type (26.8% clay, 26.3% silt, and 46.8% sand). Field capacity was 26.0–29.6%, wilting point was 13.7–15.0%, and bulk density was 1.30 g cm^{-3} (Table 2).

During the years 2012 and 2013, the soil had an average available P_2O_5 of 52.0 and 168.35 kg ha^{-1}, and K_2O of 333.2 and 1056 kg ha^{-1}. The soil was alkaline. The mean soil pH, limy, and organic matter ranged from 7.52 to 7.61, 53.89% to 61.07% $CaCO_3$, and 1.10% to 1.99% respectively (Table 2).

2.2. Sowing and fertilization

In the study, the Isella sugar beet variety was used as the plant material. Sowing was performed on April 14 and 2 in 2012 and 2013, respectively. Row spacing was 45 cm and on-row plant spacing was 20 cm. Each plot had a size of 20.25 m^2 (9 m length and 2.25 m width) with five rows. Seeds were sown at 1.5–2 cm depths using a 5-row mechanic beet seeder. Experiments were conducted in split plots in randomized blocks with three replicates. Treatments consisted of one irrigation interval (7 days) and three different irrigation levels (I_1, I_2, and I_3) adjusted according to the class A pan evaporation using three different plant-pan coefficients (K_{cp1}: 0.5; K_{cp2}: 0.75; and K_{cp3}: 1.00) and four nitrogen fertilizer levels (N_1: 30 kg ha^{-1}; N_2: 40 kg ha^{-1}; N_3: 50 kg ha^{-1}; and N_4: 60 kg ha^{-1}).

Fertilizer applications were given according to the soil analysis results. All experimental plots received the same amount of total fertilizer. A compound fertilizer of 12–30–12% N, P_2O_5, K_2O and nitrogen were applied at a rate of 50 kg ha^{-1} and 160 kg ha^{-1} prior to planting on April 14, 2012 and on April 2, 2013; the remaining the amount of nitrogen was applied to all experimental plots in the form of ammonium sulfate (21% N) in two parts on June 28 and July 25 in both irrigation season.

2.3. Irrigation and evapotranspiration

Irrigation water was supplied from a well using a pump. The water was classified as C_3S_1 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-irrigation, and at the final harvesting date. Experimental plots were irrigated by precipitation at the beginning for 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 days intervals.

Cumulative evaporation between the irrigations was measured in 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;

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

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 (m^2). Thus, treatments constituted from three different irrigation levels ($I_1 = E_{pan} \times K_{cp1} \times A$, $I_2 = E_{pan} \times K_{cp2} \times A$ and $I_3 = E_{pan} \times K_{cp3} \times A$).

Soil water measurements were taken throughout the crop growth season. The soil water profile, up to the 90 cm depth in 30 cm increments, was measured gravimetrically (oven dry basis) at sowing, 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. Cr was considered to be zero because there was no groundwater rising 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).

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 or total
		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, Kırsehir.

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):

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

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

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

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

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

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:

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

where Ya: the actual sugar beet yield ($\mathrm{t\,ha^{-1}}$), Ym: the maximum sugar beet yield ($\mathrm{t\,ha^{-1}}$), Eta: the actual plant water consumption (mm), Etm: the maximum plant water consumption (mm).

2.4. Harvest and measurements

At the harvest, to prevent the border effect, a row of each plot sides and 0.40 m at the beginning and end of each row were eliminated. The harvest was conducted in an area of 1.35 m × 8.2 m (11.07 $\mathrm{m^2}$). Harvesting time was performed on October 1 and 12 in 2012 and 2013, respectively.

Fifteen plants were selected randomly from each plot to measure root length, root diameter, and mean weight of a total of the five sugar beets per plot. Seventy randomly selected sugar beets per plot were analyzed for yield and yield components such as sugar beet yield (root yield), sugar rate (%), potassium content, sodium content, alpha-amino nitrogen content, and dry matter rate. Analyses were conducted at the laboratory of the Ankara Sugar Institute within the Sugar Factories Corporation using the International Commission of Uniform Methods of Sugar Analysis (ICUMSA, 2013). In addition, the values of refined digestion rate

Table 2
Some physical and chemical properties of the experimental soils.

Physical properties

Soil layers (cm)	Particle size distribution (%)			Texture	Field capacity (%w)	Wilting point (%w)	Bulk density (g cm^3)
	Sand	Silt	Clay				
0–30	43.3	27.8	28.9	Clay loam (CL)	29.6	15.0	1.3
30–60	45.4	26.8	27.8	Silty-clay loam (SCL)	26.8	14.1	1.3
60–90	46.8	26.3	26.8	Silty-clay loam (SCL)	26.0	13.7	1.3

Chemical properties

Soil layers (cm)	pH	Total salt (%)	EC (dS m^{-1})	$CaCO_3$ (%)	Available nutrients (kg ha^{-1})		Organic matter (%)
					P_2O_5	K_2O	
0–30	7.52	0.022	0.588	53.89	168.35	1056	1.99
30–60	7.61	0.019	0.517	59.40	82.20	530.05	1.42
60–90	7.56	0.023	0.634	61.07	52.0	333.2	1.10

Table 3
Amount of irrigation water applied in irrigation periods of 2012–2013.

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[a]	97.05[a]	20/06/2013	108.56[a]	108.56[a]	108.56[a]
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 were increased up to field capacity in the first irrigation in trial years.

and refined sugar yield using the analysis data was calculated with the Brunswick formula mentioned Buchholz et al. (1995) method.

Refined digestion rate is defined as the ratio of the weight of the sugar roots produced from a sugar beet root. Sugar rate is expressed as a percentage of the root's weight sugar in the sugar beet root.

2.5. Statistical analysis

All data were analyzed according to the analysis of variance (ANOVA) using the SAS Statistical Package Program; 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), plant water consumption (Et) and root yield

Table 3 shows the amounts of water applied in the irrigation periods of the 2012–2013 and total precipitation (from snowing dates to final irrigation dates) during the two growing seasons. The first and the last irrigations were performed on June 20 and October 20 of the first year. The relevant dates of the second year were June 20 and October 19. The plants of the first and second year were irrigated 14 times at seven days intervals, respectively. A total of 97.05 mm and 108.56 mm water were applied to all plants prior to the scheduled irrigation in the first year and the second year, respectively. Soil water deficit in all plots was replenished to field capacity at 0–90 cm soil depth and then scheduled irrigation, based on seven days of cumulative evaporation, was initiated (Table 3). The total amount of irrigation water applied ranged from 353.95 mm to 610.85 mm (2012) and from 361.06 mm to 613.56 mm (2013). Total precipitation during the growing seasons was 132.6 mm in 2012 and 91.5 mm in 2013 (Table 3). In both growing seasons, the lowest and the highest values of irrigation water and plant water consumption (Et) were observed in I_1 and I_3 treatments, respectively. The Et values increased with increasing irrigation levels (Table 4). The results of our study coincide with those reported by Ucan and Gencoglan (2004) and Baigy et al. (2012).

Highest root yield averaging 91.15 t ha^{-1} was obtained in I_3N_3 treatment, followed by I_2N_4 and I_1N_1 treatments with 81.48 and 80.76 t ha^{-1} in 2012. Minimum root yield was obtained from the I_2N_1 treatments as 55.96 t ha^{-1} for the first experimental year. In 2013, maximum root yield was obtained from the I_3N_1 treatment plots as 72.42 t ha^{-1} and followed by I_3N_3 and I_3N_2 plots with root yields of 71.91 t ha^{-1} and 69.38 t ha^{-1}, respectively. Minimum root yield was obtained from the I_1N_4 treatments with 58.18 t ha^{-1} for the second experimental year (Table 4). According to the results of both two years, it is understood that there not should be the water deficit to achieve the maximum yield. However, it was revealed that needed to achieve a maximum yield the applications below level of the highest fertilizer. Nutrients transition into plant roots can only be ensured through help of water. Irrigation and fertilization are the most effective factors in agricultural production. But, their combined impacts on the crop production are more important than individual impacts. First of all, irrigation causes more fertilizer uptake by plants. However, fertilizers can be washed below the root zone by excessive watering. Therefore, controlled irrigation and fertilization to increase plant yield is of vital importance (Ertek, 2014).

In the first year, the highest and the lowest WUE values were determined in the I_1N_1 and I_3N_1 treatments as 0.130 t ha^{-1} mm^{-1} and 0.074 t ha^{-1} mm^{-1}, respectively. In the second year, the highest and the lowest WUE values were determined in I_1N_1 and I_3N_4 treatments as 0.117 t ha^{-1} mm^{-1} and 0.080 t ha^{-1} mm^{-1}, respectively. The highest IWUE obtained was 0.190 t ha^{-1} mm^{-1} in I_1N_2 and minimum IWUE was observed in I_3N_4 treatments with 0.080 t ha^{-1} mm^{-1} in the first year. In the second year, the highest and the lowest IWUE were determined as 0.190 t ha^{-1} mm in I_1N_2 and 0.110 t ha^{-1} mm^{-1} in I_3N_4 treatment, respectively.

IWUE was higher than WUE in all treatments and whole growing seasons due to the crop water consumption was higher than the amount of applied water. The values of IWUE and WUE decreased in the levels from I_1 to I_3 in 2012 and 2013 due to the reduced in yield per unit water. Similar results by Ucan and Gencoglan (2004) revealed that the greatest values for WUE and IWUE were observed in the treatments with the highest yields, depending upon the level of irrigation water. Hassanli et al. (2010) reported that the highest IWUE for sugar was 1.26 kg m^{-3}, using surface drip irrigation in Southern Iran. In a study conducted by Topak et al. (2010) in Central Anatolia, Turkey, the values for WUE and IWUE ranged from 7.46 to 8.32 kg m^{-3} and 7.91 to 11.5 kg m^{-3}, respectively. The results show that support the findings of our study.

I_{rc} values ranged from 54 to 72.8% in I_1N_4 and I_3N_1 treatment plots in the first year, respectively. In the second year, similar to the previous year, the compensation rate of Et by applied irrigation

Table 4
Root yield, I, Et, WUE, IWUE, I_{rc} values of treatments.

Year	Treatments	I (mm)	Et (mm)	N (kg ha^{-1})	Root yield (t ha^{-1})	WUE (t ha^{-1} mm^{-1})	IWUE (t ha^{-1} mm^{-1})	I_{rc} (%)
2012	I_1N_1	353.95	622.5	30	80.76	0.130	0.228	56.9
	I_1N_2	353.95	636.8	40	76.76	0.121	0.217	55.6
	I_1N_3	353.95	645.9	50	78.00	0.121	0.220	54.8
	I_1N_4	353.95	656.0	60	79.72	0.122	0.225	54.0
	I_2N_1	482.40	682.0	30	55.96	0.082	0.116	70.7
	I_2N_2	482.40	700.1	40	69.33	0.099	0.144	68.9
	I_2N_3	482.40	711.8	50	76.27	0.107	0.158	67.8
	I_2N_4	482.40	728.0	60	81.48	0.112	0.169	66.3
	I_3N_1	610.85	839.0	30	62.24	0.074	0.102	72.8
	I_3N_2	610.85	850.0	40	80.46	0.095	0.132	71.9
	I_3N_3	610.85	861.0	50	91.15	0.106	0.149	70.9
	I_3N_4	610.85	873.7	60	73.80	0.084	0.121	69.9
2013	I_1N_1	361.06	572.0	30	67.06	0.117	0.186	63.1
	I_1N_2	361.06	588.9	40	68.47	0.116	0.190	61.3
	I_1N_3	361.06	600.1	50	64.95	0.108	0.180	60.2
	I_1N_4	361.06	615.0	60	58.18	0.095	0.161	58.7
	I_2N_1	487.31	668.0	30	64.05	0.096	0.131	73.0
	I_2N_2	487.31	680.5	40	62.24	0.091	0.128	71.6
	I_2N_3	487.31	691.6	50	66.60	0.096	0.137	70.5
	I_2N_4	487.31	702.0	60	68.99	0.098	0.142	69.4
	I_3N_1	487.31	800.5	30	72.42	0.090	0.159	76.6
	I_3N_2	613.56	820.0	40	69.38	0.085	0.113	74.8
	I_3N_3	613.56	821.0	50	71.91	0.088	0.117	74.7
	I_3N_4	613.56	844.6	60	67.39	0.080	0.110	72.6

water (I_{rc}) varied from 58.7 to 76.6% in I_1N_4 and I_3N_1 treatment plots.

The plant water consumption compensation rates (I_{rc}) of irrigation water applied are the highest for the least nitrogen and the same water application levels. These values decreased with the increase in applied nitrogen levels. Considering the yield and water use efficiency values of the treatments, the most appropriate water and nitrogen levels were in the I_1N_1 treatment to achieve the economic yield. Sahin et al. (2014) reported that irrigation water use efficiency was the highest in the lowest irrigation conditions.

3.2. Water–yield relationships

The results of the analysis of variance related to the parameters studied are shown in Tables 5a and 5b. According to the results in both years, the effect of water levels and nitrogen applied and the effect of the interaction of water–nitrogen on root yield were similar and those effects were significant at 0.1%, 1%, and 1% levels, respectively. Additionally, considering that the obtained the maximum root yield at the lowest water and nitrogen levels, I_1 irrigation levels and N_1 nitrogen levels, in terms of root yield, may be indicated to be important in achieving optimum root yield.

Baclin and Celik (1994) studied the effect of deficit irrigation on sugar beets compared to five different levels of irrigation at the Tokat Research Institute experimental site in Turkey in years 1983–1986. They reported that the highest root yield and the highest sugar yield were obtained from treatment applied to the lowest 20% and 40% of irrigation as to complete (full) irrigation treatment. Researchers also stated that it will not cause a significant yield loss of a 50% water deficit.

Elverenli (1985) examined the effects on sugar beet root yield and quality of different levels of water and nitrogen and reported that the highest water consumption was 975 mm and the highest root yield was 49.70 t ha^{-1}. Furthermore, he stated that sugar beets should be given amount of 100 kg ha^{-1} nitrogen and watered when 50% of the available water in root zone was consumed.

Sharmasarkar et al. (2001) evaluated the effect of surface drip and flood irrigation on water and fertilizer use efficiency for sugar beets. They concluded that applying irrigation water with drip systems used less water and fertilizer than when using flood irrigation. Tognetti et al. (2003) reported values for sugar beet root yields of 78.7 and 63.1 kg ha^{-1} using the drip system under full and deficit (50% full irrigation) irrigation in Southern Italy. Suheri et al. (2008) determined a largest root yield of 91.5 and 68.0 kg ha^{-1}, respectively, in 2005 and 2006 using drip irrigation under the conditions of the Konya Plain in Central Anatolia in Turkey. Hassanli et al. (2010) reported the highest sugar beet root yield to be 79.7 kg ha^{-1} and the lowest sugar beet yield of 58.6 kg ha^{-1} for surface drip irrigation. In a study carried out by Abyaneh et al. (2012) in Iran, the highest and the lowest root yield was obtained as 116.8 t ha^{-1} and 52.21 t ha^{-1} respectively. Similar results were reported by Demirer et al., 1994, Kandil et al. (2002), and Esmaeili (2010). Both the our study and literatures above mentioned, reveals that deficit irrigation was important in the increase of sugar beet root yield.

In the first year, the effect of nitrogen levels on sugar rate was determined at a 5% level of significance; the impact of the other applications was not significant. In the second year, the water and nitrogen levels were determined to have any significant effect. The sugar rate varied from a minimum of 15.71% in I_1N_4, to a maximum of 17.31% in I_3N_1, in the treatment plots in the first year; this rate varied from 15.35% in I_2N_4, to 17.35% in the I_3N_3 treatments in the second year. In a study conducted in the Kırsehir region, the average sugar rate was found as 18.12% in 2013 (TSFGD, 2013). In a study carried out by Abyaneh et al. (2012) in Iran, the highest and the lowest sugar rate was obtained as 17.43% and 16.26%, respectively. Similar results were found by Campbell and Kern (1983), Ucan and Gencoglan (2004) and Baigy et al. (2012). In general, sugar rate in the highest nitrogen application was lower. This situation shows that the effect of nitrogen subsequent a certain level of nitrogen application was not on sugar rate. Similar situation also was revealed in the irrigation application levels. According to the obtained results, it is clear that the rates of water and nitrogen application is important for maximum sugar rate.

In the first year, the effect of interactions (water × nitrogen) and nitrogen levels on refined digestion rate were determined at a 5% level of significance; the impact of the irrigation water was not significant. In the second year, the water, nitrogen levels and interactions were determined to have any significant effect. The refined digestion rates varied from a minimum of 12.71% in I_3N_2, to a maximum of 14.66% in I_3N_1, in the treatment plots in the first year; this

Table 5a
The results of variance analysis of the yield and quality parameters.

Treatments	NL	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	N_1	80.76b**	16.93^{ns}	14.27a*	11.52^{ns}	1.80ab**	4.83^{ns}	3.29a**	20.56^{ns}
	N_2	76.76bc	16.96	14.43a	11.08	1.44b	4.71	2.97a	20.42
	N_3	78.00b	16.37	13.75a	10.72	1.88a	4.64	3.16a	19.97
	N_4	79.72b	15.71	13.02a	10.38	1.96a	4.28	3.59a	19.43
I_2	N_1	55.96e	16.95	14.35a	8.03	1.60b	4.79	3.12b	20.29
	N_2	69.33cd	16.20	13.61a	9.44	1.82ab	4.53	3.11b	19.63
	N_3	76.27bc	16.91	14.39a	10.98	1.70ab	4.63	2.83b	20.45
	N_4	81.48b	16.21	13.38a	10.90	2.02a	4.64	3.96a	19.59
I_3	N_1	62.24de	17.31	14.86a	9.25	1.52b	4.64	2.61b	20.43
	N_2	80.46b	15.74	12.95b	10.42	2.09a	4.92	3.64a	19.18
	N_3	91.15a	15.87	13.06b	11.91	2.32a	4.70	3.69a	19.75
	N_4	73.80bc	16.46	13.63ab	10.06	1.97a	4.55	4.05	20.05
Irrigation level	I_1	78.81a***	16.49^{ns}	13.87^{ns}	10.93^{ns}	1.76b*	4.61^{ns}	3.25^{ns}	20.10^{ns}
	I_2	70.76b	16.57	13.94	9.86	1.78b	4.65	3.25	19.99
	I_3	76.91a	16.35	13.63	10.48	1.98a	4.70	3.49	19.85
Nitrogen level	N_1	66.32c**	17.06a*	14.49a*	9.61^{ns}	1.64c**	4.75a*	3.01c**	20.43^{ns}
	N_2	75.51b	16.30b	13.66b	10.32	1.79b	4.72a	3.24b	19.75
	N_3	81.81a	16.38b	13.73b	11.23	1.96a	4.66ab	3.22b	20.06
	N_4	78.34ab	16.13b	13.35b	10.46	1.98a	4.49b	3.86a	19.69
C.V. (%)		6.20	4.49	5.42	16.32	13.0	4.79	12.82	3.08
2013									
I_1	N_1	67.06bcd**	16.23^{ns}	13.48^{ns}	9.04^{ns}	1.21^{ns}	4.92^{ns}	3.88^{ns}	20.23^{ns}
	N_2	68.47abcd	16.83	14.33	9.81	1.39	4.53	2.97	21.04
	N_3	64.95cde	16.85	14.21	9.23	1.50	4.90	3.28	21.18
	N_4	58.18f	16.32	13.61	7.92	1.72	4.37	3.73	20.98
I_2	N_1	64.05de	16.41	13.79	8.83	1.36	5.10	3.18	20.20
	N_2	62.24ef	15.99	13.26	8.25	1.74	4.83	3.58	20.79
	N_3	66.60cde	16.86	14.10	9.39	1.59	5.07	3.67	20.91
	N_4	68.99abcd	15.35	12.76	8.80	1.83	4.19	3.29	21.79
I_3	N_1	72.42a	15.55	12.92	9.36	1.52	4.80	3.29	19.33
	N_2	69.38abc	16.89	14.23	9.88	1.82	4.91	3.20	20.53
	N_3	71.91ab	17.20	14.53	10.45	1.87	4.53	3.41	21.17
	N_4	67.39abcd	16.83	13.99	9.43	2.25	4.75	3.85	21.83
Irrigation level	I_1	64.66b***	16.56^{ns}	13.91^{ns}	8.99^{ns}	1.46b*	4.68^{ns}	3.47^{ns}	20.87^{ns}
	I_2	65.36b	16.15	13.48	8.81	1.63ab	4.80	3.43	20.94
	I_3	70.27a	16.62	13.92	9.78	1.86a	4.75	3.44	20.71
Nitrogen level	N_1	67.84a**	16.06^{ns}	13.40^{ns}	9.09^{ns}	1.36c*	4.94^{ns}	3.45^{ns}	19.93c**
	N_2	66.55ab	16.57	13.94	9.28	1.65b	4.76	3.25	20.79b
	N_3	67.82a	16.97	14.28	9.69	1.66b	4.84	3.45	21.09ab
	N_4	64.85b	16.16	13.25	8.59	1.93a	4.44	4.44	21.53a
C.V. (%)		8.0	5.57	6.41	12.81	19.57	8.33	13.17	4.11

Means in the same columns followed by the same letters are not significantly different as statistically.
C.V.: coefficient of variation (%); NL: nitrogen level.
* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
*** Significant at $P < 0.001$
^{ns} No significant.

rate varied from 12.69% in I_2N_4 to 14.39% in the I_3N_3 treatments in the second year. Okut and Yıldırım (2004) reported that the mean refined digestion rates ranged from 18.65% to 16.11%. Yolcu (2005) stated that the refined digestion rates varied from a minimum of 15.60%, to a maximum of 18.06%. The results in our study was lower than those obtained by Okut and Yıldırım (2004) and Yolcu (2005).

In both years, the effect of interactions (water × nitrogen), nitrogen and water levels on refined sugar yield were not significant. The refined sugar yields varied from a minimum of 10.96 $t\,ha^{-1}$ in I_1N_3, to a maximum of 14.51 $t\,ha^{-1}$ in I_1N_1, in the treatment plots in the first year; The refined sugar yields varied from 9.56 $t\,ha^{-1}$ in I_2N_2 to 13.13 $t\,ha^{-1}$ in the I_3N_3 treatments in the second year. In a study carried out by Abyaneh et al. (2012) in Iran, the highest and the lowest refined sugar yield was obtained as 20.36 $t\,ha^{-1}$ and 8.5 $t\,ha^{-1}$, respectively. The refined sugar yield values in our study are also included in the same range as those obtained by Abyaneh et al. (2012).

As seen from Table 5a, Na values in the first year were increased linearly with irrigation levels ($P < 0.05$) and nitrogen levels, and the interaction of irrigation levels and nitrogen levels ($P < 0.01$). In the second year, there were no significant interactions, and irrigation and nitrogen levels were affected Na values at a 5% significance level. Na values in the first year changed between 1.52 and 2.32 $mmol\,100\,g^{-1}$ beet; the second year, Na values changed between 1.21 and 2.25 $mmol\,100\,g^{-1}$ beet. In addition, many of the Na values were above the standards (1.0 ± 0.5 $mmol\,100\,g^{-1}$ beet) (Ozgur, 2014). Yolcu (2005) reported that Na values changed between 0.86 and 1.63 $mmol\,100\,g^{-1}$ beet.

Table 5b
The results of the variance analysis of some quality parameters.

Irrigation level	Nitrogen levels	2012			2013		
		Root length (cm)	Root diameter (cm)	Mean 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)
I_1	N_1	45.447ab*	29.700ns	2.567a*	41.600bc*	21.800f*	1.657abc*
	N_2	46.687a	28.347	2.567a	43.867abc	23.933def	1.700abc
	N_3	44.320abc	28.900	2.333ab	40.800c	24.333def	1.333c
	N_4	41.033c	27.300	2.033b	43.400abc	27.300abc	1.733ab
I_2	N_1	44.053abc	27.087	2.300ab	43.800abc	22.600ef	1.733ab
	N_2	46.340a	28.933	2.300ab	45.467ab	26.133bcd	1.800ab
	N_3	43.847abc	28.000	2.200ab	44.200abc	24.000def	1.633bc
	N_4	45.500ab	29.200	2.467ab	45.000ab	29.200a	1.800ab
I_3	N_1	45.407ab	29.113	2.333ab	47.000a	25.267cde	2.033a
	N_2	42.887bc	27.667	2.233ab	43.733abc	24.533cdef	1.633bc
	N_3	43.420abc	30.000	2.233ab	46.000a	26.533abcd	1.900ab
	N_4	41.433c	28.267	2.133ab	44.867abc	28.267ab	1.667abc
Irrigation levels	I_1	44.372ns	28.561ns	2.375ns	42.417b*	24.342b*	1.606b*
	I_2	44.935	28.305	2.317	44.617a	25.483ab	1.742ab
	I_3	43.287	28.762	2.233	45.400a	26.150a	1.808a
Nitrogen levels	N_1	44.969a*	28.633ns	2.400ns	44.133ns	23.222c**	1.808ns
	N_2	45.304a	28.316	2.367	44.356	24.867b	1.711
	N_3	43.862ab	28.967	2.256	43.667	24.956b	1.622
	N_4	42.656b	28.256	2.211	44.422	28.256a	1.733
C.V. (%)		4.51	7.83	12.3	5.55	6.57	13.61

Means in the same columns followed by the same letters are not significantly different as statistically.
C.V.: coefficient of variation (%).
* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
ns No significant.

The first year, effects of interaction and irrigation levels on K values was not significant, while the nitrogen levels were a significant at 5% of the level. There was not a significant effect on the K values of water and nitrogen levels in the second year. The first year, K values of treatments ranged from 4.28 to 4.92 mmol 100 g^{-1} beet; K values in the second year ranged from 4.19 to 5.10 mmol 100 g^{-1} beet. The K values in some treatments were slightly above the standard (4.0 ± 0.5 mmol 100 g^{-1} beet) (Ozgur, 2014). Similar results reported by Yolcu (2005). However, K values was generally increased with increasing of irrigation levels, but with increasing nitrogen levels, they exhibited a tendency to decrease.

In the second year, irrigation and nitrogen levels and the effect of their interaction on the value of alpha-amino nitrogen were not significant. In the first year, nitrogen levels and interaction effects were significant ($P < 0.01$). The irrigation levels were not significant. The values of alpha-nitrogen in the first year ranged from 2.61 to 4.05 mmol 100 g^{-1} beet; in the second year, the values of alpha-nitrogen ranged from 2.97 to 4.44 mmol 100 g^{-1} beet. Furthermore, the alpha-amino nitrogen values were above the standards (1.5 ± 0.5 mmol 100 g^{-1} beet) (Ozgur, 2014). In the study, the values of alpha-amino nitrogen obtained the slightly above of the standarts. Tognetti et al. (2003) reported that K values ranged from approximately 6 mmol 100 g^{-1} beet for the unirrigated control, to 5.4 mmol 100 g^{-1} beet for drip irrigation with 100% of estimated ET replaced. Na ranged from 3 mmol 100 g^{-1} beet in the unirrigated control, to 1.9 mmol 100 g^{-1} beet for both drip and low pressure sprinkler irrigation with 50% of estimated ET replaced; alpha-amino nitrogen decreased from 2.5 mmol 100 g^{-1} beet for the unirrigated control, to approximately 2 mmol 100 g^{-1} beet for irrigated plots. Okut and Yıldırım (2004) reported that the average value of the alpha-amino nitrogen ranged from 1.36 meq 100 g^{-1} beet to 0.97 meq 100 g^{-1} beet. The differences between the values of Na, K, and alpha-amino given above may be due to the planting time, irrigation and fertilizer practices and irrigation technologies. The results of our experiments are similar to the above-mentioned findings.

Kirda (2002) stated that yield loss caused by deficit irrigation less from the losses occurred due to diseases and pests and during harvest, and that properly applied deficit irrigation might increase in the quality of the product (sugar rate in sugar beets, length and strength of fiber in cotton, etc.).

Almani et al. (1997) reported that water deficits decreased root yield but increased sugar, potassium, and amino nitrogen amounts, and total irrigation increases the sugar amount in sugar beets. A high amount of N increased sodium, potassium, and amino nitrogen concentrations in the roots. The unlikely effect on α-amino N caused by the excessive nitrogen fertilization could be explained by increasing the role of photosynthesis as well as formation of protein and amino acids (Hoffmann, 2005).

Fathy et al. (2009) studied the effect of nitrogen and potassium fertilization on grown root yield and quality, as well as nutrient content of sugar beet plants grown on sandy calcareous soil. Their results showed that increasing nitrogen and potassium rates significantly increased root yield, dry weight, and sugar yield of sugar beet plants. Increasing nitrogen levels up to 285 kg ha^{-1} (under 0.0 kg K_2O ha^{-1}) significantly increased impurities (Na, K, and alpha-amino nitrogen) and the percentage of sugar loss. The obtained results coincide with findings above-mentioned.

Water and nitrogen levels and their interaction did not have a significant effect on dry matter rate (%) in the first year. In the second year, only nitrogen levels had a significant effect ($P < 0.01$). The dry matter rates varied from a minimum of 19.18% in I_3N_2, to a maximum of 20.56% in I_1N_1 the treatment in the first year; this rate varied from 19.33% in I_3N_1 to 21.83% in the I_3N_4 treatments in the second year. Generally, dry matter rate increased in the lowest nitrogen application. Okut and Yıldırım (2004) reported that a dry matter rate averaging ranged from 23.92% to 21.34%. Yolcu (2005) reported that a dry matter rate ranged from 25.46% to

28.46%. The results in present study were found lower than those reported by Okut and Yıldırım (2004) and Yolcu (2005). These differences among the results may be due to the different fertilizer and water levels applied in different regions. Choluj et al. (2004) also reported that the dry matter of the whole plants during application of a water shortage reduced all drought treatments at growth stage. Armestrong et al. (1986) and Esmaeili (2010) were stated that an increase of N in the soil increased in the root yield, N uptake by the plant, and also root dry matter ratio. In addition, Esendal (1989) and Çimrin (2001) also reported that increasing nitrogen fertilizer doses caused great decrease in dry matter rate.

As shown in Table 5b, in the first year, irrigation levels had no significant effect on root length. Nitrogen levels and irrigation levels and nitrogen level interaction was significant at 5% level. The highest group for root length consisted of the N_2 and I_1N_2 treatments. In both years, the effect of nitrogen levels on the root length was not significant; irrigation levels and irrigation level × nitrogen level interaction was significant at a 5% level. The highest values were determined in the treatments of I_3 and I_3N_1. The effect of nitrogen levels and irrigation level × nitrogen level interaction on root diameter was significant at a 5% level. Nitrogen levels were significant at a 1% level. The highest values were determined in the I_3, N_4, and I_2N_4 treatments. According to the results of statistical analysis, it is understood that irrigation water levels are important for both root length and root diameter. But the increase in nitrogen levels has not contributed to the improvement of the root diameter.

In the first year, the effect of the irrigation level and nitrogen levels were not significant on mean root weight of five sugar beet randomly selected per treatment. The interactions of the irrigation level × nitrogen level were determined to be significant at a 5% level. The highest values were determined in the I_1N_1 and I_1N_2 treatments. This situation indicates that the levels of the lowest water and nitrogen applied in this study were sufficient for a maximum mean root weight of five sugar beet randomly selected per treatment.

In the second year, the effect of nitrogen levels on mean weight of five sugar beet randomly selected per treatment was not significant. The effects of irrigation and interactions of the irrigation level × nitrogen level were determined at a 5% significance level. The highest values were determined in the I_3 and I_3N_1 treatments. The effects of irrigation and nitrogen levels on the mean weight of five sugar beet randomly selected per treatment are similar with effects on the root length. Khan et al. (1990) and Badawi et al. (1995) reported that root length, diameter, and weight of roots increased with increasing nitrogen fertilizer levels. Kandil et al. (2002) in Egypt, also noticed that there was a significant increase in root weights, root length and diameter due to raising nitrogen fertilizer levels. This accounts for the increase in the amount of metabolites synthesized by plants.

Yield response factors (ky) of treatments in the first and the second years were 0.78 and 0.40, respectively (Fig. 1). This indicates that the first and second year might decrease 0.78 and 0.40 units yield per one unit of water deficiency, respectively. The ky value in the first year increased and was slightly higher than the second year. Furthermore, the ky values were lower due to the unimportant of influence on yield of irrigation water levels in both years. The ky values of 0.78 and 0.40 obtained in the current study (Fig. 1) for the entire sugar beet growing season in 2012 and 2013 was lower than the values of 0.6–1.0 reported by Doorenbos and Kassam (1979), 0.8–0.9 by Kassam and Smith (2001), and 0.73 by Ucan and Gencoglan (2004) for the Kahramanmaras region in Turkey. However, the ky values obtained in this study are close to the ky value of 0.45 reported by Pejić et al. (2011). The differences in the ky of the response factor indicate that ky may be affected by other factors in addition to the soil's water deficiency, namely by soil properties, climatic conditions, and growing season length, irrigation methods and programs, and inadequacies of production technology (Petcu et al., 2009; Ucan and Gencoglan, 2004; Pejić et al., 2011).

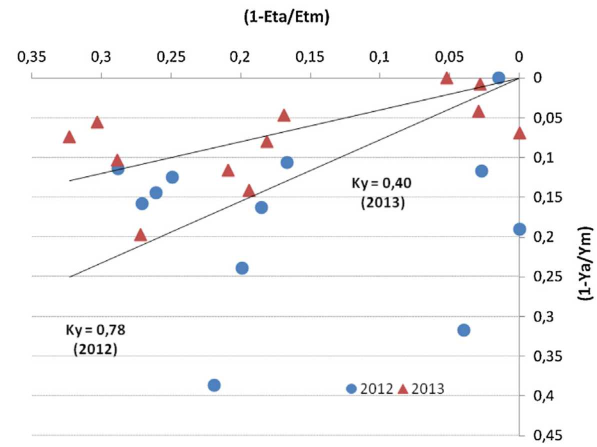

Fig. 1. The relationship between relative yield decrease and relative evapotranspiration deficit for sugar beets in the total growing period.

3.3. Relationship between the yield, yield components and quality parameters

The relationship between yield, yield components and some quality parameters (root yield, Et, Na, K, alpha-amino nitrogen, dry matter rate, sugar rate, refined digestion rate, and refined sugar yield) were graphically evaluated and the correlation coefficient are given in Table 6. In the first year of the study the relationship between sugar rate, Na, and dry matter rate was significant at a level of 1%. Sugar rate, K, and alpha-amino nitrogen were had a significant relationship at a 5% level.

The relationship between refined digestion rate, Na, and dry matter rate was determined a significant relationship at the level of 1%; the relationship between refined digestion rate, K, and alpha-amino nitrogen was determined a significant relationship at the level of 5%. The relationship between root yield and Na had a 5% significance level. The relationship between dry matter rate, Na, K, and alpha-amino nitrogen was determined at a 5% significant level. The relationship between Na and alpha-amino nitrogen was established at a level of 1%. The relationship between K and Et was at level of 5%. In the second year, the relationship between sugar rate, dry matter rate, and refined sugar yield was at a level of 5%. The relationships between the sugar rate and dry matter rate; root yield and Et; dry matter rate and Na were determined at a level of 5%, 5%, and 5% respectively. Campbell and Kern (1983) reported that root yield was positively associated with amino-nitrogen, sodium, and potassium significant at 0.01%, 0.01%, and 5% respectively, whereas sugar content percent was negatively associated with amino-nitrogen, sodium, and potassium significant at 0.01%, 0.01%, and 0.01% respectively. Çimrin (2001) and Okut and Yıldırım (2004) stated that the relationship between the sugar rate and dry matter rate was a significant ($P < 0.05$). Fathy et al. (2009) stated that nitrogen fertilizer tended to increase root yield of sugar beet. Esmaeili (2010) determined that effects of the different irrigation treatments and different amounts of N fertilizer on root yield were significant at a level of 1% and interactions of water and N also were not significant, statistically for all the traits. Jahedi et al. (2012) stated that the effect of N fertilizer levels on root yield, sugar yield, α-amino N was significant ($P < 0.05$).

In addition, in our study, the relationships between the root yield and Et were statistically determined at a 5% level. The results of our study support the findings by many researchers reported that there was a linear the relationship between Et and sugar beet

Table 6
The coefficient of correlation between the yield, yield components and some quality parameters.

Year	Yield components	Na	K	Alpha-amino nitrogen	Dry matter rate	Et
2012	Sugar rate	$R^2 = 0.72^{**}$	$R^2 = 0.56^{*}$	$R^2 = 0.48^{*}$	$R^2 = 0.88^{**}$	$R^2 = 0.05$
	Refined digestion rate	$R^2 = 0.81^{**}$	$R^2 = 0.53^{*}$	$R^2 = 0.56^{*}$	$R^2 = 0.84^{**}$	$R^2 = 0.09$
	Refined sugar yield	$R^2 = 0.01$	$R^2 = 0.135$	$R^2 = 2\text{E-}05$	$R^2 = 0.24$	$R^2 = 0.01$
	Root yield	$R^2 = 0.51^{*}$	$R^2 = 0.14$	$R^2 = 0.28$	$R^2 = 0.15$	$R^2 = 0.08$
	Dry matter rate	$R^2 = 0.52^{*}$	$R^2 = 0.56^{*}$	$R^2 = 0.38^{*}$		$R^2 = 0.09$
	Na		$R^2 = 0.13$	$R^2 = 0.62^{**}$		$R^2 = 0.21$
	K			$R^2 = 0.085$		$R^2 = 0.46^{*}$
	Alpha-amino nitrogen					$R^2 = 0.13$
2013	Sugar rate	$R^2 = 0.23$	$R^2 = 0.09$	$R^2 = 2\text{E-}05$	$R^2 = 0.54^{*}$	$R^2 = 0.013$
	Refined digestion rate	$R^2 = 0.11$	$R^2 = 0.043$	$R^2 = 0.014$	$R^2 = 0.47^{*}$	$R^2 = 0.0003$
	Refined sugar yield	$R^2 = 0.076$	$R^2 = 0.12$	$R^2 = 0.06$	$R^2 = 6\text{E-}05$	$R^2 = 0.21$
	Root yield	$R^2 = 0.0002$	$R^2 = 0.001$	$R^2 = 0.17$	$R^2 = 0.08$	$R^2 = 0.32^{*}$
	Dry matter rate	$R^2 = 0.41^{*}$	$R^2 = 0.006$	$R^2 = 0.213$		$R^2 = 0.0012$
	Na		$R^2 = 0.0002$	$R^2 = 0.12$		$R^2 = 0.192$
	K			$R^2 = 0.01$		$R^2 = 0.05$
	Alpha-amino nitrogen					$R^2 = 0.12$

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.

yield (Ucan and Gencoglan, 2004; Suheri et al., 2008; Topak et al., 2010; Pejić et al., 2011; Sahin et al., 2014). In addition, Shrestha et al. (2010) also reported that there was both a linear and polynomial relation yield decline and water stress. The results of the studies mentioned-above are similar to the results of our experiments.

4. Conclusions

The current study investigated the relationships between water–nitrogen–yield in sugar beets, and the highest yields were obtained from treatments that received of the highest water and nitrogen. However, the maximum yield per unit of water and nitrogen was obtained from treatments applied of the lowest water and nitrogen. Therefore, the highest WUE and IWUE values were determined at the level of the lowest water and nitrogen application.

Furthermore, a statistically significant impact was not found on the yield of water and nitrogen levels; water × nitrogen interaction was determined that effective ($P < 0.05$) in both years. It was also determined that the lowest water and nitrogen levels had a greater effect on the quality parameters (*sugar rate*, *refined digestion rate*, and *refined sugar yield*) of sugar beets. Therefore, I_1N_1 treatment (K_{cp1}: 0.5 and 30 kg ha^{-1} of N) with the highest WUE value can be recommended for the cultivation of sugar beet in similar climatic and soil conditions in terms of water and fertilizer saving.

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