

Effects of depth-dependent irrigation regimes and organomineral fertilizers on water use and quality attributes of sugar beet

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Abstract: Experiments were conducted under provincial conditions of Kayseri, Turkey, for two years in the growing seasons of 2014 and 2015 to determine the effects of irrigation water applications based on different sugar beet root zone depths and different organomineral fertilizers on sugar beet yield, root quality, water consumption, and water use efficiency. Two constant root depths ($D_1 = 0.9$ m and $D_2 = 0.6$ m) and one active water extraction root depth ($D_3 = 0.4-0.9$ m) were investigated. A mineral fertilizer (F_1), an organomineral fertilizer (F_2), and organic + mineral fertilizer (F_3) were considered as the subtreatments in the experiments carried out in a completely randomized block split-split plots design with 3 replications. Despite the lower nitrogen and phosphorus quantities applied, the F_2 treatment produced the same sugar beet root yield (95.31 t/ha) as F_1 (88.59 t/ha) and F_3 (94.56 t/ha) treatments. The irrigation water requirements of D_1 for two years were 22.8% and 27.6% greater than the D_2 and D_3 treatments, respectively. Irrigation water use efficiencies of D_2 and D_3 treatments were higher than D_1 . Digestion and recoverable sugar percent and Na, K, and N contents of roots were not affected significantly by the treatments. Using organomineral fertilizers would offer various advantages for disposing of huge urban waste deposits and returning organic matter to agricultural areas. Use of active root water extraction depth or 0.60-m root depth for irrigation applications will also contribute to efficient use of water resources and improve the income of sugar beet farmers due to reduced irrigation costs.

Key words: Irrigation requirement, fertilizer types, sugar beet yield, various rooting depth, water use efficiency

1. Introduction

Fertilizer and irrigation applications are effective and practical ways to control and improve yield and nutritional quality of crops for human consumption. In the current food production scenario, across major cropping systems of the world, crop yield is limited more by availability of nitrogen (N) and water resources than by the crop genetics (Sahin et al., 2002; Sinclair and Rufty, 2012; Kale et al., 2017; Sarı et al., 2017; Sarafi et al., 2018).

Sugar beet farming is practiced over 4.56 million hectares worldwide with an annual sugar beet root production of 277.2 billion tons and average yield of 60.73 tons per hectare. The Russian Federation, France, the United States, Germany, Turkey, and Ukraine are the greatest sugar beet producer countries of the world. Turkey, with 19.46 billion tons of production from an area of 321,953 ha, ranks sixth in world sugar beet production.¹

Different rooting depths have been advised and considered for sugar beet irrigation. For instance, effective rooting depth of sugar beet was accepted as 0.9 m by

a majority of the researchers in Turkey and irrigation practices were carried out according to 0.9-m root depth throughout the entire growing season (Ertaş, 1984; Uçan and Gençoğlan, 2004; Köksal, 2006; Köksal and Yıldırım, 2011; Topak et al., 2011; Kıymaz and Ertek, 2015a, 2015b). However, sugar beet irrigation practices were carried out based on 0.55-m soil depth in semiarid regions of Spain (Faberio et al., 2003), based on 0.45-m rooting depth in Iran (Mahmoodi et al., 2008), and with a 0.5-m soil profile in Albacete/Spain under center-pivot irrigation (Ortiz et al., 2010). Furthermore, a 0.7-m rooting depth was suggested by Doorenbos and Kassam (1986) and Allen et al. (1998) for irrigation practices of sugar beet.

Long-term use of inorganic fertilizers has not been very effective for sustainable cropping systems. Such fertilizers usually lead to soil acidification and degradation through reducing soil organic matter in the long run. On the other hand, organic manures improve soil fertility by activating microbial biomass and improving both soil structure and water-holding capacity. They release plant nutrients

1 Food and Agriculture Organization of the United Nations (2019). FAOSTAT [online]. Website: <http://www.fao.org/faostat/en/#data/QC>.

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slowly and steadily over a long time, but large quantities of organic matter are required to meet crop nutrient needs. Therefore, organomineral fertilizers have been recommended to sustain cropping systems and supply crop nutrient needs (Makinde, 2007). Organomineral fertilizers consist of mineral compounds and organic matter. Humic acid-containing materials like peat, lignite, humus, silts, and shale are commonly used in organomineral fertilizer production. Humic substances like humic acid, fulvic acid, organic matter, humate, and humin are essential elements of soil fertility and plant nutrition (Pettit, 2019).²

It was hypothesized that using different rooting depths for sugar beet irrigation would affect irrigation water requirements and water use efficiency. Higher irrigation water quantities would be required to replenish the moisture of deeper rooting depths and such higher quantities would then result in higher amounts of percolated water than in the case of lower water application for sufficient or actual rooting depth under the same irrigation system efficiencies. The primary objective of this study was to apply three different sugar beet rooting depth approaches for irrigation practices and to assess the effects of organomineral fertilizers on sugar beet yield, yield quality, water consumption, and water use efficiency under these irrigation practices.

2. Materials and methods

The experiments were conducted in the experimental area of the Kayseri Sugar Beet Factory (38°44'N, 35°25'E, altitude 1050 m) in the 2014 and 2015 growing seasons to determine the effects of irrigation water applications based on different sugar beet root zone depths and different organomineral fertilizers on sugar beet yield, root quality, water consumption, and water use efficiency. Three different rooting depths of $D_1 = 0.9$ m, $D_2 = 0.6$ m, and $D_3 = 0.4-0.9$ m were considered in main plots for irrigation practices. Three different fertilizers, namely F_1 (mineral fertilizer), F_2 (organomineral fertilizer), and F_3 (organic + mineral-fertilizer), were tested in subplots for fertilizer treatments. Experiments were conducted in split-split plots of completely randomized block design with three replications. The root zone depth treatments were allocated randomly to main plots of 12 m wide and 25 m long. The subplots for the fertilizer treatments were 12 m wide and 6.25 m long. Irrigation applications of D_3 were carried out by considering the root zone as 0.4 m at the beginning of the irrigation season. Soil moisture content was monitored with a neutron moisture meter (503 DR Hydro-probe) to a depth of 1.1 m with 0.2-m increments in polyvinyl chloride (PVC) access tubes, 5 cm in diameter and resistant to 10 bar (Evelt, 2007). Whenever considerable water depletion

occurred below the current root zone depth of D_3 , then the root zone depth of D_3 increased gradually to 0.9 m. Therefore, the D_3 treatment could be described as the active root water extraction depth. Root zone depths of the D_1 and D_2 treatments were accepted as constant from the beginning to the end of the irrigation season for all irrigation treatments.

A neutron moisture meter was calibrated according to Evelt (2007) in early June. After taking standard counts at depths of 20, 40, 60, 80, and 100 cm in two PVC access tubes, one in relatively dry soil and the other in wet soil, 4 undisturbed soil samples were taken around each depth. Volumetric soil moisture and soil bulk density were determined and then relationships between neutron meter counts and volumetric soil moistures were found by regression. Standard counts were taken just before each irrigation until the chi-square value of the neutron meter dropped to 0.95–1.05.

F_1 , F_2 , and F_3 fertilizers were applied to plots just before sowing with the ratio of 500 kg/ha. Mineral fertilizer (F_1) consisted of 13% nitrogen, 24% P_2O_5 , and 12% K_2O . Organomineral fertilizer-1 (F_2) is composed of 20% organic matter, 7% nitrogen, 18% P_2O_5 , and 7% K_2O while organic + mineral fertilizer (F_3) is composed of 25% organic matter, 25% humic-fulvic acids, 13% nitrogen, 24% P_2O_5 , and 12% K_2O . Following the emergence of plots, ammonium sulfate fertilizer ($(NH_4)_2SO_4$) was applied to the whole plots at a ratio of 500 kg/ha in two equal parts. The first half was administered at the first hoeing and the second half at the second hoeing just before the first irrigation.

The Zanzibar sugar beet cultivar was used and sowing was performed at 0.45-m row spacing and 0.20-m in-row plant spacing. Zanzibar is a widely cultivated high-yielding, rhizomania-resistant, and *Cercospora*- and powdery mildew-tolerant sugar beet cultivar in Kayseri Province. Sowing and root harvesting were respectively carried out on 5 May 2014 and 29 October 2014 in the first year and on 27 April 2015 and 22 October 2015 in the second year. The sugar beet growing season lasted 177 days and 178 days for the first and second years of the experiments, respectively. Weeds in the plots were controlled by hand hoeing two times in both years.

Experimental soils (soil profile of 0–100 cm) had a loamy fine sand texture with 85% sand, 8% clay, and 7% silt. Mean volumetric water content at field capacity and at wilting point and the mean bulk density of the soil were 32%, 15.8%, and 1.42 g cm⁻³, respectively.

A minisprinkler system was used for irrigations. Minisprinklers with 8-m wetting diameter were installed in a square pattern of 4 × 4 m and operated at 2 bar. The water application rate of the irrigation system was

² Pettit RE (2019). Organic matter, humus, humate, humic acid, fulvic acid and humin. Their importance in soil fertility and plant health. [online]. Website: <https://humates.com/pdf/ORGANICMATTERPettit.pdf>

calculated by dividing minisprinkler discharge into the irrigation area of each minisprinkler (Keller and Bliesner, 1990). Minisprinkler discharge at constant pressure was determined by measuring water volume in a container against time.

Irrigation requirements for the different root depth treatments were determined as follows (James, 1988):

$$I = \frac{(P_{vfc} - P_{va}) \times D}{100}$$

Here, I is the irrigation water requirement (mm), P_{vfc} is the volumetric soil moisture content at field capacity (%), P_{va} is the volumetric soil moisture content just before irrigation (%), and D is the root zone depth of the treatments. The crops were irrigated each week from mid-June to September and then biweekly irrigations were carried out until the harvest. Irrigation efficiency was accepted as 100% due to pressure control at manifold inlets for each main plot and irrigation applications in calm or light windy weather. Irrigation water application duration of these three treatments was calculated by dividing the required irrigation water depth into the irrigation water application rate. All the main plots were irrigated according to water application durations at constant pressure.

Water consumptions of sugar beet for different root depth treatments were determined according to soil water budget as follows (James, 1988):

$$ET = R + I - D_p \pm \Delta S$$

Here, ET is the water consumption of sugar beet (mm), R is the rainfall (mm), I is the irrigation water depth

applied (mm), D_p is deep percolation (mm), and ΔS is the soil water difference (mm) between the sowing and the harvest. Deep percolation in the water budget equation was ignored because of controlled irrigation based on soil moisture. Some weather data were obtained from the Erkilet Airport Meteorology Station, 5.91 km away from the experimental area, and are listed in Table 1.

Sugar beets inside 10-m² rectangular frames were harvested two times in each subplot to consider side effects. These harvested sugar beet roots were weighed after cutting leaves and these data were accepted as gross sugar beet yield. Sugar beet yield was determined after reducing 5% of gross root yield because of the common practice of Kayseri Sugar Beet Factory Inc.

Irrigation water use efficiency (IWUE) and water use efficiency (WUE) were calculated by dividing sugar beet yield (kg/ha) into the amount of irrigation water (m³/ha) and water consumption of sugar beet (m³/ha), respectively (Howell et al., 1992).

Sodium, potassium, amino nitrogen, sugar (digestion), and extractable sugar content of roots were analyzed at the laboratory of the Kayseri Sugar Beet Factory. About 25 kg of sugar beet samples from each subplot was washed and minced. A polarimetric method was used to determine digestion. Sodium and potassium contents were analyzed with a FP-5 flame photometer (Betalyser Anton Paar). A double beam spectrophotometer (Testamin 5) was used to obtain amino-nitrogen contents of root samples.

Table 1. Atmospheric parameters affecting crop evapotranspiration in 2014 and 2015.

2014						
	May	June	July	August	Sep.	Oct.
T _{max} (°C)	31.0	32.9	38.2	37.9	34.8	24.7
T _{min} (°C)	3.4	7.0	10.9	10.4	1.4	-2.3
RH _{max} (%)	94	93	88	94	94	95
RH _{min} (%)	10	9	4	6	11	23
Wind speed (m/s)	1.6	1.5	1.4	1.2	1.2	1.0
Sunshine duration (h)	246.1	278.5	367.0	340.1	224.9	-
2015						
T _{max} (°C)	30.5	29.5	37.3	38.0	36.0	25.9
T _{min} (°C)	3.1	6.7	7.9	8.2	7.0	1.0
RH _{max} (%)	93	99	96	97	91	97
RH _{min} (%)	14	24	10	11	9	18
Wind speed (m/s)	1.4	1.3	1.3	1.3	1.2	0.9
Sunshine duration (h)	260.7	255.1	352.9	344.4	270.7	151.7

T_{max} and T_{min}: Maximum and minimum temperatures (°C), RH_{max} and RH_{min}: maximum and minimum relative humidity (%). Source: <https://mevbis.mgm.gov.tr>.

Statistical analyses were performed using SPSS 13.0. A general linear model was used for variance analyses and means were separated with the aid of Duncan's multiple range test at 5% significance level.

3. Results and discussion

3.1. Effects of organomineral fertilizers on sugar beet

Totally, 170 kg of nitrogen, 120 kg of P₂O₅, 60 kg of K₂O, and 120 kg/ha sulfur were applied in F₁ treatments. Totally, 140 kg of nitrogen, 90 kg of P₂O₅, 35 kg of K₂O, 100 kg of organic matter, and 120 kg/ha sulfur were applied in F₂

treatments. Totally, 170 kg of nitrogen, 120 kg of P₂O₅, 60 kg of K₂O, 125 kg of organic matter, 125 kg of humic-fulvic acid, and 120 kg/ha sulfur were applied in F₃ treatments. As a result, F₂ treatments received 30 kg/ha less nitrogen and P₂O₅ than the F₁ and F₃ treatments.

Slight but insignificant sugar beet yield increases were achieved with the use of F₂ and F₃ fertilizers in both years. Root yields of F₁, F₂, and F₃ treatments were respectively measured as 74.48, 84.02, and 85.42 t/ha in the first year and respectively as 102.7, 106.6, and 103.7 t/ha in the second year (Tables 2 and 3). It should be noted that although 30

Table 2. Effects of different irrigation practices with different rooting depths and various fertilizers on sugar beet in 2014.

	Irrigation treatments			Fertilizer treatments			Mean
	D ₁	D ₂	D ₃	F ₁	F ₂	F ₃	
IWUE (kg/m ³)	16.1 b*	21.5 a	24.1 a	18.8	21.5	21.5	20.6
WUE (kg/m ³)	9.2 b^	10.9 a	11.5 a	9.6	10.9	11.0	10.5
Sugar beet yield (t/ha)	80.44	82.56	80.92	74.48	84.02	85.42	81.31
Digestion (%)	17.78	17.73	17.58	17.70	17.56	17.83	17.70
Na (mmol/100 g)	1.02	1.40	1.14	1.06	1.39	1.12	1.19
K (mmol/100 g)	4.97	4.98	5.12	5.13	4.96	4.98	5.02
N (mmol/100 g)	3.50	3.89	3.86	3.64	3.79	3.83	3.75
Rec. sugar ratio (%)	15.61	15.44	15.29	15.49	15.28	15.58	15.45
Sugar yield (t/ha)	12.55	12.73	12.36	11.56	12.81	13.26	12.54

IWUE: Irrigation water use efficiency, WUE: water use efficiency, F₁: mineral fertilizer, F₂: organomineral fertilizer, F₃: organomineral and mineral fertilizer, *, ^: significant at 1% and 5%, respectively.

Table 3. Effects of different irrigation practices with different rooting depths and various fertilizers on sugar beet in 2015.

	Irrigation treatments			Fertilizer treatments			Mean
	D ₁	D ₂	D ₃	F ₁	F ₂	F ₃	
IWUE (kg/m ³)	14.2 b^	16.2 a	16.0 ab	15.3	15.8	15.3	15.5
WUE (kg/m ³)	12.2	12.8	12.7	12.4	12.9	12.5	12.6
Sugar beet yield (t/ha)	104.8	104.2	104.1	102.7	106.6	103.7	104.3
Digestion (%)	16.12	16.19	16.13	16.07	16.29	16.08	16.15
Na (mmol/100 g)	0.66	0.69	0.68	0.66	0.66	0.70	0.68
K (mmol/100 g)	4.40	4.60	4.60	4.58	4.42	4.60	4.53
N (mmol/100 g)	2.33	2.22	2.25	2.19	2.14	2.47	2.27
Rec. sugar ratio (%)	14.35	14.42	14.36	14.31	14.56	14.25	14.38
Sugar yield (t/ha)	15.00	15.01	14.96	14.70	15.50	14.76	14.99

IWUE: Irrigation water use efficiency, WUE: water use efficiency, F₁: mineral fertilizer, F₂: organomineral fertilizer, F₃: organomineral and mineral fertilizer, ^: significant at 5%.

kg/ha less nitrogen and 30 kg/ha less P₂O₅ were applied in F₂ treatments, F₂ had almost identical sugar beet yields with F₁ and F₃ treatments.

Smith et al. (2015) reported that organomineral fertilizer produced similar crop yields with ammonium nitrate fertilizer for forage maize, winter wheat, and grass cut for silage.

Half of the F₃ fertilizer consisted of organic matter and humic-fulvic acids, and F₂ had 20% organic matter. Soil degradation is one of the major problems in Turkey. Using organic-based fertilizers for agricultural production may contribute to alleviation efforts for soil degradation. Another major problem is the disposal of huge urban waste deposits. Organic wastes from urban areas are valuable organic matter sources for organomineral fertilizer production. Therefore, using organic-based fertilizers in agriculture has many advantages, such as returning organic wastes from urban areas to agricultural areas.

Similar to root yields, root sugar content, extractable sugar content, irrigation and water use efficiencies, and harmful substance contents of roots such as N, Na, and K were not affected significantly by different fertilizers (Tables 2 and 3).

3.2. Irrigation water quantity and water consumption of sugar beet

First irrigations were carried out on 13 June 2014 and 19 June 2015 after spring rainfalls. Totally 15 irrigations were performed in both years. As seen in Table 4, irrigation water quantities applied to D₁, D₂, and D₃ treatments were respectively measured as 516 mm, 388 mm, and 337 mm in the first year and respectively as 750 mm, 643 mm, and 655 mm in the second year. Irrigation water needs were lower in the first year than in the second year due to lower rainfall in the second year. Differences in irrigation water quantities of D₁, D₂, and D₃ treatments were found to be significant in both years. The highest irrigation water requirement was determined for D₁ and the lowest ones were determined for D₂ and D₃ treatments. Using a deeper rooting depth for irrigation caused higher irrigation water requirements.

Uçan and Gençoğlan (2004) applied 1282 mm and 1132 mm of water to the full irrigation treatments of sugar beet for two years in Kahramanmaraş; Topak et al. (2010, 2011) applied 977 mm in Konya, and Köksal and Yıldırım (2011) applied 731 mm and 809 mm water in two consecutive years in Ankara. Sugar beet root depth was accepted as 0.9 m for irrigation in all of these studies. However, Karaş et al. (2012) applied 550 mm of water to sugar beet in Eskişehir by using 0.60-m root depth. Based on pan evaporation, Kıymaz and Ertek (2015a, 2015b) applied 611 mm and 614 mm of water under Kırşehir conditions, while Sahin et al. (2007) and Sahin et al. (2014) applied 353–412 mm and 191.9–250.9 mm under cool season semiarid climatic conditions.

Mean irrigation water quantity applied to the D₁ treatment was 22.8% and 27.6% higher than that for D₂ and D₃ treatments, respectively. Performing irrigations based on 0.6-m or active water extraction depth of the roots led the sugar beet to take up stored or percolated water from the deeper root zone. Topak et al. (2010) concluded that irrigation consumed about 60% of total energy needed for sugar beet production under semiarid conditions in Turkey. Water savings achieved in D₂ and D₃ also mean a reduction in sugar beet production costs. However, soil water status in the top 0.6-m root depth could be monitored easily and cheaply as compared to deeper soil layers.

Sugar beets consumed 884 mm, 761 mm, and 704 mm of water in 2014 under D₁, D₂, and D₃, respectively, and 865 mm, 813 mm, and 825 mm of water in 2015 (Table 4). Differences in water consumptions of the treatments were found to be significant in the first year. The highest water consumption occurred under D₁ treatment. Sugar beets under D₂ and D₃ treatments consumed nearly 100 mm less water in two years than D₁. Water savings of 100 mm may be considered as important in the semiarid Central Anatolia region with deficit water resources. It may be concluded that sugar beet under D₂ and D₃ used both soil water and also some percolated water in the deeper root

Table 4. Water consumptions of sugar beet based on different root depths.

Treatments	2014				2015			
	R (mm)	I (mm)	DS (mm)	ET _c (mm)	R (mm)	I (mm)	DS (mm)	ET _c (mm)
D ₁	332	516 a*	35	883 a*	138	750 a^	-22	866
D ₂	332	388 b	40	760 b	138	643 b	32	813
D ₃	332	337 b	35	704 b	138	655 b	33	826

R: Rainfall, I: irrigation water depth applied, DS: soil moisture difference between the sowing and the harvest, ET_c: crop evapotranspiration or water consumption, *, ^: significant at 1% and 5%, respectively.

zone effectively. Likewise, Erie and French (1968) stated that sugar beet extracted 70% of water from the 0.6-m upper root zone and 90% of water from the 1.0-m upper root zone, respectively, although they could extend their roots to 2 m.

Katerji and Mastrorilli (2009) reported water consumption of sugar beets in the Mediterranean region to be between 731 and 836 mm. Kiyamaz and Ertek (2015a, 2015b) reported water consumption of sugar beet to be between 888 and 919 mm under full irrigation based on pan evaporation in Kırşehir. Faberio et al. (2003) used 0.55-m root depth and determined 897 mm of water consumption in Spain. Uçan and Gençođlan (2004) found 1446 mm and 1491 mm for two years in Kahramanmaraş, Yıldırım (1990) found 953 mm and 865 mm under furrow and drip irrigation in Ankara, Köksal (2006) found 1010 mm in Ankara for full irrigation, and Topak et al. (2011) and Ertaş (1984) found 1036 mm and 1293 mm, respectively, in Konya. Sugar beet root depth for irrigation was accepted as 0.9 m for the last 5 experiments and water consumption of sugar beet of these experiments was higher than the sugar beet water consumption especially under D_2 and D_3 treatments in the present experiments.

To use water more efficiently, a constant root depth of 0.6 m could be advised for irrigations throughout the entire growing season of sugar beet. Active root water extraction depth of sugar beet could be taken as 0.40 m at the beginning of irrigation season and as 0.7 m in early August.

3.3. Sugar beet root yield

Sugar beet root yields are provided in Tables 2 and 3 for both years. Root yields of D_1 , D_2 , and D_3 were respectively measured as 80.44, 82.56, and 80.92 t/ha in the first year and respectively as 104.8, 104.2, and 104.1 t/ha in the second year. Root yields in the two years were considerably higher than the mean sugar beet yield of Turkey (47.24 t/ha) as reported by Pankobirlik (2017).³

Different sugar beet root yield results were obtained from different regions of Turkey, such as 65.10 t/ha in Ankara (Yıldırım, 1990) and 57.36–62.35 t/ha and 73.64–79.69 t/ha in Kahramanmaraş (Uçan and Gençođlan, 2004; Sunulu et al., 2012). In Konya, 74.40 t/ha, 91.50 t/ha, and 77.30 t/ha yields of sugar beet were reported by Ertaş (1984), Süheri et al. (2008), and Topak et al. (2011). Sugar beet rooting depth for irrigation applications in all of these studies were accepted as 0.9 m. Faberio et al. (2003), Ortiz et al. (2010), and Karaş et al. (2012) obtained 112.95–121.33 t/ha, 103.8–135.0 t/ha, and 92.28–118.14 t/ha root yields by using rooting depths of 0.55 m, 0.50 m, and 0.60 m, respectively. Differences in root yields of D_1 , D_2 , and D_3 rooting depth treatments were not found to be significant.

3 Pancar Ekicileri Kooperatifleri Birliđi (2017). Dünya, AB ve Türkiye Şeker İstatistikleri [online] (in Turkish). Website: <http://pankobirlik.com.tr/ISTATISTIKLER.pdf>

3.4. Irrigation water and water use efficiency

IWUE was calculated as 20.6 kg/m³ in 2014 and 15.5 kg/m³ in 2015 (Tables 2 and 3). Irrigation water quantities constituted 52.8% and 81.8% of total water consumption of sugar beet for two consecutive years. Therefore, the second-year mean IWUE (15.5 kg/m³) was lower than the first year mean IWUE (20.6 kg/m³) due to differences in rainfall. IWUE values were significantly affected by various irrigation application treatments that considered different sugar beet root depths, but were not significantly affected by fertilizer types for both years. IWUE values of D_1 , D_2 , and D_3 treatments were respectively determined as 16.1, 21.5, and 24.1 kg/m³ in the first year and respectively as 14.2, 16.2, and 16.0 kg/m³ in the second year. Active root depth treatment (D_3) and relatively shallow root depth treatment (D_2) used irrigation water more efficiently. The D_2 and D_3 treatments produced 25% and 33% higher sugar beet per 1 m³ of irrigation water as compared to D_1 treatments in two years. Using a deeper root zone for irrigation of sugar beet reduced irrigation water use efficiency. Davidoff and Hanks (1989) concluded that using water efficiently reduced irrigation costs by lowering labor, water, and energy needs.

Different root depths affected WUE for roots only in the first year of the experiments. WUE values of D_1 , D_2 , and D_3 treatments were respectively calculated as 9.2, 10.9, and 11.5 kg/m³ in 2014 and respectively as 12.2, 12.8, and 12.7 kg/m³ in 2015 (Tables 2 and 3). The highest WUE values were obtained from D_2 and D_3 treatments in the first year. D_2 and D_3 treatments produced 11% and 13% higher root yields per depleted 1 m³ of water than D_1 treatments in two years.

In Spain, sugar beet was exposed to controlled deficit irrigation treatments using 0.55-m root depth in different growth periods and WUE values varied between 13.3 and 17.5 kg/m³ (Faberio et al., 2003). However, 0.9-m rooting depth was used by Uçan and Gençođlan (2004), Topak et al. (2011), and Süheri et al. (2008) and WUE values ranged within 1.9–4.1 kg/m³, 7.46–8.32 kg/m³, and 6.62–8.40 kg/m³. These WUE values were considerably lower than the ones reported by Faberio et al. (2003) and those of the D_2 and D_3 treatments of the present study.

3.5. Digestion ratio, recoverable sugar ratio, and sugar yield

Due to Na, K, and N, digestion, sugar percentages of root are reduced to recoverable sugar content in the manufacturing process (Winter, 1989). Root digestion percentages of D_1 , D_2 , and D_3 were respectively determined as 17.78%, 17.73%, and 17.58% in 2014 and respectively as 16.12%, 16.19%, and 16.13% in 2015. Recoverable sugar percentages of D_1 , D_2 , and D_3 treatments were respectively obtained as

15.61%, 15.44%, and 15.29% in 2014 and respectively as 14.35%, 14.42%, and 14.36% in 2015. Sugar yields of D₁, D₂, and D₃ treatments were respectively determined as 12.55, 12.73, and 12.36 t/ha in 2014 and respectively as 15.0, 15.01, and 14.96 t/ha in 2015 (Tables 2 and 3). The differences in sugar beet digestion percent, recovery sugar percent, sugar yield, and Na, K, and N contents of both the rooting depth treatments and fertilizer treatments were not found to be significant.

Topak et al. (2011) reported that recoverable sugar content varied between 15.95% and 18.68% with deficit irrigation and the lowest recoverable sugar contents were obtained under full irrigation conditions. However, in a two-year study, recoverable sugar content (13.63%–13.94%) did not vary highly among irrigation levels (Kiyamaz and Ertek, 2015a). Our sugar contents were nearly 1% or 2% lower than those reported by Topak et al. (2011) for full irrigation treatment and similar to those reported by Kiyamaz and Ertek (2015a).

3.6. Conclusions

A two-year experiment was conducted to determine the effects of depth-dependent irrigation regimes and

organomineral fertilizer effects on sugar beet water use and quality attributes.

Similar root yield was obtained with the use of organomineral and mineral fertilizer treatments. However, similar root yield was obtained with lower nitrogen and phosphorous doses when organomineral fertilizer was applied. Sugar beet root digestion content and harmful constituents of roots such as N, Na, and K were not significantly affected by organomineral fertilizers. Continuous organic-based fertilizers may help to reduce soil degradation and eliminate urban organic wastes. Sugar beet irrigation based on 0.6-m rooting depth saved irrigation water considerably and improved irrigation water use efficiency. Increasing irrigation use efficiency also decreases irrigation costs. Similar results were obtained for irrigation based on active water extraction root depth (0.4–0.9 m).

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