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RESEARCH ARTICLE

Effects of Different Irrigation and Fertilization Levels on the Yield and Quality of Sugar Beet Molasses

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Abstract

The aim of this research is to investigate the yield and quality effects of different irrigation and fertilization levels on sugar beet roots and molasses. Field studies of sugar beet were carried out in the Agricultural Research Area of BUÜ Yenişehir İbrahim Orhan Vocational School in the 2019–2020 trial years, physical analyses were carried out in the food Laboratory and nutritional content analyses of molasses were carried out at Bursa Food and Feed Control Research Institute. Twelve different study treatments were created by combining four different irrigation levels and three different fertilization levels. Drip irrigation system was used to carry out the irrigation and fertilization applications in the study subjects in a controlled manner. The amount of plant water consumption (ET) was calculated with the water balance equation ($I+P-Dp\pm\Delta SW$). In the study, the maximum and minimum amounts of irrigation water applied in both years were calculated as 880.0–220.0 mm and 820.0–205 mm, respectively, while the lowest and highest plant water consumption values were calculated as 842.0–336.0 and 854.0–342 mm. While the root yields of sugar beet in the research years varied between 115.8–36.0 and 114.6–34.6 t ha^{-1}, respectively, the molasses rates in sugar beet varied between 5.12–4.00 and 4.97–4.00, respectively. When the productivity and quality losses in sugar beet are evaluated together in response to the decrease in irrigation and fertilization levels, it is recommended that the $I_{75}F_{75}$ issue be preferred. The use of molasses obtained from sugar beet roots as animal feed is of great industrial importance.

Keywords Sugar beet molasses · Plant nutrition · Cultural practices · Industrial plants · Feed additives

Introduction

Sugar beet is used both as an important food source in human nutrition and as an animal feed additive as sugar beet molasses and pulp, which are by-products (Rajaeifar et al. 2019; Yetik and Candoğan 2022; Ayas 2024). Molasses is a dark brown colored, high viscosity syrup containing an average of 50% sugar, which is left at the end of the gradual processes carried out in sugar beet factories to obtain sucrose in crystalline form. Molasses is rich in organic substances such as sugar, nitrogen, protein, and vitamins and is a valuable industrial raw material used in animal nutrition. The main fields of use for molasses are feed additives in animal husbandry, the coal industry, vegetable fertilizer, feed production, alcohol production, and yeast production. Molasses is also used in brown sugar production. After pretreatment, brown sugar is obtained by mixing white crystalline sugar with some molasses (Şanlı et al. 2015; Mohamed et al. 2023).

In 2022, world sugar beet production was 269.9 million tons and Turkey ranked 5th in the world with 19.0 million tons of production. Russia ranks first with 48.9 million tons, followed by France (31.5 million tons), the USA (29.6 million tons), and Germany (28.2 million tons) (FAOSTAT 2024). According to the Ministry of Agriculture and Forestry data for the 2023 season, it is estimated that sugar production in the world reached 177.2 million tons and consumption reached 176.0 million tons (TUIK 2023). According to 2022 data, although sugar beet production is carried out in a large area of 2,745,240 decares in Turkey, the unit area yield value (7.36 t da-1) has increased recently. The sugar beet cultivation area of Bursa province is 26.682 decares and the unit area root yield value is 7.98 t da-1, ranking first in Turkey (TUIK 2023).

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Different irrigation water and fertilizer levels significantly affect the yield and quality parameters of sugar beet. A drip irrigation system is essential for the controlled application of different irrigation water and fertilization levels (Kassem et al. 2022; Bilir and Saltalı 2023). When compared in terms of sugar beet yield, it is seen that the Central Anatolia Region is more advantageous than the Marmara Region. This is due to the high demand for sugar beet due to the difference in day-night temperature. Although the day–night temperature difference of Bursa, which is in the Marmara Region, is not high, the highest unit area of sugar beet root yield can be reached (Ayas 2024). In a study conducted by Ayas (2024) under Bursa conditions, it was tried to determine the response of sugar beet plants to different irrigation levels and macronutrients. In the study, yield and quality responses of sugar beet were measured at four different irrigation levels and three different fertilization levels, and the highest yield and quality values were obtained from the $I_{100}F_{100}$ application. According to the results of the study, when the reduction in yield and quality losses was compared with the reduction in irrigation and fertilization amounts, the application of $I_{75}F_{75}$ was recommended. In other words, despite yield and quality losses, the highest water and fertilizer saving gains were obtained from the $I_{75}F_{75}$ treatment. Yetik and Candoğan (2022) attempted to determine to what extent different irrigation levels affect sugar beet yield and quality in a study they conducted under Bursa conditions in 2019 and 2021. In the study, the highest root and sugar yields were obtained from 100% (S1) where irrigation was fully applied, while it was recommended that 66% (S_2) could be applied in conditions where water resources were limited and again in conditions where water resources were insufficient, it was recommended to cut water during the root ripening period.

Fertilization is essential to achieve high root yield and quality in sugar beet (Zhou et al. 2024). While plant root yield and quality increase with fertilization, sugar polarity also increases and the nutrient content in sugar beet molasses and pulp increases as a by-product. The amount of fertilizer to be given to sugar beet should be determined by considering climate and soil conditions, variety, and plant row spacing. One month before sugar beet planting, base fertilization should be done using farm fertilizer and it is recommended that the base fertilizer should be rested for one year under ideal conditions. It is a common practice to apply 2 tons of farm manure per decare as base fertilizer in Marmara Region conditions (Ayas 2024).

Another preferred practice in the Marmara Region is to apply 400 kg of 12–30-12 compound fertilizer per hectare as base fertilizer. In this method, chemical fertilizer is applied to the soil in conditions where farm manure is not available and, in this way, 40 kg ha^{-1} N, 100 kg ha^{-1} P_2O_5, and 48 kg ha^{-1} K_2O are applied to the soil as pure matter. Top fertilization is as important as base fertilizer in sugar beet plants and top fertilizer should be applied to the plant at the first and second hoe. As a general practice, 300 kg ha^{-1} urea (46%) fertilizer is applied at the first hoe and 225 kg ha^{-1} ammonium sulfate (21%) fertilizer is applied at the second hoe. During the root development period of the sugar beet plant, 200 kg ha^{-1} ammonium sulfate (21%) promotes successful root development. Considering the climatic and geographical conditions of the country and the Marmara Region, the growing period of sugar beet lasts 8–10 months.

In this study, it was tried to determine the changes in yield and quality parameters of sugar beet plants irrigated with controlled drip irrigation systems at different irrigation and fertilization levels and the effect on the quality of molasses as a by-product under the conditions of the Turkey–Marmara Region. The need for the amount of chemical fertilizer applied to sugar beet during the growing period was determined by analyzing the soil samples of the location where the experiment was conducted (Özbay and Yıldırım 2019; Aksu and Altay 2020; Marajan et al. 2021; Ayas 2024).

The sugar beet plant is a very important industrial plant and molasses, wet pulp (bagasse), and ethanol are obtained as by-products along with sugar as the main product. Once the sugar is extracted from sugar beet, the pulp is used as animal feed, while molasses syrup is used as an animal feed additive, fertilizer, alcohol, and yeast production. This study aimed to investigate the effects of different irrigation and fertilization levels on sugar beet root yield and quality parameters and the importance of the by-product molasses as a feed additive in animal nutrition.

Materials and Methods

Field Trials and Weather Conditions

The research was conducted in the Agricultural Trial Field (40°15′09 "N latitude, 29°38′43"E longitude) of Bursa Uludağ University Yenişehir İbrahim Orhan Vocational School and was conducted for two years (2019–2020). The climatic character of the Marmara Region is hot in summer and moderately cold and rainy in winter. The average temperature and total amount of precipitation during the growing period of sugar beet (March–October) were very important for optimum plant growth and were measured as 18.3–17.4 °C and 802.6–300.0 mm, respectively (Figs. 1 and 2). The average relative humidity values and the lowest and highest radiation values were 69.2–64.3% (Fig. 3) and 1926–1635 W m-2 and 1983–1769 W m-2 (Fig. 4) in both experimental years and throughout the plant growth period (Meteorological Report 2021a, b). While it is important to prefer sandy soils with good aeration for sugar beet plants, the fact that the characteristic of the soil at the trial site was

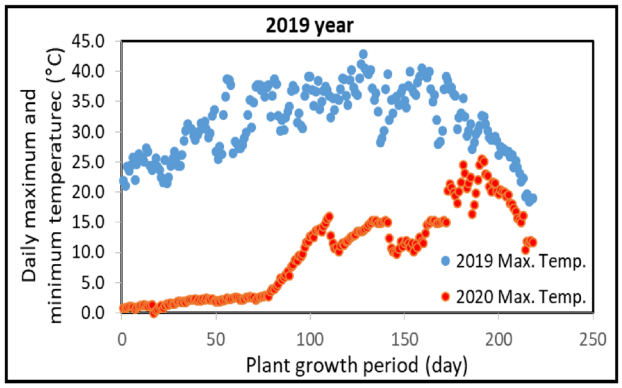


Fig. 1 Daily maximum and minimum temperatures during the 2019 plant growth period

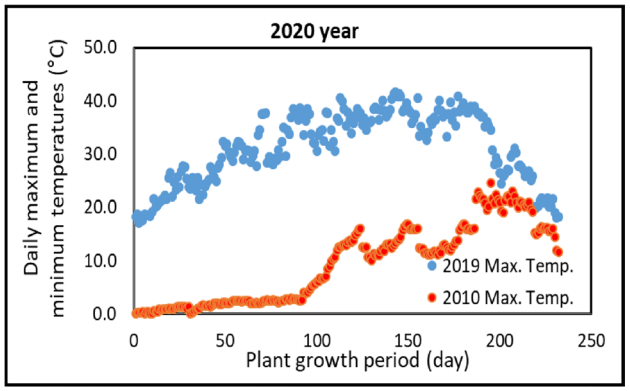


Fig. 2 Daily maximum and minimum temperatures during the 2020 plant growth period

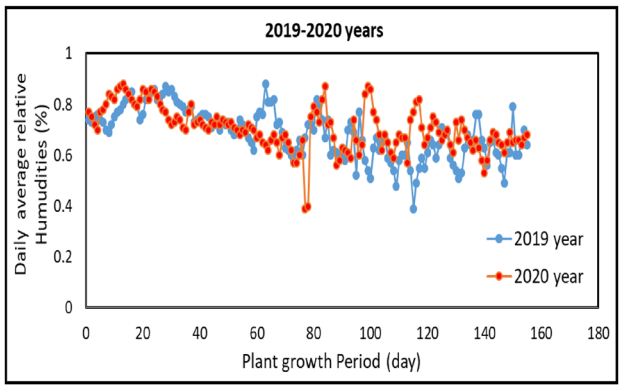


Fig. 3 Daily average relative humidity during the 2019–2020 plant growth periods

sandy-loam shows that a correct soil preference was made. In both experimental years, the soil was analyzed before sowing the seeds with an air planter and it was determined that the pH value of the soil was alkaline (7.85 and 8.18) (Table 1). Important climatic parameters of the location

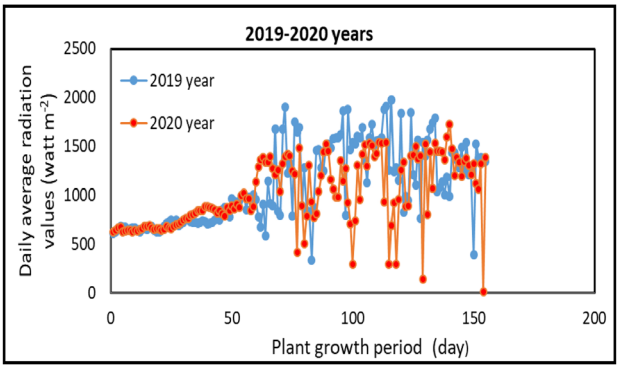


Fig. 4 Daily average radiation values during the 2019–2020 plant growth periods

where the study was carried out are shown in Tables 2 and 3. Chemical analysis of irrigation water is also of great importance for sugar beet plants and the quality class of irrigation water applied in the study was detected as C_2S_1 (Table 4). C_2S_1 quality class waters can be easily used in sugar beet cultivation with low sodium risk and moderate electrical conductivity (EC) properties (Yetik and Candoğan 2022; Ayas 2024). 20 tons ha^{-1} of farm fertilizer was applied to the soil as base fertilizer by the recommendations of the District Directorate of Agriculture of the Ministry of Agriculture and Forestry before sowing the sugar beet seeds. The fertilizer levels applied in both experimental years were similar to previous studies on sugar beet (Ekinci et al. 2022). Leafworms are the most important pest of sugar beet in the study area and Best Siper 25 EC 30 ml da^{-1} was applied as a chemical measure.

Characteristic of the Sugar Beet Plant Variety

Sugar beet producers prefer the Serenada KWS variety in Marmara region conditions due to its high root yield and sugar content. While the coated seeds of the variety used do not create germination problems, it is an advantage that the growing period of the plant varies between 8 and 10 in the climatic conditions of the Marmara Region. Serenada KWS sugar beet variety is suitable for hand and machine harvesting and is highly resistant to Rhizomania, which is very important for the plant and is highly tolerant to Powdery Mildew and Cercospora. Moreover, the variety has upright and green leaves compared to other sugar beet varieties, allowing it to reach higher root yield and quality during the growing period (Hossain et al. 2021; Ayas 2024) (Fig. 5).

Details of Treatments and Experimental Design

In the study, the drip irrigation system was preferred for the successful application of different irrigation and fertilization

Table 1 Some specific properties of the experimental soil

Soil depth (cm)	Soil type	Unit weight (g cm^{-3})	Field capacity (%)	Wilting point (%)	pH	Total salt (%)	$CaCO_3$ (%)	Organic matter (%)
0–30	SL	1.32	29.43	21.46	7.88	0.037	16.2	2.86
30–60	SL	1.35	27.86	20.35	7.90	0.031	29.2	1.59
60–90	SL	1.55	32.84	23.68	7.86	0.032	30.8	1.28
90–120	SL	1.50	34.45	27.7	8.00	0.034	32.5	0.92

SL: Sandy loam

Table 2 Climate characteristics of the study place in 2019–2020

Ministry of environment. Urbanization and climate change general directorate of meteorological													
2019													
Meteorological Elements	1	2	3	4	5	6	7	8	9	10	11	12	Annual
Average temperature	4.9	7.6	9.9	14.0	17.3	21.7	24.0	26.2	20.1	13.2	13.3	7.8	15.0
Average maximum temp	23.6	25.6	22.1	26.5	31.5	37.4	36.6	36.0	34.5	24.1	26.3	26.8	29.3
Average minimum temp	− 15.3	− 11.5	0.6	1.7	2.4	10.2	13.3	12.6	6.6	0.5	0.3	− 5.3	1.3
Average relative humidity	79.6	77.9	74.8	72.1	65.1	70.0	65.6	59.5	67.5	79.0	69.2	78.5	71.6
Average total precipitation	75.4	101.4	149.2	109.4	100.4	78.0	23.2	0.2	39.6	302.6	12.2	89.2	1080.8
2020													
Average temperature	3.7	6.1	7.2	12.8	17.3	20.9	23.4	23.4	19.7	14.6	9.8	6.4	13.8
Average maximum temp	19.2	20.2	21.9	27.7	32.9	37.8	38.2	37.0	36.7	36.3	26.8	22.3	29.8
Average minimum temp	− 19.7	− 10.3	0.7	1.8	2.4	10.4	13.4	13.3	6.8	4.9	0.9	− 7.6	1.4
Average relative humidity	80.9	77.8	75.8	71.2	73.4	73.2	68.3	67.6	70.7	77.6	80.0	82.4	74.9
Average total precipitation	56.1	47.6	45.5	35.0	69.7	69.0	17.1	7.9	17.2	38.5	30.9	67.4	501.9

Table 3 Specific properties of irrigation water

Water source	$EC_{25}x$ (10^6)	Na^+	K^+	Ca^{2+}	Mg^{2+}	pH	Class	SAR (meq/L)
		(me L^{-1})						
Deep well	715	2.3	2.56	9.25	5.7	7.12	C_2S_1	0.85

levels. Irrigation water was supplied from an 18 m deep well located in the experimental area with the help of a submersible pump with a flow rate of 16 m^3 h^{-1} and the submersible pump drew water from a depth of 12 m. In-line lateral pipes with a dripper flow rate of 4 L h^{-1} and a dripper spacing of 0.20 m were used for the cultivated plants. The gravimetric method was used to monitor soil moisture before and after irrigations. Although sugar beet roots cannot go to a soil depth of 1.20 m, the movement of moisture in the soil was monitored to determine the amount of irrigation water. The water balance formula used in the study helped to calculate evapotranspiration (Formula 1).

$$ET = I + P - R_f - D_p \pm \Delta S \quad (1)$$

ET refers to evapotranspiration (mm), I refers to the amount of irrigation water during the crop growing period (mm), P refers to total precipitation (mm), R_f refers to the amount of surface runoff (mm), D_p refers to deep drainage (mm) and ΔS refers to the soil water content (mm 120 cm^{-1}) at the beginning and end of the experiment and indicates the important symbols in the water balance formula. Runoff (Rf) is calculated as given in Eq. 2.

$$Rf = P - (Dp + E) \quad (2)$$

In the equation, surface runoff is represented by the symbols Rf, precipitation P, infiltration Dp and evaporation E. According to the rational method (Q = C..i..A), the runoff coefficient (C) was chosen as 0.50 for flat agricultural areas with slopes between 0–5% and clay silt loam soils (Fig. 6).

In the experiment, the percentage of the wetted area was calculated by Formula 3 since the distance between rows was 0.25 m and the distance between rows was 0.50 m..

Table 4 Relationship between yield and yield response factor (ky) with the decrease in water use, for sugar beet in 2019 and 2020

Table 5

Treatments	2019				2020			
	Yield (t ha^{-1})	AW (mm)	ET (mm)	ky	Yield (t ha^{-1})	AW (mm)	ET (mm)	ky
$I_{100}F_{100}$	115.8	880.0	842.0	0.000	114.6	820.0	854.0	0.000
$I_{100}F_{75}$	113.9	880.0	824.0	0.768	113.0	820.0	830.0	0.497
$I_{100}F_{50}$	111.5	880.0	810.0	0.977	112.5	820.0	832.0	0.711
$I_{75}F_{100}$	111.0	660.0	750.0	0.000	110.6	615.0	785.0	0.000
$I_{75}F_{75}$	108.2	660.0	732.0	1.051	106.3	615.0	750.0	0.872
$I_{75}F_{50}$	105.4	660.0	717.0	1.147	104.6	615.0	741.0	0.968
$I_{50}F_{100}$	80.6	440.0	676.0	0.000	85.8	410.0	684.0	0.000
$I_{50}F_{75}$	76.2	440.0	642.0	1.085	83.0	410.0	663.0	1.063
$I_{50}F_{50}$	73.3	440.0	625.0	1.201	81.7	410.0	655.0	1.127
$I_{25}F_{100}$	44.9	220.0	375.0	0.000	40.2	205.0	380.0	0.000
$I_{25}F_{75}$	38.1	220.0	340.0	1296	36.5	205.0	354.0	1.345
$I_{25}F_{50}$	36.0	220.0	336.0	1.557	34.6	205.0	342.0	1.393

AW: Applied water, ETa: Actual evapotranspiration, ky: Yield response factor



Fig. 5 Control unit of the drip irrigation system used in the study

Since the dripper spacing (Sd = 0.20 m) was smaller than the plant row spacing (Sl = 0.25 m), one lateral pipeline was laid in each plant row.

$$P = \frac{Sd}{Sl} \times 100 \quad (3)$$

In Formula 3, P stands for the percentage of the wetted area (%), Sd stands for the interval of the dripper (m) and Sl stands for the intervals of the lateral (m). The P value was calculated greater than the 1-*Ps* value (*Ps* = Percentage of area shaded by vegetation (%)). In the study, Ps value was accepted as 70%, so that 1-*Ps* value was calculated as 0.30 (30%). Formula 4 was used to calculate the net amount of irrigation water applied at each irrigation during the plant growth period.

$$dn = \frac{(FC - WP)xRy}{100} \times \gamma t \times D \times x\frac{P}{100} \quad (4)$$

In Formula 4, dn is the net amount of irrigation water to be applied in each irrigation (mm), FC is the field capacity (%), WP is the wilting point (%), R_y is the fraction of the available water holding capacity that is allowed to be consumed, γt: the soil bulk density (g cm^{-3}), D is the wetted soil depth (mm) and P is the percentage wetted area (%) and are crucial for determining the net amount of irrigation water. R_y value varies according to irrigation methods and the sensitivity of the plant to soil moisture deficiency. In drip irrigation method and small sprinkler systems, R_y value is 0.30–0.40. In the drip irrigation system, irrigation was started when 30% (0.30) of the available water holding capacity was consumed.

The Stewart model in Formula 5 shows the relationship between yield and ET.

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

Y_a in Formula 5 is the actual yield (t ha^{-1}), Y_m is the maximal yield (t ha^{-1}), ET_a is the actual evapotranspiration (mm), ET_m is the maximal evapotranspiration (mm) and k_y is the yield response factor.

Sugar beet seed sowing is carried out in March under the conditions of Bursa. In the research, seed sowing dates were preferred as March 15–16, 2019/20, respectively. In both research periods, the period from sowing to harvest was determined as 225 and 250 days, respectively. The distance between rows and between rows in the experimental plots was determined as 0.25 m and 0.50 m, respectively. The plot sizes were designed as 1.75 × 1.75 m and 64 sugar beet

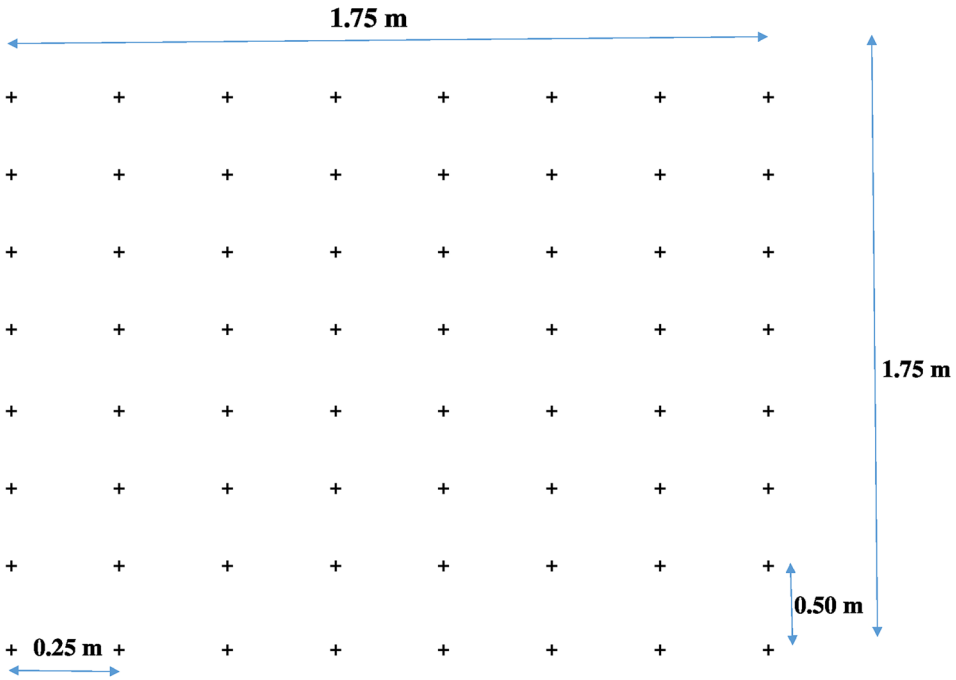


Fig. 6 Detailed view of the subject parcel

plants were placed in each plot. From the center of each plot, 16 sugar beet plants were used for sampling. Twelve study subjects were formed with the combination of irrigation and fertilization subjects. The design of the experiment was planned as three replications (three blocks) according to the split-plot experimental design in randomized blocks. Before sowing the sugar beet seeds, soil moisture was measured by gravimetric method and it was determined that the moisture was at field capacity level due to rainfall. For this reason, the moisture value in the 0–1.20 m soil profile was monitored every week and irrigation was started on April 15. Irrigations ended on October 15. Sugar beet was harvested 10 days after the end of irrigation.

Twelve different study subjects were determined with the combination of four different irrigation levels (I_{100}, I_{75}, $I_{50,}$ and I_{25}) and three different fertigation levels (F_{100}, $F_{75,}$ and F_{50}). The full irrigation subject was considered as I_{100} treatment, while the other three subjects (I_{75}, $I_{50,}$ and I_{25} treatments) were treated with 75%, 50%, and 25% irrigation water amount. Likewise, full fertilization was considered as F_{100} treatment, while chemical fertilizer was applied at the rate of 75% and 50% in the other two treatments (F_{75} and F_{50} treatments). Since macro elements are very important for the sugar beet plant, nitrogen (N), phosphorus (P), and potassium (K) were tried to be applied to the soil at the right times and amounts throughout the growing period. In the study, nitrogen (N) was applied to the soil in two periods; namely, urea (46% N) fertilizer in the first hoe and ammonium sulfate (21% N) fertilizer in the second hoe. A drip irrigation system was used to apply the fertilizers to the plant in a controlled manner. In the F_{100} treatment, which is considered as full fertilization, 600 kg urea fertilizer (46%) was applied in the first hoe with 300 kg pure nitrogen (N) per hectare, while 1000 kg ammonium sulfate (21%) fertilizer was applied in the second hoe with 200 kg pure sulfur per hectare. The reason for the high amount of nitrogen fertilizer was the high pH value of the soil, the high nitrogen requirement of sugar beet, and the low amount of nitrogen in the soil of the experimental area despite the presence of sufficient phosphorus and potassium. Sugar beet plants need high amounts of nitrogen (N) in the first three growth periods (establishment-vegetative-yield formation), while the need in the ripening period is low (Özbay and Yıldırım 2019). Furthermore, 30 kg Magnesium Sulfate (15% MgO) and 80 kg potassium nitrate (KNO3-13%N and 46% K2O) fertilizers were applied per hectare before the yield formation period to ensure good root development in sugar beet plants. Urea, ammonium sulfate, and potassium nitrate fertilizers used as chemical plant nutrients were applied at the rate of 75% and 50% of the fertilizer amounts applied in F_{75} and F_{50} subjects and F_{100} subject.

The root length and diameter of the sugar beet samples were measured with a millimeter caliper and the average of the measured values was taken. The weights of the sugar beet roots taken from the subject plots were measured one by one and the average fresh root weight was found. Leaf water content and root dry matter ratios of sixteen plants taken from the middle of the subject plots were tried to be determined. For this purpose, the roots and leaves of the plants were cut and separated from each other and both parts

were cut into small pieces. The cut-up leaf and root samples were dried in an oven at 70 °C for 48 h. Samples converted into dry matter were weighed and leaf water content percentage and root dry matter ratio were calculated (Yetik and Candoğan 2022).

Measurement of Quantitative and Quality Characteristics

Determination of Sugar Ratio (%)

The sugar content of sugar beet root samples from each experimental plot was determined by using the Lane-Eynon method in the college food laboratory (Yetik and Candoğan 2022). Sugar yield was calculated using Formula 6.

$$SY = RY \times SR \tag{6}$$

The symbols SY, RY, and SR in Formula 5 refer to sugar yield (t ha-1), root yield (t ha^{-1}), and sugar ratio (%), respectively.

Yield Quality Analysis of Sugar Beet Molasses

Sugar beet root samples representing each experimental plot were sent to Balıkesir Susurluk Sugar Factory to be converted into molasses syrup samples with high viscosity consistency remaining at the end of the gradual processes to obtain sucrose in crystalline form. Molasses syrup samples were analyzed at The Central Research Institute of Food and Feed Control, Bursa, Turkey. As a result of the analysis, total dry matter content (%), total sugar (%), reducing sugar (%), brix (%), ash (g 100 g-mL^{-1}), pH, protein (g 100 g^{-1}), specific gravity, Ca (g kg^{-1}), P (g kg^{-1}) and K (g kg^{-1}) values of molasses samples in both years were determined.

Statistical Analysis

Yield and quality values of sugar beet samples were subjected to analysis of variance using MINITAB 17 software. When the F-test was significant in the analysis of variance, the LSD test was applied to group irrigation and fertigation factors. MINITAB 17 statistical program was used to determine root yield, root length, root diameter, fresh root weight, fresh leaf weight, dry leaf weight, dry matter content, sugar content, sugar yield, and WSBMR values of sugar beet. In addition, total dry matter content, total sugar, reducing sugar, brix, ash, ash, pH, protein, free weight, Ca, P, and K content were analyzed from molasses samples obtained from sugar beets. With the help of the values obtained from the analysis of sugar beet molasses samples, the use of molasses as an animal feed additive as a by-product of sugar beet was evaluated.

Results and Discussion

Sugar beet seeds were sown with a pneumatic seeder with a distance of 0.50 m × 0.25 m between and above rows. There were eight sugar beet plants in each plot, totaling 64 plants. Sixteen plants in the middle of each subject plot were selected as sample plants and their physical and chemical analyses were carried out. Three days before sowing the sugar beet seeds, the soil moisture was brought to the field capacity level to calculate the amount of irrigation water. Since sugar beet is a storage-rooted plant, it was considered appropriate to monitor the field capacity moisture level only at a depth of 0–90 cm. The first irrigation was carried out one week after the sugar beet seeds were sown with an air seeder.

Ayas (2024), in a two-year study on sugar beet under Bursa conditions in the Marmara Region of Turkey, obtained 12 different treatment subjects by combining four different irrigation levels (I_{100}, I_{75}, $I_{50,}$ and I_{25}) and three different fertilization levels (F_{100}, $F_{75,}$ and F_{50}) and calculated the irrigation water amounts in both years as 800.0–200.0 mm and 820.0–205.0 mm, respectively. Plant water consumption values were 842.0–336.0 mm and 854.0–342.0 mm, respectively. Yetik and Candoğan (2022) examined the yield response of sugar beet under S_{100}-S_{66}-S_{33}-S_0 irrigation levels under Bursa conditions in Turkey. In the sugar beet study, they applied 750.3–135.0 mm and 765.7–160 mm irrigation water amounts in two different growing seasons, respectively. They also reported that the ET values obtained from four different irrigation levels during the growing season were calculated as 896.9–362.3 mm and 830.0–387.3 mm, respectively. Özbay and Yıldırım (2019) tried to determine the root and sugar yield of sugar beet at three different irrigation levels (D100-D66 and D33) with and without foliar fertilizer application under Kütahya conditions in Turkey. In the study, the amount of irrigation water applied varied between 867–268 mm, while plant water consumption values varied between 894–313 mm. Ünlükara (2019) calculated the amounts of irrigation water applied at three different root depths of the plant as 516–337 mm and 750–643 mm in a two-year study conducted under Kayseri conditions in Turkey. He reported that the plant water consumption values of sugar beet varied between 883–704 mm and 866–813 mm, respectively.

The maximum and minimum irrigation water amounts in the 2019–2020 study years were calculated between 880–220 mm and 820–205 mm, respectively, while the maximum and minimum ET values were calculated as 842–336 mm and 854–342 mm, respectively (Table 5). The highest irrigation water amounts and plant water consumption values were obtained from $I_{100}F_{100}$, while the

Table 5 Effects of irrigation and fertigation treatments on yield and physical quality parameters of sugar beet in 2019

Irrigation Treatments	Fertigation Treatments	Root yield (t ha^{-1})	Root length (cm)	Root diameter (cm)	Root fresh weight (g)	Leaf fresh weight (g)	Leaf dry weight (g)	Dry matter (%)	Sugar rate (%)	Sugar yield (t ha^{-1})	WSBPR (%)
I_{100} Irrigation (I_{100}:%100)	F_{100} (%100)	115.8 a	27.0 a	16.5 a	2285.5 a	161.5 a	59.1 a	22.8 g	15.4 bcde	17.8 ab	4.56 abcd
	F_{75} (%75)	113.9 a	26.8 a	16.3 ab	2139.8 ab	153.0 ab	56.3 ab	24.1 f	15.3 bcde	17.4 ab	4.59 abcd
	F_{50} (%50)	111.5 a	26.2 ab	16.0 abc	2116.5 ab	147.8 ab	53.2 abc	25.0 ef	15.0 cde	16.7 b	4.67 abcd
I_{75} Irrigation (I_{75}:%75)	F_{100} (%100)	111.0 a	23.5 abc	15.0 abcd	1990.2 ab	142.5 ab	53.1 bc	25.1 ef	16.9 abc	18.7 a	4.73 abcd
	F_{75} (%75)	108.2 a	23.0 abcd	14.7 bcd	1962.3 ab	140.2 b	52.5 bc	25.8 ef	16.5 abcd	17.8 ab	4.77 abc
	F_{50} (%50)	105.4 a	22.3 bcde	14.5 cd	1938.0 b	136.3 b	50.6 bcd	26.0 def	16.3 abcde	17.2 b	4.80 abc
I_{50} Irrigation (I_{50}:%50)	F_{100} (%100)	80.6 b	19.7 cdef	14.0 d	1348.1 c	80.6 c	47.5 cde	28.2 cde	17.8 a	14.3 c	4.83 abc
	F_{75} (%75)	76.2 b	19.1 def	14.0 d	1255.2 c	75.1 cd	45.0 de	29.7 bcd	17.6 a	13.4 cd	4.96 ab
	F_{50} (%50)	73.3 b	18.6 ef	13.6 d	1114.8 cd	70.8 cde	44.3 e	31.6 abc	17.2 ab	12.6 d	5.12 a
I_{25} Irrigation (I_{25}: %25)	F_{100} (%100)	44.9 c	17.4 f	11.0 e	783.7 de	58.7 def	36.7 f	33.0 ab	15.0 cde	6.7 e	4.26 bcd
	F_{75} (%75)	38.1 c	17.2 f	10.2 e	754.9 e	55.1 ef	35.3 f	34.3 a	14.8 de	5.6 ef	4.10 cd
	F_{50} (%50)	36.0 c	17.0 f	9.8 e	720.6 e	50.4 f	30.9 f	35.0 a	14.5 e	5.2 f	4.00 d
Irrigation		**	**	**	**	**	**	**	**	**	**
Fertigation		**	ns	*	**	**	**	**	ns	**	ns
Blocks		ns	*	ns	*	*	ns	*	ns	*	ns
I*F Interaction		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level, ns non-significant

lowest irrigation water amounts and plant water consumption values were obtained from $I_{25}F_{50}$. The irrigation water amounts, and plant water consumption values obtained from the study subjects were consistent with the values obtained from previous studies (Özbay and Yıldırım 2019; Ünlükara 2019; Żarski et al. 2020; Yetik and Candoğan 2022; Çiçek et al. 2022; Ayas 2024).

The relationship between yield (Ya) and evapotranspiration (ETa) for the years 2019–2020 is as given in Fig. 7. The yield response factor (ky) values obtained from I_{100}, I_{75}, I_{50}, and I_{25} irrigation subjects were calculated as 0.87–0.60, 1.10–0.92, 1.14–1.10, and 1.43–1.37, respectively. There were significant decreases in k_y values for each unit increase in the amount of irrigation water applied. When the k_y values of the I_{100} and I_{75} treatments are compared, it is important to prefer the I_{75} treatment in terms of saving irrigation water. Crop yield response factors (k_y) values in the 2019–2020 trial years are given in Fig. 8. A significant similarity was observed between the ky values calculated in the study and the crop yield response factor (k_y) values calculated from previous studies (Uygan et al. 2021; Yetik and Candoğan 2022; Ayas 2024).

The maximum and minimum sugar beet root yield values obtained from the experimental subjects in the study years were calculated as 115.8.0–36.0 t ha^{-1} and 114.6–34.6 t ha^{-1} from $I_{100}F_{100}$ and $I_{25}F_{50}$ treatments, respectively (Tables 5 and 6). Sugar beet root yield values obtained from the study years were consistent with the previous studies (Çınar and Ünay 2021; Uygan et al. 2021; Yetik and Candoğan 2022; Pişkin 2022; Ayas 2024).

The physical properties of sugar beet were tested at a 99% confidence level. In 2019, sugar beet root yield values were found to be significant at the 1% level when evaluated in terms of irrigation and fertilization subjects, but insignificant at the block level. Furthermore, the correlation relationship in terms of the binary interaction of irrigation-fertilization factors was found insignificant. In 2020, the relationship between root yield values and irrigation water subjects was found significant at a 1% level, while it was found insignificant in terms of different fertilization levels and irrigation-fertilization binary interactions. Furthermore, yield values in the second year were also found insignificant in terms of blocks. While the root yield values obtained from I_{100} and I_{75} subjects in both years of the experiment were in the same statistical class, the values obtained from the I_{50} irrigation subject were in a different statistical class. The root yield values obtained from the I_{25} irrigation subject were much lower than the other irrigation subjects and were in a different statistical class.

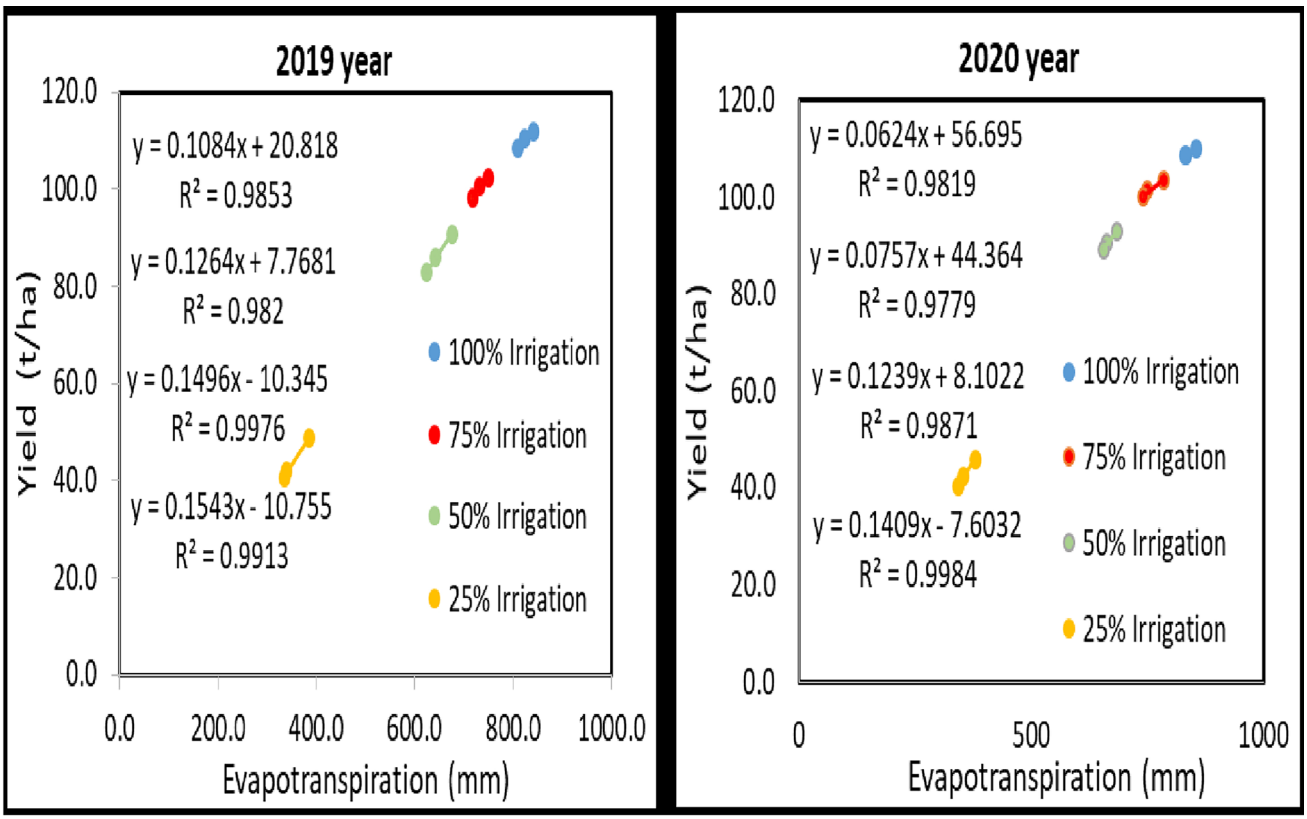


Fig. 7 Evapotranspiration-yield relationship in 2019–2020

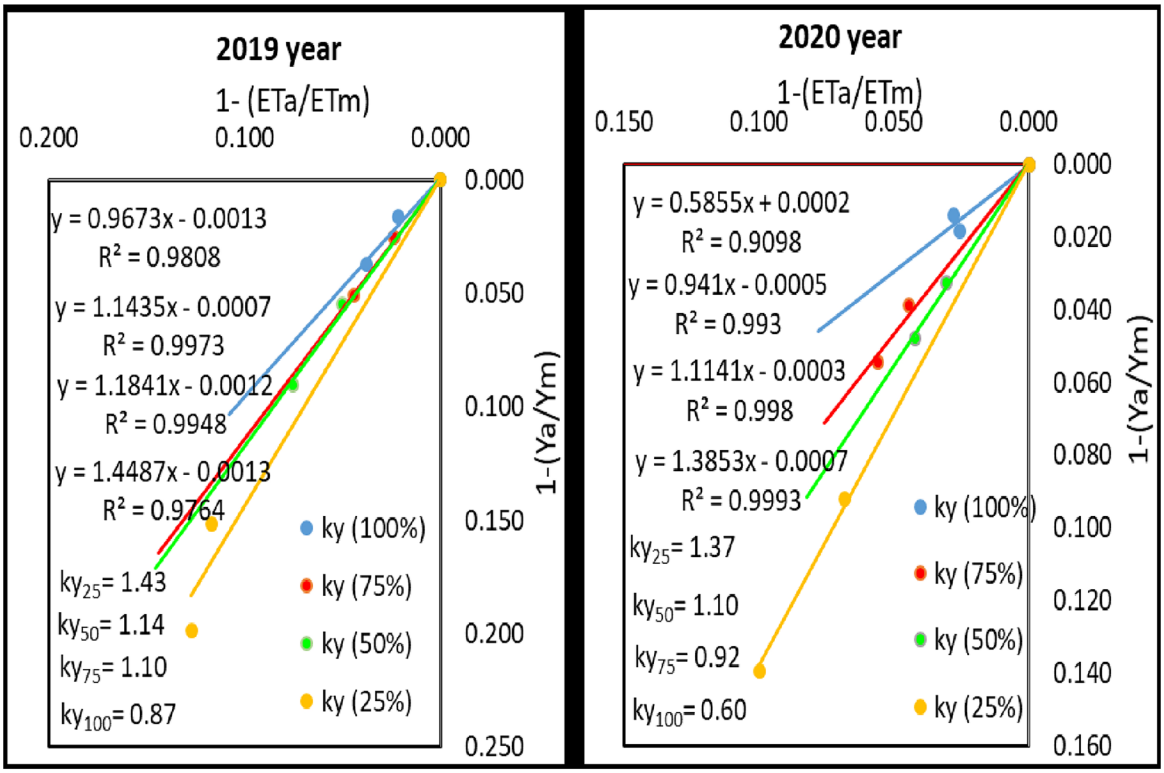


Fig. 8 Relationship between 1-(ET_a/ET_m) and 1-(Y_a/Y_m) in 2019–2020

Root length values in both experimental years were found significant at a 1% level for irrigation, while the correlation relationship was found insignificant for fertilization. The correlation value was similarly insignificant when evaluated in terms of the binary interaction of irrigation-fertilization factors. When root length values were evaluated in terms of blocks, the correlation level was found to be 5% significant in both years. While the root length values of sugar beet in both years were close to each other in I_{100} and I_{75} irrigation subjects, the lowest root length values were obtained from I_{25} irrigation subject and these values were in the same statistical class.

Root diameter values obtained from the trial subjects were found significant at a 1% level for irrigation subject in both years, while they were found significant at a 5% level for fertilization subject in the first year and insignificant in the second year. Although the root diameter values obtained from I_{50} and I_{25} subjects in the first year were in different statistical classes, they were in the same statistical class in terms of fertilization levels. When evaluated in terms of blocks and irrigation-fertilization interaction levels, the correlation relationship was found to be insignificant for both years. In the second experimental year, root diameter values obtained from I_{100}, $I_{75,}$ and I_{50} irrigation subjects were in the same statistical class, while root diameter values obtained from I_{25} irrigation subject were in a different statistical class.

When the root fresh weight values in both years were evaluated in terms of irrigation and fertilization, the correlation relationship was found significant at a 1% level, while it was found significant at a 5% level for the first year and at a 1% level for the second year in terms of blocks. The correlation relationship was found to be insignificant for the first year and significant at a 5% level for the second year. While irrigation subjects in the first year were in different statistical classes, I_{100} and I_{75} irrigation subjects in the second year were in the same statistical class. Although I_{50} and I_{25} irrigation subjects in the second year were in different statistical classes, they were in the same statistical class in terms of fertilization subjects. When leaf fresh weight values were evaluated for both experimental years, it was found significant at a 1% level for irrigation and fertilization subjects, while it was found significant at a 5% level for block subjects. The correlation relationship was found to be insignificant in terms of irrigation-fertilization interaction. While the leaf fresh weight values obtained from I_{100} and I_{75} subjects were close to each other in both years, the values obtained from I_{25} subject in the second year were in the same statistical class. The lowest leaf fresh weight values were obtained from the I_{25} irrigation subject. The leaf dry weight values in the experimental years were found to be significant at a 1% level when evaluated in terms of irrigation and fertilization, while the correlation relationship was

Table 6 Effects of irrigation and fertigation treatments on yield and quality parameters of sugar beet in 2020

Irrigation Treatments	Fertigation Treatments	Root yield (t ha^{-1})	Root length (cm)	Root diameter (cm)	Root fresh weight (g)	Leaf fresh weight (g)	Leaf dry weight (g)	Dry matter (%)	Sugar rate (%)	Sugar yield (t ha^{-1})	WSBPR (%)
I_{100} Irrigation (I_{100}:%100)	F_{100} (%100)	114.6 a	30.0 a	16.3 a	2080.6 a	150.9 a	50.0 a	23.5 f	16.1 abc	18.4 a	4.62 cd
	F_{75} (%75)	113.0 a	28.5 ab	16.2 a	1985.3 a	149.1 a	53.3 ab	25.6 ef	16.0 abc	18.1 ab	4.67 bcd
	F_{50} (%50)	112.5 a	27.9 abc	16.0 a	1965.1 a	140.7 b	50.5 bc	25.8 ef	15.6 abc	17.6 ab	4.70 bcd
I_{75} Irrigation (I_{75}:%75)	F_{100} (%100)	110.6 a	27.5 abc	15.1 a	1968.5 a	137.8 bc	49.8 bc	26.0 ef	16.2 abc	17.9 ab	4.75 abcd
	F_{75} (%75)	106.3 a	26.8 abc	14.6 a	1955.2 a	136.0 bc	48.7 bc	26.7 def	16.0 abc	17.0 ab	4.79 abc
	F_{50} (%50)	104.6 a	24.7 abcd	14.4 a	1941.0 a	130.5 c	47.2 cd	28.0 cde	15.8 abc	16.5 b	4.83 abc
I_{50} Irrigation (I_{50}:%50)	F_{100} (%100)	85.8 b	23.5 abcd	14.3 a	1340.7 b	75.2 d	45.8 cde	29.4 cd	17.2 a	14.8 c	4.85 ab
	F_{75} (%75)	83.0 b	21.8 bcd	14.0 a	1319.8 b	70.7 de	42.9 de	30.5 bc	16.9 ab	14.0 c	4.89 ab
	F_{50} (%50)	81.7 b	20.1 cd	14.0 a	1085.5 b	65.9 e	41.3 e	30.9 bc	16.5 abc	13.5 c	4.97 a
I_{25} Irrigation (I_{25}: %25)	F_{100} (%100)	40.2 c	18.0 d	11.2 b	762.4 c	52.3 f	34.4 f	33.4 ab	15.4 abc	6.2 d	4.54 d
	F_{75} (%75)	36.5 c	17.8 d	10.6 b	750.8 c	50.6 fg	32.1 f	33.8 ab	15.1 bc	5.5 cd	4.25 e
	F_{50} (%50)	34.6 c	17.5 d	10.0 b	733.5 c	45.8 g	30.3 f	34.4 a	14.7 c	5.1 d	4.00 f
Irrigation		**	**	**	**	**	**	**	**	**	**
Fertigation		**	ns	ns	**	**	**	**	*	**	*
Blocks		ns	*	ns	**	*	ns	*	ns	ns	ns
I*F Interaction		ns	ns	ns	*	ns	ns	ns	ns	ns	**

** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level, ns non-significant

found to be insignificant when evaluated in terms of blocks and the binary interaction of irrigation-fertilization factors. While the values obtained from I_{100}, $I_{75,}$ and I_{50} irrigation subjects were close to each other in both years, the values obtained from I_{25} irrigation subjects were in the last statistical class as the lowest leaf dry weight values. Sugar beet dry matter content decreased as the amount of irrigation water increased. In other words, while the highest root dry matter rate was obtained from the I_{25} irrigation subject, the lowest dry matter rate was obtained from the I_{100} irrigation subject. Root dry matter ratio was found to be significant at a 1% level for both years in terms of irrigation and fertilization, while it was found to be significant at a 5% level in terms of blocks. Furthermore, the correlation relationship was found to be insignificant in terms of irrigation-fertilization interaction. Although the values obtained from irrigation subjects were close to each other, they were in different statistical classes. Root sugar content values, just like the dry matter content values, showed an inversely proportional change with the amount of irrigation. In other words, as the irrigation water level increased, the sugar content in the sugar beet root decreased. The sugar content values in the experimental years were found to be significant at a 1% level in terms of irrigation subjects, while they were found to be insignificant in the first year and significant at a 5% level in the second year in terms of fertilization levels. When the sugar content values were evaluated in terms of blocks and irrigation-fertilization interactions, they were found insignificant for both years. Although the root sugar content values in both years were close to each other in terms of irrigation subjects, the values in the first year were in different statistical classes. Although the values obtained from I_{100} and I_{75} irrigation subjects in the second year were in the same statistical class, the other irrigation subjects were in different statistical classes. Sugar yield in the 2019–2020 trial years was found to be significant at a 1% level in terms of irrigation and fertilization subjects, while it was found to be significant at a 5% level in the first year and insignificant in the second year in terms of blocks. When irrigation-fertilization factors were evaluated in terms of binary interaction, the correlation relationship was found insignificant for both years. While almost all of the sugar yield values obtained from irrigation subjects in the first year were in different statistical classes, the values obtained from I_{50} and I_{25} irrigation subjects in the second year were in different statistical classes in terms of irrigation, but they were in the same statistical class in terms of fertilization subjects. Wet sugar beet molasses rate (WSBMR) values were found to be significant at a 1% level in terms of irrigation, insignificant in the first year, and significant at a 5% level in the second year. When evaluated in terms of blocks, the correlation relationship was found insignificant. When it was evaluated in terms of the double interaction of irrigation and fertilization factors, it was found insignificant in the first year and significant in the second year at a 1% level. When the wet sugar beet molasses ratio was evaluated in terms of irrigation subjects, the values obtained from the I_{100} irrigation subject in the first year were in the same statistical class in terms of irrigation, while the values in the second year were in different statistical classes in terms of irrigation and fertilization subjects. The effects of different irrigation and fertilization levels on the physical quality parameters of sugar beet roots are given in Tables 5 and 6 for both experimental years. The physical quality values of sugar beet roots obtained in the study were similar to the values obtained from previous studies (Özbay and Yıldırım 2019; Çınar and Ünay 2021; Uygan et al. 2021; Marajan et al 2021; Yetik and Candoğan 2022; Ayas 2024).

The nutrient content of fresh sugar beet molasses is very important in animal nutrition as a feed additive. Total dry matter content (%), total sugar (%), reducing sugar (%), ash (g 100 g-mL^{-1}), pH, specific gravity, and P (g kg^{-1}) of molasses decreased as the amount of irrigation water increased in both experimental years. Since the amount of irrigation water supplied to the plant was very low in irrigation subject I_{25}, the physical quality and nutrient content of molasses samples were also found to be very low. The nutrient content of sugar beet molasses was tested at a 99% confidence level. When the percentage of total dry matter in sugar beet molasses was evaluated in terms of four different irrigation subjects, it was found significant at 1% level for both experimental years, while it was found significant at 1% level in the first year and insignificant in the second year in terms of fertilization subjects. When evaluated in terms of blocks and irrigation-fertilization interaction, the correlation level was found insignificant. While the total dry matter content values obtained from each irrigation level subject were in different statistical classes for the first year, the values obtained from the I_{100} subject in the second year were in the same statistical class in terms of irrigation subject. When total sugar values were evaluated in terms of irrigation, the correlation relationship in both years was found significant at a 1% level. When evaluated in terms of fertilization subject, it was found significant at 1% level in the first year and significant at 5% level in the second year. When evaluated in terms of blocks and irrigation-fertilization interaction values, the correlation relationship was found insignificant for both years. While the values of irrigation subjects in the first year were in different statistical classes, the values of I_{25} irrigation subject in the second year were in the same statistical class. As in total dry matter percentage, total sugar content decreased with increasing irrigation water level. The reducing sugar values obtained from irrigation and fertilization subjects were similar to the total dry matter and total sugar values. In other words, as the amount of irrigation applied increased, reducing sugar values decreased. When the reducing sugar values were evaluated in terms of irrigation for

both trial years, the correlation relationship was found significant at a 1% level. In terms of fertilization, it was found significant at a 5% level in the first year and insignificant in the second year. When evaluated in terms of blocks and irrigation-fertilization binary interactions, it was found to be insignificant except for the irrigation-fertilization binary interactions in the second year. The irrigation-fertilization double interaction in the second year was found to be significant at a 5% level. While the values obtained from irrigation and fertilization subjects were in different statistical classes, the values obtained from I_{75} irrigation subject in both years were in the same statistical class. When brix percentage was evaluated in terms of irrigation, the degree of correlation was found to be significant at a 1% level for both years, while it was found to be insignificant in terms of fertilization. When it was evaluated in terms of block subjects, it was found significant at a 1% level for the first year and insignificant for the second year. When the irrigation-fertilization interaction was evaluated, it was found to be insignificant in both years of the experiment. In the first year of the experiment, the brix values obtained from the I_{100}, $I_{75,}$ and I_{50} irrigation subjects were in the same statistical class, while the values obtained from the I_{25} irrigation subject were in a different statistical class. In the second year, while the values obtained from I_{100} and I_{75} irrigation subjects were in the same statistical class, the values obtained from I_{50} irrigation subject were in a different statistical class. Brix values obtained from the I_{25} irrigation subject were in the lowest statistical class in both years. Ash values, as in the total dry matter percentage, showed a decrease as the irrigation water level increased. The lowest ash values were obtained from subject I_{25}. Ash values were found to be significant at 1% level in terms of irrigation for both experimental years, but insignificant in terms of fertilization. In terms of blocks and irrigation-fertilization interaction, it was found to be insignificant. Ash values obtained from irrigation subjects in both years were in different statistical classes. When the pH values of sugar beet molasses were evaluated in terms of irrigation subjects, the correlation relationship was found significant at a 1% level. When evaluated in terms of fertilization, it was found significant at a 5% level in the first year and significant at a 1% level in the second year. When evaluated at the level of blocks, it was found insignificant for both years, while when evaluated in terms of irrigation-fertilization double interaction, it was found insignificant in the first year and significant at a 1% level in the second year. While pH values in both years were in different statistical classes, pH values decreased as the irrigation amounts increased. The lowest pH values were obtained from the I_{25} irrigation subject. When the protein amount of molasses was evaluated in terms of irrigation subjects, it was found to be significant at a 1% level for both years, while it was found to be insignificant in terms of fertilization. When evaluated in terms of blocks, it was found insignificant for both years. In terms of irrigation-fertilization interaction, it was found to be insignificant in the first year and significant at a 5% level in the second year. While the molasses protein values obtained from I_{100}, $I_{75,}$ and I_{50} irrigation subjects were in the same statistical class in the first year, the values obtained from I_{25} irrigation subject were in the other statistical class. In the second year, while the values obtained from the I_{75} irrigation subject were in the same statistical class, the values obtained from the I_{25} irrigation subject were in a different statistical class. The lowest molasses protein values were obtained from the I_{25} irrigation subject.

When the specific gravity values of molasses were evaluated in terms of irrigation, they were found to be significant at a 1% level for the first year and insignificant for the second year. When evaluated in terms of fertilization, it was found insignificant for both years. When evaluated in terms of blocks, it was found significant at a 5% level in the first year and insignificant in the second year. When the specific gravity values of molasses were evaluated in terms of irrigation-fertilization interaction, it was found insignificant for both years. While I_{100} and I_{75} irrigation subjects were in the same statistical class for the first year, I_{25} irrigation subject values were in a different statistical class. In the second year, all irrigation subjects were in the same statistical class.

When Ca, P, and K values in both years of the experiment were evaluated in terms of irrigation, they were found significant at a 1% level for both years of the experiment, while when evaluated in terms of fertilization subjects, all values obtained except potassium (K) in the second year were found insignificant for both years. When evaluated in terms of blocks, Ca, *P*, and *K* values were found to be insignificant. When evaluated in terms of irrigation-fertilization interaction, all values except the second year of potassium (K) were found insignificant. Potassium (K) values were found significant at a 1% level in the second year. While Ca values and potassium (K) values in the first year were in the same statistical class for both years, potassium (K) values in the second year were in different statistical classes. Phosphorus (P) values in molasses were in different statistical classes for I_{75}, $I_{50,}$ and I_{25} irrigation treatments in the first year, while they were in the same statistical class for fertilization treatments. In the second year, I_{75} and I_{50} irrigation subjects were in the same statistical class. The effects of different irrigation and fertilization levels on the yield and quality values of fresh sugar beet molasses are given in Tables 7 and 8. The Ca, P and K values obtained in the study were similar to previous studies on sugar beet (Ceylaner et al. 2020; Zarski et al. 2020; Özkan and Deniz 2023; Mohamed et al. 2023; Ayas 2024). The quality values and statistical classifications of sugar beet molasses are given in detail in Tables 7 and 8.

Table 7 Effects of irrigation and fertigation treatments on yield and quality parameters of wet sugar beet molasses in 2019

Irrigation Treatments	Fertigation Treatments	T. Dry matter (%)	Total sugar (%)	Reducing sugar (%)	Brix (%)	Ash (g 100 g-L^{-})	pH	Protein (g 100^{-1})	Specific gravity	Ca (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
I_{100} Irrigation (I_{100}:%100)	F_{100} (%100)	72.5 cd	48.2 def	0.18 bcd	78.9 a	7.7 def	5.8 efg	10.7 a	1.37 ab	0.2 a	0.21 b	3.2 a
	F_{75} (%75)	72.7 cd	48.9 cde	0.18 bcd	78.7 a	7.8 cde	6.2 def	10.9 a	1.38 ab	0.3 a	0.25 ab	3.5 ab
	F_{50} (%50)	73.0 c	50.1 bcd	0.17 cde	78.6 a	8.0 cd	6.5 cde	11.0 a	1.38 ab	0.3 a	0.26 ab	3.6 abc
I_{75} Irrigation (I_{75}:%75)	F_{100} (%100)	74.4 c	52.8 abc	0.21 abc	79.0 a	8.3 cd	6.7 bcde	11.2 a	1.38 ab	0.3 a	0.26 ab	3.8 abc
	F_{75} (%75)	74.9 c	53.5 ab	0.20 abc	78.8 a	8.5 bcd	6.9 bcd	11.4 a	1.39 ab	0.4 a	0.27 ab	4.0 abc
	F_{50} (%50)	75.3 bc	53.9 ab	0.20 abc	78.7 a	8.8 abc	7.0 abcd	11.5 a	1.39 ab	0.4 a	0.28 ab	4.1 abc
I_{50} Irrigation (I_{50}:%50)	F_{100} (%100)	78.9 ab	54.0 ab	0.25 a	82.7 a	9.0 abc	7.3 abc	11.7 a	1.40 ab	0.4 a	0.29 a	4.4 abc
	F_{75} (%75)	79.5 a	55.1 a	0.24 a	82.5 a	9.6 ab	7.6 ab	11.9 a	1.41 ab	0.5 a	0.30 a	4.7 abc
	F_{50} (%50)	80.6 a	56.8 a	0.23 ab	82.2 a	9.9 a	7.9 a	12.0 a	1.42 a	0.5 a	0.30 a	4.9 abc
I_{25} Irrigation (I_{25}: %25)	F_{100} (%100)	65.4 e	45.1 ef	0.13 def	72.3 b	6.7 efg	5.3 fg	7.5 b	1.36 ab	0.2 a	0.12 c	3.0 abc
	F_{75} (%75)	67.1 e	44.3 f	0.12 ef	72.0 b	6.5 fg	5.1 g	7.3 b	1.35 b	0.2 a	0.10 c	2.8 bc
	F_{50} (%50)	68.9 de	44.6 f	0.10 f	72.0 b	6.2 g	5.0 g	7.0 b	1.35 b	0.2 a	0.10 c	2.5 c
Irrigation		**	**	**	**	**	**	**	**	**	**	**
Fertigation		**	*	*	ns	ns	*	ns	ns	ns	ns	ns
Blocks		ns	ns	ns	**	ns	ns	ns	*	ns	ns	ns
I*F Interaction		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level, ns non-significant

Table 8 Effects of irrigation and fertigation treatments on yield and quality parameters of wet sugar beet molasses in 2020

Irrigation Treatments	Fertigation Treatments	T. Dry matter (%)	Total sugar (%)	Reducing sugar (%)	Brix (%)	Ash (g 100 g-L^{-})	pH	Protein (g 100^{-1})	Specific gravity	Ca (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
I_{100} Irrigation (I_{100}:%100)	F_{100} (%100)	72.7 def	48.4 e	0.20 bcd	78.5 ab	7.8 cdef	6.0 fgh	10.8 c	1.38 a	0.2 a	0.22 abc	3.3 defg
	F_{75} (%75)	72.9 def	48.7 e	0.19 bcd	78.4 ab	8.0 cde	6.3 efg	11.0 bc	1.39 a	0.2 a	0.24 ab	3.4 defg
	F_{50} (%50)	73.0 def	49.9 de	0.17 cdef	78.1 ab	8.0 cde	6.5 def	11.1 abc	1.39 a	0.3 a	0.25 a	3.5 defg
I_{75} Irrigation (I_{75}:%75)	F_{100} (%100)	73.8 cde	51.8 cd	0.21 abc	78.8 ab	8.2 cd	6.6 def	11.2 abc	1.39 a	0.4 a	0.25 a	3.6 cdef
	F_{75} (%75)	74.5 bcd	52.7 bcd	0.22 abc	78.7 ab	8.6 bc	6.8 cde	11.5 abc	1.40 a	0.4 a	0.26 a	3.8 bcde
	F_{50} (%50)	75.0 abc	53.6 abc	0.23 abc	78.5 ab	9.0 abc	7.1 bcd	11.6 abc	1.40 a	0.4 a	0.28 a	3.9 bcd
I_{50} Irrigation (I_{50}:%50)	F_{100} (%100)	77.8 abc	54.1 abc	0.24 a	81.4 a	9.2 abc	7.4 abc	11.6 abc	1.41 a	0.4 a	0.28 a	4.3 bc
	F_{75} (%75)	78.6 ab	54.9 ab	0.25 ab	81.4 a	9.8 ab	7.7 ab	11.8 ab	1.42 a	0.5 a	0.29 a	4.5 ab
	F_{50} (%50)	79.1 a	55.8 ab	0.27 a	81.2 a	10.1 a	8.0 a	12.0 a	1.42 a	0.5 a	0.30 a	5.0 a
I_{25} Irrigation (I_{25}: %25)	F_{100} (%100)	67.8 g	45.0 f	0.14 def	74.1 ab	6.8 def	5.7 gh	7.7 d	1.37 a	0.3 a	0.15 bc	3.1 efg
	F_{75} (%75)	68.7 fg	45.1 f	0.13 ef	73.5 b	6.7 ef	5.5 h	7.5 d	1.37 a	0.2 a	0.14 cd	3.0 fg
	F_{50} (%50)	69.5 efg	45.3 f	0.11 f	72.7 b	6.4 f	5.4 h	7.1 d	1.35 a	0.2 a	0.12 d	2.7 g
Irrigation		**	**	**	**	**	**	**	ns	**	**	**
Fertigation		ns	**	ns	ns	ns	**	ns	ns	ns	ns	*
Blocks		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
I*F Interaction		ns	ns	*	ns	ns	**	*	ns	ns	ns	**

** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level, ns non-significant

Conclusion

Total rainfall in the first growing period of sugar beet was 1080.8 mm, while in the second year, it was 501.9 mm. When the amounts of irrigation water applied in both trial years were compared, it was determined that the values in the second year were lower. Due to the lower average temperatures in the second year, evaporation losses were also lower. The decrease in evaporation losses led to a decrease in the amount of irrigation water applied and plant water consumption values. The lower rainfall and irrigation water applied in the second year of the study compared to the first year caused lower values of root yield, root diameter, root fresh weight, root fresh weight, leaf fresh, and dry weight. As the amount of irrigation water decreased in both years, yield, root height, root diameter, root diameter, root fresh weight, leaf fresh and dry weight and sugar yield values of sugar beet roots increased, while dry matter, sugar yield, and wet sugar beet molasses (WSBMR) ratio decreased. When evaluated in terms of fertilization subjects, as the fertilization level increased, the yield and quality values of sugar beet roots increased. When the nutrient content of molasses obtained from sugar beet was evaluated in terms of irrigation and fertilization subjects for both experimental years, total dry matter ratio, total sugar, reducing sugar, ash, pH, specific gravity, and phosphorus (P) values decreased as the amount of irrigation water increased. Brix, protein, calcium (Ca), and potassium (K) values were not affected by different irrigation and fertilization levels. This may be attributed to the fact that the roots of the sugar beet plant grow under the soil and the water and mineral substances in the soil where cultivation is carried out are sufficient.

Despite the increase in irrigation water level, when the decreases in total dry matter ratio, total sugar, reducing sugar, ash, and pH in molasses are evaluated together, the sugar beet plant reaches a high polarity value under water-limited conditions. As a result, when sugar beet is grown in semi-arid regions, root yield decreases but polarity and nutrient content values increase. As a result, the use of molasses syrup obtained as a by-product from sugar beet roots as an additive in animal feed makes sugar beet an important industrial plant.

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Data availability All the data are included in the MS.

Declarations

Conflict of interest The author declares that there are no conflicts of interest regarding the publication of this paper.

Ethical approval No applicable.

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