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Improving quantity and quality of sugar beet yield using agronomic methods in summer cultivation

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Abstract: The effect of agronomic factors on the amount of water consumption and its productivity in arid and semiarid regions is very important. This study was conducted to diagnose agronomical procedures for increasing the yield and water productivity of sugar beet in two years (2016 and 2017). The experimental factors were: sowing date (spring and summer), planting arrangement (25–50 cm and 40–50 cm, double rows with a distance of 25 cm or 40 cm and a distance between each double row of 50 cm), and plant density (90, 120 and 160 thousand plant/ha). In the second year, the harvesting date, which consisted of conventional (October) and delayed (November), was added to the experiment. High temperature during and immediately after planting decreased emergence on the summer sowing date. The uniformity of roots and irrigation water productivity (WP_{irrig}) in spring crops was higher than those of summer crops; meanwhile, on the summer sowing date, water consumption declined by 27% (and the sugar yield decreased intensively by 44%). Furthermore, planting arrangements of 25–50 resulted in better plant establishment and eventually increased the number of final plants. Besides, increasing plant density improved the uniformity of plants root. Sowing in summer compared to spring reduced root and sugar yield on a conventional harvesting date by about 40%. After 25 days' delay in harvesting time on both sowing dates (by mean), root yield, sugar yield, and WP_{irrig}, increased by about 14, 28 and 22%, respectively. In general, at moderate densities (about 120 000), planting arrangement 40–50 and at low densities (less than 90 000, which usually occurs on the summer sowing date), planting arrangement 25–50 is recommended to increase yield and WP_{irrig}.

Keywords: cultivation lines; growth period; plant population; sugar percentage; water productivity

Food production and water consumption are inextricably linked. Restriction of irrigation water, especially in areas where there is insufficient rainfall, along with the continued increase in demand for agricultural commodities, has led to improved water productivity to ensure future food security (Steduto et al. 2012). Sugar yield in sugar beet is affected by various factors such as climatic conditions and crop management (Andrade et al. 2002, Jaggard et al. 2009). One of the agricultural techniques is to observe planting and harvest dates and thus affect the growth period of the plant. The growth period of the spring-sown sugar beet is from early spring to autumn, which is about 200 days (Schnepel and Hoffmann 2016). Prolongation increases leaf area index and consequently increases light absorption and sugar assimilation in leaves, followed by increased dry matter and yield (Schnepel and Hoffmann 2016). On the other hand, in some areas, such as the Americas, the Eastern Mediterranean, Iran, and Chile, between 80% and 100% of sugar beet cultivation require irrigation water (Steduto et al. 2012). Therefore, prolonging the growth period is associated with increased yield and water consumption, both of which can affect irrigation water productivity (Li et al. 2019).

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Of course, due to the global warming trend and its direct impact on agricultural products, usually through changing the pattern of precipitation and increasing air temperature, the possibility of cultivating crops at the right time is of great importance. Furthermore, the high water requirement of sugar beet is one of the substantial factors limiting the development of this plant in arid and semiarid regions. Despite the importance of a long growth period and early cultivation in sugar yield, farmers in arid and semiarid areas inevitably delay the sowing time. Among the reasons for that is the lack of water, especially the coincidence of the last cereal water with the primary sugar beet water and the land scarcity (Mohammadian et al. 2008). Also, in other regions such as part of Europe, water stress has affected the flowering and filling of winter crops and spring cereals, but summer crops such as sugar beet are not so harmful. Therefore, some countries, such as Spain, Russia, and Ukraine, delay planting (late spring and early summer) (Bussay et al. 2018). On the other hand, in Minnesota and North Dakota, which account for 56% of sugar beet cultivation (Khan et al. 2021), it is done with a delay in cultivation. In any case, in late sowing date, furthermore reduced yields due to reduced growth period, plant establishment is also reduced (Håkansson et al. 2006) and can affect irrigation water productivity.

It has been proven that there is a relationship between plant density with yield (Jaggard et al. 2009). Increasing plant density reduces the time required to achieve more radiation, followed by increasing the total photosynthetic active radiation received during the season and producing more biomass at plant maturity (Purcell et al. 2002). On another side, the feasibility of reaching equal space and uniform size of plants can be regarded as an important factor in achieving a high yield per unit area (Andrade et al. 2002), which changes under the influence of planting arrangement. Planting arrangement, while having a direct effect on plant density, can affect the yield and productivity of irrigation water by affecting the improvement of seed germination and emergence (Li et al. 2015). However, changing the planting arrangement by changing the planting row spacing or plant spacing on the planting row due to the production of new cultivars needs to be investigated.

Given that increasing yield alongside irrigation water productivity in arid and semiarid regions is vitally important, agricultural operations can have a significant impact on it. Therefore, this study aimed to investigate increasing the sugar beet yield and productivity of irrigation water in spring and summer (especially) sowing dates by changing the agronomical components, including planting arrangement, plant density, and harvesting date in drip-strip irrigation conditions.

MATERIAL AND METHODS

Study area. This study was conducted in 2016 and 2017 at Sugar Beet Seed Institute (290 ha), Karaj, Iran (35°59'N, 51°06'E; altitude 1 300 m a.s.l.), with a Mediterranean climate. This area has a Xeric moisture regime and thermic thermal regime. Based on the soil taxonomy method, the soil type of this region is Inceptisol. Some physicochemical properties of soils such as potassium, phosphorus, nitrogen, salinity, organic carbon, pH, and soil texture were determined according to the standard protocols, as Miransari et al. (2007). Meteorological data and physicochemical properties of soil in two years of the experiment are shown in Tables 1 and 2, respectively.

Table 1. Measurement of some meteorologic parameters in the years 2016 and 2017 in Karaj of Iran

	Mean air temperatures (°C)		Mean soil temperatures (°C)		Rainfall (mm)		Average relative humidity (%)		Average wind speed (km/h)		Sunny hours (h)	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
May	21.28	21.93	9.58	10.42	12.63	22.01	42.02	38.72	3.29	2.70	292.40	323.50
Jun	25.61	26.08	14.27	13.41	0.01	0.00	30.97	32.30	3.39	3.40	329.80	382.90
Jul	27.59	28.88	17.19	16.65	0.01	0.41	37.69	29.54	3.86	2.69	348.40	361.80
Aug	27.36	27.44	14.19	16.26	0.00	0.00	30.45	32.57	1.92	2.28	360.40	369.90
Sep	22.84	23.72	11.50	12.53	0.00	0.00	39.11	34.37	2.93	2.20	314.00	321.70
Oct	16.58	17.02	6.55	7.00	2.40	4.80	42.54	38.55	2.12	2.40	258.70	279.00
Nov	8.13	11.53	–0.40	2.10	0.92	0.64	45.81	43.48	2.22	2.18	206.80	208.80

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Table 2. Physicochemical properties of soil at experimental location Karaj, Iran

Soil physicochemical properties	2016		2017	
	sampling depth (cm)			
	0–30	30–60	0–30	30–60
K (ppm)	566	535	256	241
P (ppm)	31.4	12.19	7.8	6.25
NO_3 (ppm)	7.3	5.3	4.97	4.83
NH_4 (ppm)	18.2	20.3	20.65	16.66
EC (mS/cm)	1.11	1.34	1.96	1.52
Organic carbon (%)	0.8	0.8	0.77	0.7
pH	8.08	8.11	7.25	7.35
Soil texture	L	L	SCL	SCL

EC – electrical conductivity; L – loam; SCL – silty clay loam

Performance of the experiment. Based on the soil test results, in the first year of the experiment, 300 kg/ha of urea, and in the second year, 300 kg/ha of urea and 300 kg/ha of triple superphosphate were applied. Total needed phosphorus was added to the soil at tillage time each year, but nitrogen fertiliser as urea was added to the soil in three stages after thinning at about 10 days intervals. In the first year, the experimental design was a randomised complete block design (RCBD) with a split-split plot arrangement with four replicates. The main factor was sowing date (S) with two levels: spring sowing (S1: early May) and summer sowing (S2: early July), the sub-factor was planting arrangement (P) with two levels (P1: 25–50 cm and P2: 40–50 cm, which means double rows with a distance of 25 cm or 40 cm and a distance between each double row of 50 cm) and the sub-sub factor was planting density (D) with three levels (D1: 90 000 plant/ha, D2: 120 000 plant/ha and D3: 160 000 plant/ha). In the second year, we added the harvesting date factor (H) with two levels, including conventional harvesting date (H1: October 25) and delayed harvesting date (H2: November 20) as the second sub-sub factor to the factors mentioned above in the first year. Therefore, the second-year experiment was conducted as a split-split plot factorial arrangement based on RCBD. The sugar beet cultivar used was a mono-germ hybrid called Futura (Syngenta Company).

Each plot had four rows in both years, and the length of rows was 5 m and 10 m in the first and second years, respectively. Drip irrigation with tape strips was used for the irrigation of experimental plots. Irrigation strips (16 mm diameter, droplets of 20 cm and a discharge of 1 L per h) were placed in the middle of rows at shorter distances in each of these planting arrangements (Figure 1).

The crop reference evapotranspiration (ETo) was estimated by ETo calculator (FAO) software (version 3.2, Rome, Italy) and using ten-day of meteorological statistics data (by means of the FAO Penman-Monteith equation). The net water requirement (ETc) of the crop was calculated by Eq. 1 of Allen et al. (1998):

$$ETc = Kc \times ETo \quad (1)$$

where: ETc – crop evapotranspiration (mm/d); Kc – crop coefficient that represents the crop type and the development stage of the crop [dimensionless]; ETo – reference crop evapotranspiration (mm/d). The required gross water was calculated by considering the efficiency of drip irrigation (90%). The duration of each irrigation was determined at a 3-days interval by considering the shading percentage of plant cover. The percentage of shading cover was also estimated using images of plants before each irrigation.

The amount of consumed water, as well as, the received growing degree days and the number of days after planting at different planting and harvest-

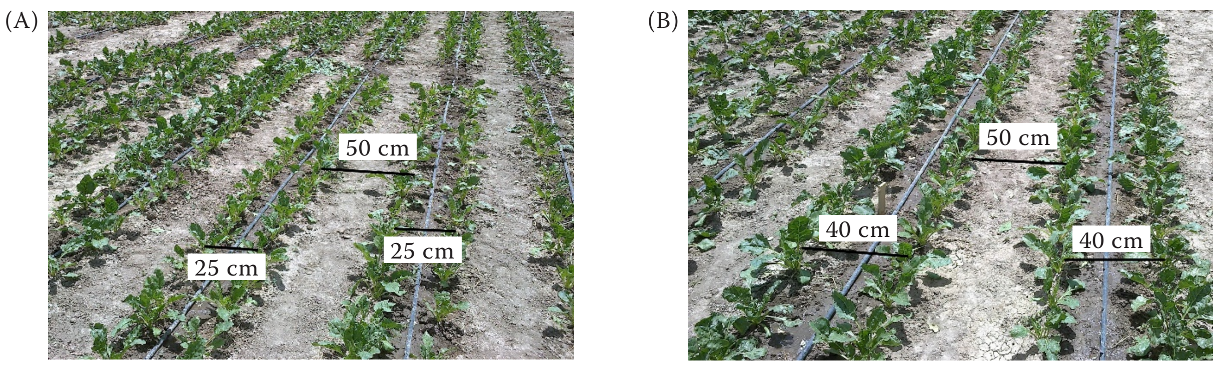

Figure 1. Use of two planting arrangements (A) 25–50 and (B) 40–50 on the sugar beet field (2016–2017)

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Table 3. The amount of water applied in irrigation (WA), growing degree days (GDD) and length of the growth period (GP) in sugar beet field after the first irrigation in years 2016 and 2017 with different treatments

		Conventional harvesting date				Late harvesting date			
		spring sowing date		summer sowing date		spring sowing date		summer sowing date	
		25–50	40–50	25–50	40–50	25–50	40–50	25–50	40–50
2016	WA (m^3/ha)	12 757	12 697	9 618	9 439				
2017		12 392	13 127	8 823	9 390	12 772	13 530	9 289	9 884
2016	GDD (°C)	3 581		2 341					
2017		3 759		2 369		4 098		2 708	
2016	GP (day)	173		113					
2017		180		112		205		137	

Planting arrangement: at 25–50 means planting arrangement with pairs of rows with a distance of 25 cm and a distance between pairs of rows of 50 cm and at 40–50 means planting arrangement with pairs of rows with a distance of 40 cm and a distance between pairs of rows of 50 cm

ing dates, are shown in Table 3. Expected values of plant density were obtained from two planting arrangements with different planting intervals in the planting row. The amount of seed used to achieve the expected plant density was doubled, and the sown seeds were 1.7, 2.4, and 3.1 units per hectare for the plant densities mentioned above, respectively. Therefore, the seed distance on the rows in the 25–50 planting arrangement was 14.5, 11, and 8.5 cm, and for the 40–50 planting arrangement was 12.5, 9, and 7 cm (for plant density 90, 120, and 160 thousand plant/ha). The number of consumed seeds and the expected plant densities are shown in Table 4.

Plant sampling and analysis. The number of plants on both sowing dates was counted in the two middle lines of each plot before thinning. At harvesting time, the plants of the two middle rows were harvested, and after crown removal, the final number of roots was counted. Then, 15 roots were randomly harvested by hand, and the values of the largest diameter as well as the weight of the single storage root were measured with the calliper and scale, respectively. To determine the uniformity of the largest diameter as well as the weight of the single roots, the variance between the roots was calculated using Eq. 2:

$$var = \frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n-1} \quad (2)$$

where: X_i – sample of i, $\overline{X}$, the mean of the sample; n – sample size. The percentage of sugar was measured using a polarimetric method (ICUMSA 2007). Irrigation water productivity was calculated by using Eq. 3 of Pereira et al. (2012):

$$WP_{Irrig} = \frac{Y_a}{IWU} \quad (3)$$

where: Y_a – product sugar yield (kg/m^2); IWU – total irrigation water use (m^3/m^2). WP_{Irrig} was reported as kg/m^3.

Table 4. Amount of sugar beet seeds used in the two planting arrangements to achieve the expected plant densities with different plant intervals in the years 2016 and 2017

Planting arrangement	Amount of seed consumed (unit/ha)	Seed distances planted (cm)	Amount of seed sown (number/ha)	Expected plant distance (cm)	Expected plant number (number/ha)
25–50	1.7	14.5	183 908	29	91 954
	2.4	11	242 424	22	121 212
	3.1	8.5	313 725	17	156 863
40–50	1.7	12.5	177 778	25	88 889
	2.4	9	246 914	18	123 457
	3.1	7	317 460	14	158 730

Planting arrangement: at 25–50 means planting arrangement with pairs of rows with a distance of 25 cm and a distance between pairs of rows of 50 cm and at 40–50 means planting arrangement with pairs of rows with a distance of 40 cm and a distance between pairs of rows of 50 cm. Each unit contains 100 000 monogerm seeds

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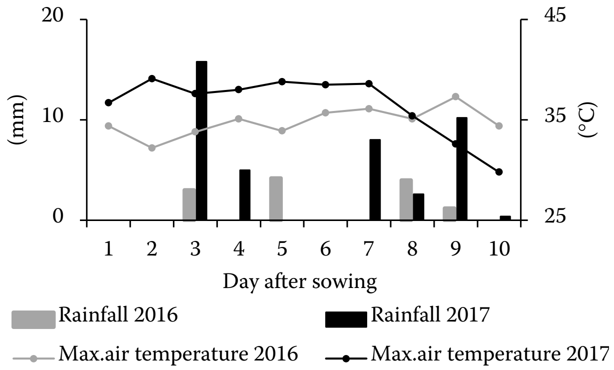

Figure 2. Comparison of rainfall on the spring sowing date and maximum air temperature in the first 10 days of growth on the summer sowing date in two years 2016 and 2017

Statistical method. After testing the normal distribution of data, analysis of variance (GLM) was determined using SAS software, version 9.2 (SAS Institute Inc., Cary, USA). The mean-variance homogeneity tests were performed by the K_{max} Hartley test (Pearson and Hartley 1972) for the compound analysis of both years. Due to heterogeneity of variances, combined analyses were not allowed. The least significant difference (*LSD*) test at the 5% level was used for the mean comparison.

RESULTS AND DISCUSSION

Number of plants before and after thinning and at harvesting time. The change in the number of plants obtained in two years was due to adverse weather conditions during emergence in the second year. Thus, in the second year of the spring sowing date, rainfall and unfavourable cultivation bed resulted in crusting, along with slowing down the germination rate and subsequently reducing emergence. On the summer sowing date in the second year of the experiment, the occurrence of high air temperature (about 39 °C) in 7 days compared to the spring sowing date had a very negative effect on the germination rate (Figure 2). On the spring and the summer sowing dates of the second year, compared to the first year, the number of plants pre-thinning decreased by 23% and 50%, respectively (Table 5). After thinning, the number of plants in the second year on the spring sowing date was almost the same as in the first year, but on the summer sowing date, it was about 29% less than the first year. Germination has a substantial role in the establishment of seedlings, which is affected by

Table 5. The main effect of different treatments on sugar beet plant population, the average diameter and single weight root and their variances in the years 2016 and 2017

Treatment		Plants before thinning (number/m^{2})		Plants after thinning (number/m^{2})		Root numbers (number/ha)		Average diameter (cm)		Average weight (g)		Variance diameter		Variance weight	
		2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Sowing date	spring	22.53^{a}	17.26^{a}	12.71^{a}	12.72^{a}	127 056^{a}	110 818^{a}	10.46^{a}	10.62^{a}	980.75^{a}	903.56^{a}	1.73^{a}	1.91^{b}	136 283^{a}	132 864^{a}
	summer	22.85^{a}	11.52^{b}	12.77^{a}	9.01^{b}	125 426^{a}	79 321^{b}	8.98^{b}	9.91^{b}	624.61^{b}	785.39^{a}	1.54^{a}	2.57^{a}	61 205^{b}	144 803^{a}
Planting arrangement	25–50	23.41^{a}	14.83^{a}	13.30^{a}	11.61^{a}	131 556^{a}	100 556^{a}	9.45^{b}	10.33^{a}	758.42^{b}	847.91^{a}	1.72^{a}	2.41^{a}	97 890^{a}	159 674^{a}
	40–50	21.96^{b}	13.95^{a}	12.17^{b}	10.12^{b}	120 926^{b}	89 583^{b}	9.99^{a}	10.20^{a}	846.94^{a}	841.04^{a}	1.55^{a}	2.07^{a}	99 597^{a}	117 992^{a}
Expected plant density	90 000	17.75^{c}	10.71^{c}	10.19^{c}	8.81^{c}	98 028^{c}	74 144^{c}	10.26^{a}	10.66^{a}	941.75^{a}	966.51^{a}	1.70^{a}	2.68^{a}	120 960^{a}	200 196^{a}
	120 000	22.02^{b}	13.84^{b}	12.90^{b}	10.43^{b}	126 250^{b}	91 667^{b}	9.73^{b}	10.34^{a}	794.27^{b}	866.26^{a}	1.77^{a}	2.57^{a}	107 815^{ab}	141 260^{a}
	160 000	28.30^{a}	18.63^{a}	15.13^{a}	13.35^{a}	154 444^{a}	119 398^{a}	9.17^{c}	9.79^{b}	672.02^{c}	700.66^{b}	1.44^{a}	1.47^{b}	67 456^{b}	75 043^{b}

Planting arrangement: at 25–50 means planting arrangement with pairs of rows with a distance of 25 cm and a distance between pairs of rows of 50 cm and at 40–50 means planting arrangement with pairs of rows with a distance of 40 cm and a distance between pairs of rows of 50 cm. Expected plant density: it was defined as a plant/ha. Means followed by the same letter(s) within the column were not significantly different at the 0.05 probability level, according to the *LSD* (least significant difference) test

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environmental factors (Donohue et al. 2010), so that with increasing the distance from suitable germination temperature in sugar beet genotypes (20 °C), seed germination will be reduced and reaches zero at 44 °C (Malmir et al. 2017).

In the first year, the number of plants after thinning was relatively similar to the number of plants at harvesting time (1% drop in root numbers), but in the second year, there was a significant decrease in the number of plants at harvesting time (13% drop) (Table 5). The reason for this difference in the second year may be due to pest and disease damage (data not shown). Also, the reduction in the number of plants on the summer sowing date compared to spring in the first and second years was about 2% and 29%, respectively. The reason for the difference between the two years is mainly due to the bad greenery and, as a result, the lack of a suitable number of plants in the second year of the experiment (Figure 2). Therefore, it can be concluded that, on the summer sowing date, due to the coincidence of germination with high temperature, it should be expected that the number of final plants will be less than the spring sowing date. As expected, the number of plants before and after thinning, as well as the final number of roots in both years, increased by decreasing plant spacing on the rows. However, at each level of plant density, the number of roots in the 25–50 planting arrangement was higher than 40–50, which is due to the better irrigation effect in the first planting arrangement at the germination stage (shorter distance between seeds and strip tape) (Table 6). Mohammadian and Sadrahghan (2013) also showed that increasing the distance of the strips tape from 20 cm of seeds to 22.5, 25, and 30 cm reduced the number of final plants by 12, 12, and 34%, respectively.

Root yield and single root features. The 50-day delay in sowing in both years reduced the root yield (RY) by about 40%, which can be considered as a result of the growth period and consequently further increase in solar radiation absorption on the spring sowing date (that increases photosynthesis and creates more storage cells) compared to summer (Table 3). In general, plant growth is affected by growth degree day (GDD), and there is a positive correlation between GDD and the length of the growing season with plant yield (Hoffmann and Kluge-Severin 2010, Schnepel and Hoffmann 2016). Furthermore, it should be mentioned that a high correlation has been observed between increasing root diameter and increasing single root weight (Hoffmann 2017). Also, greater crop yield at a sooner sowing date can be associated with early growth and development and reach to high leaf area for radiation absorption and photosynthesis in the long term (Rinaldi and Vonella 2006).

Table 6. Interaction effect of planting arrangement and sowing date with expected plant density on the sugar beet root numbers, root yield, sugar yield and irrigation water productivity (WP_{irrig}) in the years 2016 and 2017

Expected plant density (plant/ha)	Planting arrangement	Sowing date	Root numbers (number/ha)		Root yield (t/ha)		Sugar yield (t/ha)		WP_{irrig} (kg/m^3)	
			2016	2017	2016	2017	2016	2017	2016	2017
90 000	25–50		103 000^{d}	71 667^{b}	78.18^{b}	64.88^{a}	12.45^{b}	10.65^{a}	1.09^{b}	0.98^{ab}
	40–50		93 056^{d}	76 620^{b}	85.99^{a}	57.45^{a}	13.43^{ab}	10.04^{a}	1.19^{ab}	0.87^{b}
		spring	100 006^{c}	88 704^{bc}	103.91^{b}	77.57^{a}	16.54^{b}	13.57^{a}		
		summer	960 000^{c}	59 583^{d}	60.26^{c}	44.76^{b}	9.34^{c}	7.12^{b}		
120 000	25–50		128 333^{c}	108 333^{a}	88.63^{a}	64.83^{a}	14.00^{a}	11.11^{a}	1.23^{a}	1.03^{ab}
	40–50		124 167^{c}	75 000^{b}	87.60^{a}	63.68^{a}	13.88^{a}	10.80^{a}	1.23^{a}	0.94^{ab}
		spring	124 667^{b}	104 306^{b}	110.38^{ab}	79.61^{a}	17.37^{ab}	14.16^{a}		
		summer	127 833^{b}	79 028^{c}	65.86^{c}	48.90^{b}	10.51^{c}	7.74^{b}		
160 000	25–50		163 333^{a}	121 667^{a}	86.18^{a}	68.87^{a}	13.92^{a}	11.65^{a}	1.22^{a}	1.07^{a}
	40–50		145 556^{b}	117 130^{a}	93.93^{a}	62.49^{a}	14.62^{a}	10.77^{a}	1.30^{a}	0.94^{ab}
		spring	156 444^{a}	139 444^{a}	113.35^{a}	81.69^{a}	17.99^{a}	14.51^{a}		
		summer	152 444^{a}	99 352^{b}	66.76^{c}	49.68^{b}	10.55^{c}	7.91^{b}		

Planting arrangement: at 25–50 means planting arrangement with pairs of rows with a distance of 25 cm and a distance between pairs of rows of 50 cm and at 40–50 means planting arrangement with pairs of rows with a distance of 40 cm and a distance between pairs of rows of 50 cm. Means followed by the same letter(s) within the column were not significantly different at the 0.05 probability level, according to the *LSD* (least significant difference) test

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In the first year, the RY in 40–50 planting arrangement (with a mean 120 000 plant/ha) compared to 25–50 (with a mean 130 000 plant/ha) in the two dates of spring (significantly) and the summer sowing date (non-significant), increased by about 8% and 1%, respectively. On the other hand, by increasing the row spacing on both sowing dates, which reduced the negative effect of competition between plants, increasing the values of diameter and single root weight led to increased RY (Table 7). While in the second year, the RY in 40–50 planting arrangement (with a mean 90 000 plant/ha) was lower (non-significant) than 25–50 (with a mean of 100 000 plant/ha) by about 6% and 13% in spring and the summer sowing date, respectively. When the plant density was relatively low (like the second year), due to increasing available resources for each plant (light, nutrients and water), changing row spacing did not have a significant effect on root diameter and weight (Table 7). Whereas higher diameter and weight variance of the second year compared to the first year, related to change in plant density which confirms our conclusion (Table 5). Therefore, according to the results, it can be deduced that in high densities (120 to 130 thousand plant/ha), 40–50 planting arrangements, and in low densities (90 to 100 thousand plant/ha), 25–50 planting arrangements are more appropriate in drip irrigation methods to increase the RY. Closer planting arrangements (18–45 cm and 18–60 cm) resulted in better plant establishment (Zahoor et al. 2010). Also, in the study of planting arrangement with distances of 40, 50 and 60 cm and pairs of rows, the maximum RY was obtained from the ridge of 50 cm and cultivation in pair of rows bed with a row spacing of 80–30. This result was due to better nutrient use and more light absorption (Zahoor et al. 2007).

Based on results obtained from both years, yield can be increased to some extent by increasing plant density on both sowing dates; however, it reduces the average diameter and weight of a single root (Tables 5 and 6). There are many reports which confirm (similar to our results) the effect of plant density on root growth characteristics (Cakmakci and Oral 2002, Milković et al. 2019). Therefore, increasing plant density on planting rows had a better effect on the RY and uniformity (as it was observed in both years, high uniformity was achieved by increasing plant density) because reducing the distance between planting rows at high densities may increase competition between plants. It has been reported that with increasing plant density, biomass will be increased at a higher density than 75 000 plants, and the high RY is considered to be dependent on a plant density of 70 000 to 110 000 plant/ha (Scott and Jaggard 1993).

Investigating the interaction effects of P × D in Table 6 confirms that in both years, in each planting arrangement, the plant density increased by reducing plant distance on planting rows, which in most cases showed an increasing trend of the RY. However, these differences were only significant in the first year of the 25–50 planting arrangement. Therefore, it can be concluded that in high densities (such as the first year), low distances of planting rows (25–50) along with decreasing plant distances on the row can have a negative effect (increased competition) on the RY. We recommend that the 40–50 planting arrangement be used in the drip irrigation method when many plants are anticipated in the field (usually in spring). The RY on the spring and the summer sowing dates with delaying harvest dates increased by about 20% and 4%, respectively, compared to the usual harvest-

Table 7. Interaction effect of sowing date and planting arrangement on the average sugar beet root diameter and weight, root yield and sugar content in the years 2016 and 2017

Sowing date	Planting arrangement	Average root diameter (cm)		Average root weight (g)		Root yield (t/ha)		Sugar content (%)	
		2016	2017	2016	2017	2016	2017	2016	2017
Spring	25–50	10.31^{a}	10.67^{a}	946.11^{a}	897.05^{a}	104.79^{b}	81.75^{a}	16.24^{a}	17.7^{a}
	40–50	10.6^{a}	10.56^{ab}	1015.39^{a}	910.07^{a}	113.64^{a}	77.49^{a}	15.51^{b}	17.7^{a}
Summer	25–50	8.59^{c}	9.98^{bc}	570.72^{c}	798.78^{a}	63.88^{c}	50.64^{b}	15.52^{b}	15.37^{c}
	40–50	9.37^{b}	9.83^{c}	678.50^{b}	772.01^{a}	64.7^{c}	44.92^{b}	15.98^{ab}	16.41^{b}

Planting arrangement: at 25–50 means planting arrangement with pairs of rows with a distance of 25 cm and a distance between pairs of rows of 50 cm and at 40–50 means planting arrangement with pairs of rows with a distance of 40 cm and a distance between pairs of rows of 50 cm. Means followed by the same letter(s) within the column were not significantly different at the 0.05 probability level, according to the *LSD* (least significant difference) test

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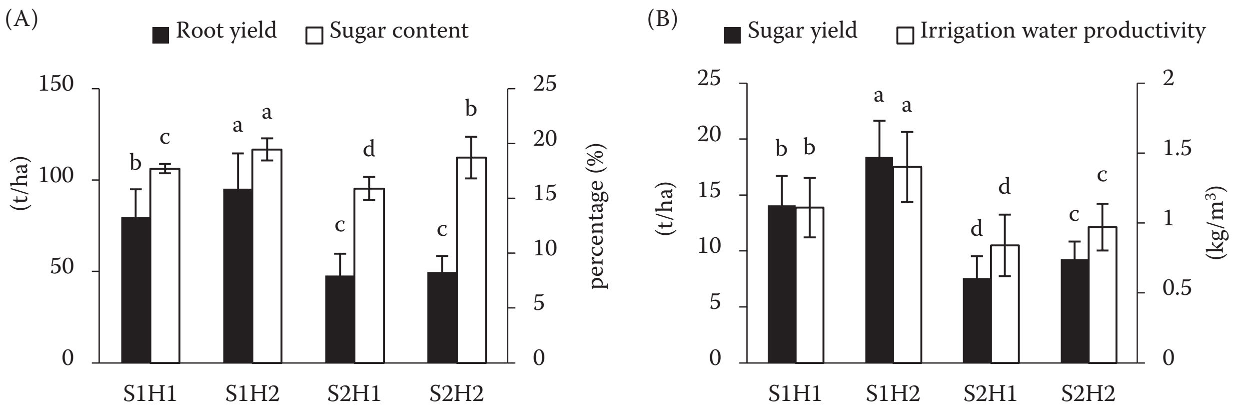

Figure 3. Interaction effect of sowing date (S) and harvesting date (H) on root yield (t/ha) and sugar content (%) (A), and sugar yield (t/ha) and irrigation water productivity (kg/m^3) (B) of sugar beet in the year 2017. Sowing date: S1 – spring sowing date; S2 – summer sowing date; harvesting date: H1 – October 25; H2 – November 20. The vertical bars represent ± the standard deviation of the sample mean (n = 24). Columns with different letters indicate significant differences at P < 0.05 (least significant difference test)

ing date (Figure 3A). It seems that on the spring sowing date, as the temperature decreases in early autumn, more photosynthetic substances were translocated to the root due to the completion of leaf growth, thus increasing the speed of root growth. However, due to the incomplete growth period in the summer sowing date, the plant tends to produce more leaves. It has been reported by Altunbay (2017) that increasing growth period (delayed harvesting) results in more assimilation and more time to transfer assimilates from leaf to root.

Sugar content. On the summer sowing date with greater row spacing (40–50), sugar content (SC) increased due to reduced plant competition and faster maturity. On the spring sowing date, when the plant density is high, reducing the row space (25–50), it may increase the SC (such as the first year) due to the loss of single root weight (about 7%) and diameter. On the other hand, when the weight of a single root does not change much due to the relatively low plant density (as in the second year), the change in planting space by the change in planting arrangement may not make a difference in SC (Table 7).

Although the differences in SC at different levels of plant density were not significant, with increasing plant density, the SC had a relatively increasing trend (Table 8). A slight increase in the percentage of

Table 8. The responses of root yield, sugar content, sugar yield and irrigation water productivity (WP_{irrig}) to different treatment of sowing date, planting arrangement and expected plant density in sugar beet in the years 2016 and 2017

Treatment		Root yield (t/ha)		Sugar content (%)		Sugar yield (t/ha)		WP_{irrig} (kg/m^3)	
		2016	2017	2016	2017	2016	2017	2016	2017
Sowing date	spring	109.21^a	79.62^a	15.87^a	17.70^a	17.30^a	14.08^a	1.36^a	1.11^a
	summer	64.29^b	47.78^b	15.75^a	15.89^b	10.13^b	7.59^b	1.06^b	0.84^b
Planting arrangement	25–50	84.33^b	66.19^a	15.88^a	16.54^b	13.45^a	11.14^a	1.18^b	1.03^a
	40–50	89.17^a	61.21^a	15.74^a	17.06^a	13.98^a	10.54^a	1.24^a	0.91^a
Expected plant density	90 000	82.09^b	61.16^a	15.71^a	16.73^a	12.94^b	10.35^a	1.14^b	0.93^a
	120 000	88.12^a	64.26^a	15.86^a	16.80^a	13.94^a	10.95^a	1.23^a	0.98^a
	160 000	90.06^a	65.68^a	15.86^a	16.86^a	14.27^a	11.21^a	1.26^a	1.01^a

Planting arrangement: at 25–50 means planting arrangement with pairs of rows with a distance of 25 cm and a distance between pairs of rows of 50 cm and at 40–50 means planting arrangement with pairs of rows with a distance of 40 cm and a distance between pairs of rows of 50 cm. Expected plant density: it was defined as a plant/ha. Means followed by the same letter(s) within the column were not significantly different at the 0.05 probability level, according to the *LSD* (least significant difference) test

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sugar was associated with a decrease in the diameter and weight of single roots (Tables 5 and 8). In agreement with these results, it has been reported that the amount of sugar is more in the roots closer to each other (DeBruyn et al. 2017). It has also been reported that increasing plant density with decreasing root size leads to increased SC (Cakmakci and Oral 2002). Thus, the SC usually increases with decreasing root size due to reduced cell size, especially the development of cambium cells (without affecting the number of cambium rings) (Milford 1976). However, it has been reported that by increasing the plant density to 160 000 plants, the amount of leaf area decreases and leads to a decrease in SC (Pospisil et al. 2000). There is almost always a negative correlation between the RY and SC (Hoffmann 2019), but in this study, the SC had a negative relationship with the amount of weight of single roots at different levels of plant density. While it had a positive relationship with the RY (Figure 4).

Although the highest SC in the late harvesting date was observed on the spring sowing date, the SC increase on the summer sowing date (18%) was somewhat higher than on the spring sowing date (10%) (Figure 3A). The positive effect of the delayed harvesting date on the SC is due to the increase in the length of the growth period, simultaneously with an increase in GDD and the rate of photosynthesis. In the added time to the growth period (in autumn), the amount of respiration is also very low due to the decrease in night temperature. Peraudeau et al. (2015) have reported that the rate of respiration in plants increases with increasing night temperature. Therefore, most of the photosynthetic material was stored in the root. It has been reported that the

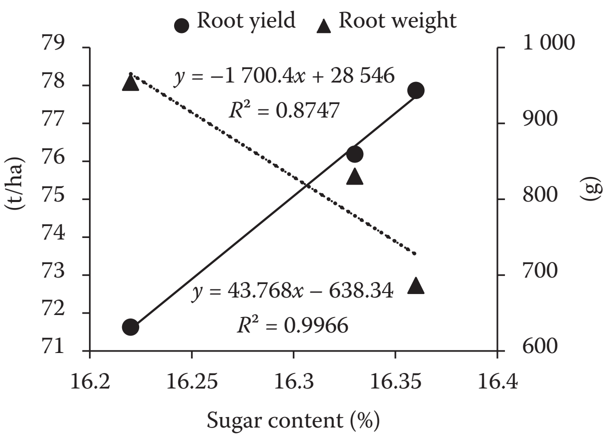

Figure 4. Correlation of sugar content with the root yield and single root weight with using of average data for the two years 2016 and 2017

amount of SC will increase until the cumulative receiving temperature is 3 400 to 5 000 °C, but then the SC will decrease because the storage of sugar in the roots will be limited by physiological limits (Schnepel and Hoffmann 2016). As a result, by postponing the harvest date until the sugar beet growth is possible, the sugar content is improved (especially on the summer sowing date).

Sugar yield. The rate of sugar yield (SY) decline in the two years on the summer sowing date compared to the spring sowing date was 41% and 46%, respectively (Table 8). On the late sowing date, SY decreases with failure to intercept solar radiation and decreases radiation absorption (Jaggard et al. 2009). Delay in the sowing date reduces the length of the growth period, so at the early sowing date, the increase in radiation use efficiency with the increase in thermal accumulation is higher than that of the late sowing date (Florio et al. 2014).

The effects of planting row spacing under different plant densities in both years on the RY and SC probably prevented the significant effect of planting arrangement on SY (Table 8). However, based on the results, it can be concluded that in high plant density (as in the first year of the experiment), more row distances (40–50) and in relatively low-density conditions (such as the second year of the experiment), the closer row distances (25–50) can increase SY to some extent (Table 8).

In contrast to distances between planting rows, the reduction in plant spacing on the planting rows every two years had a relatively positive effect on the RY, SC, and SY (Table 8). Sadre et al. (2012) report indicates a positive and significant effect of plant density on SY in sugar beet. Optimal plant density has a positive effect on root quality (Jafarnia et al. 2013), symmetrical increase in SY (Scott and Jaggard 1993, Jaggard et al. 2009), and a reduction in time to achieve the highest radiation intake (Purcell et al. 2002) through achieving uniform and same space for plants (Andrade et al. 2002). However, it should be noted that the increase in plant density to over-optimal decrease the SY because of the amount of the RY loss (Cakmakci and Oral 2002). At each level of P or S, with increasing plant density, the SY increased (Table 6). However, the intensity in two years of the experiment differed in two sowing dates and two planting arrangements. Therefore, it seems that the positive effects of increasing plant distances on planting rows in this study have more stability on the quantitative and qualitative yield of

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sugar beet compared to the changes in the distances between planting rows.

The greater positive effect of the delayed harvesting date (25 days) on the spring sowing date (31%) compared to the summer sowing date (22%) was mainly due to its greater effect on the RY on the spring sowing date (Figure 3B). Jozefyova et al. (2003) reported that with a one-month delay in the harvesting date, an 18% increase in the SY can be achieved. Another report has confirmed the significant effect of delayed harvesting dates on SY (Altunbay 2017).

Irrigation water productivity. The WP_{irrig} on the spring sowing date was higher on the usual harvesting date than on the summer sowing date (Table 8), although water consumption on the summer sowing date was about 27% lower than on the spring sowing date (Table 3). In the first year, the highest WP_{irrig} was obtained in the 40–50 planting arrangement, but in the second year, opposite results were obtained. The reason for these differences could be due to the differences in the SY in the two planting arrangements, as well as the amount of evaporation from the soil surface in two years of experiment. Badr et al. (2016) have reported that in intensive cultivation, due to higher yields and reduced evaporation from the soil surface, the WP_{irrig} increased. Therefore, it can be argued that in the first year of the experiment, the level of evaporation from the soil surface in both planting arrangements was almost the same due to the high plant density. Therefore, WP_{irrig} only depended on the amount of yield in planting arrangements with more row spacing. While in the second year, due to low plant density, the evaporation level from the soil surface in the 25–50 planting arrangement was lower than the 40–50, and the SY was higher in the first planting arrangement (25–50); therefore, WP_{irrig} increased (Table 6). Mohammadian and Sadrahghan (2013) mentioned that at similar plant density, SY and WP_{irrig} at more distance of planting rows in 60–40 planting arrangement were more than the planting rows with a short distance (40–50). Under drip irrigation on the spring and summer sowing date, we recommend 40–50 and 25–50 cm planting arrangements for increasing yield and, subsequently, WP_{irrig}.

Mainly due to the positive effects of reducing plant distance on planting rows (up to about 17 cm in 25–50 planting arrangement and up to about 14 cm in 40–50 planting arrangement) on SY, the increasing trend of WP_{irrig} was observed by reducing plant distance in both planting arrangements (Table 6). However, Ahmadi et al. (2019) reported that high plant density could decrease evaporation and increase transpiration, but it may also cause plants to compete for water and nutrients, which in turn may reduce the yield, and has a direct effect on WP_{irrig}.

The reason for the WP_{irrig} enhancement (22%) in the delayed harvesting date (Figure 3B) is both due to the effect of increasing the growth period on SY and due to the sharp decrease in irrigation water consumption during the 25 days added to the growth period. As can be deduced from Table 3, an average of about 11 000 m^3/ha of water has been consumed during the 146 days of the sugar beet growth period (average of the two growing seasons of spring and summer). While, in the 25 days added to the growth period on the late harvesting date, due to the lack of need for irrigation, only about 436 m^3/ha has been irrigated. In other words, at the first harvesting date, an average of about 75 m^3 of water has been consumed per day, and from the first harvesting date to the second, an average of about 17 m^3/ha of water has been consumed per day. On the other hand, 28% SY was added on average during days between the first and second harvesting dates.

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