

Effect of Row Spacing and Phosphorus Fertilization on the Productivity and Quality of Sugar Beet (*Beta Vulgaris* L.) Cultivar HM10 in Deir Ezzor Governorate, Syria

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Abstract. A field experiment was conducted at Saalu Research Station, General Commission for Scientific Agricultural Research, Deir Ezzor Governorate, Syria, during the 2025/2026 winter growing season to evaluate the effects of row spacing and phosphorus fertilization on the productivity and technological quality of sugar beet (*Beta vulgaris* L.) cultivar HM10. Three row spacings (35, 45 and 55 cm) and three phosphorus rates (15, 20 and 25 kg P₂O₅ dunum⁻¹) supplied as triple superphosphate (46% P₂O₅) were evaluated in a split-plot design with three replications. Sowing was carried out on 30 October 2025 and roots were lifted at maturity on 24 June 2026. Mean root weight, root yield, soluble solids (°Brix), sucrose content, juice purity, and theoretical and actual sugar yields were determined. The largest mean root weight (870 g) and highest root yield (79.6 t ha⁻¹) occurred at 55 cm × 25 kg P₂O₅ dunum⁻¹. The 35 cm × 25 kg P₂O₅ dunum⁻¹ combination produced the highest sucrose content (15.9%) and the highest theoretical (12.3 t ha⁻¹) and actual (9.9 t ha⁻¹) sugar yields, while the highest °Brix value (20.6%) occurred at 45 cm × 25 kg P₂O₅ dunum⁻¹ and the highest juice purity (83.5%) at 35 cm × 20 kg P₂O₅ dunum⁻¹. The results indicate that wider rows favored individual root growth and root biomass, whereas narrower rows favored sucrose accumulation and sugar yield per unit area. Under the conditions of the study, the 25 kg P₂O₅ dunum⁻¹ rate gave the strongest overall response, while the preferred row spacing depended on the production objective.

Keywords: sugar beet; HM10; row spacing; phosphorus fertilization; P₂O₅; root yield; sucrose content; sugar yield.

1. INTRODUCTION

Sugar beet (*Beta vulgaris* L.) is an important industrial crop cultivated for sucrose stored in its storage root. Root and sugar productivity depend on plant establishment, population

density, individual root growth, sucrose concentration and technological quality. Recent research has emphasized the importance of crop geometry, canopy development and balanced nutrient management for maximizing sugar yield and processing quality [1], [7], [8], [11].

Row spacing determines the spatial distribution of plants and influences competition for light, water and nutrients. Recent field studies have shown that plant population and geometrical arrangement affect canopy closure, root yield, sucrose concentration and sugar yield, and that the response varies with cultivar and environment [1], [4], [6], [8]. Current evidence generally supports plant populations near 80,000–100,000 plants.ha⁻¹ under favourable establishment, although the optimum arrangement remains site-specific [8].

Phosphorus is essential for energy transfer, root development and carbohydrate metabolism, and its agronomic response depends strongly on soil available P and the fertilizer source and rate. Recent sugar beet studies have reported yield and quality responses to phosphorus fertilization and have emphasized the need to match P application to soil fertility and local production conditions [2], [3], [5], [9]. Information on the combined effect of row spacing and phosphorus rate under the heavy clay soils of the Euphrates valley in eastern Syria remains limited. Therefore, this study aimed to (i) identify a suitable row spacing for sugar beet production in Deir Ezzor, (ii) evaluate three P₂O₅ rates, and (iii) assess the interaction between row spacing and phosphorus fertilization on productive and technological traits.

These objectives are particularly relevant for irrigated sugar beet systems in arid and semi-arid environments, where efficient use of plant density, water and mineral nutrients is central to sustainable production [7], [10], [11].

The experiment therefore focused on the response of cultivar HM10 to row spacing × phosphorus-rate combinations under the local conditions of Deir Ezzor.

2. MATERIALS AND METHODS

2.1. MATERIALS

2.1.1. Experimental site and season

The experiment was conducted at Saalu Research Station, Deir Ezzor Research Centre, General Commission for Scientific Agricultural Research (GCSAR), Syria, during the 2025/2026 winter growing season. The region is characterized by hot, dry summers and cold winters. Monthly minimum and maximum air temperatures and rainfall during the growing season are presented in Table 1. Sowing was carried out on 30 October 2025, and the crop was lifted at physiological maturity on 24 June 2026.

Table 1. Monthly air temperature and rainfall during the growing season.

Month	Min. temperature (°C)	Max. temperature (°C)	Rainfall (mm)
October	16.0	31.0	6.1
November	4.5	25.5	7.5
December	1.4	18.1	13.0
January	1.7	13.2	25.7
February	4.5	16.6	6.4
March	7.2	22.6	1.3
April	14.5	28.8	58.4
May	16.5	31.3	4.9

2.1.2. Soil properties

Soil samples were collected before planting from the 0–25 cm layer using a zig-zag sampling pattern, composited and analyzed at the Soil Research Laboratory, Deir Ezzor. The soil was a heavy clay with a slightly alkaline reaction and the properties shown in Table 2.

Table 2. Physical and chemical properties of the experimental soil.

pH	EC (dS m ⁻¹)	OM (%)	Total N (%)	Available P (mg kg ⁻¹)	Exch. K (mg kg ⁻¹)	Clay (%)	Sand (%)	Silt (%)
7.54	2.23	1.02	0.10	3.7	196	51	24	25

2.1.3. Plant material

The sugar beet cultivar HM10 was used. HM10 is a multigerm triploid hybrid obtained through the General Commission for Scientific Agricultural Research. It is a late-maturing sugar type used for winter cultivation and was selected for the present field experiment under Deir Ezzor conditions.

2.2. METHODS

2.2.1. Treatments and experimental design

The experiment was laid out in a split-plot design with three replications. Row spacing was assigned to the main plots and phosphorus rate to the sub-plots. Three row spacings (35, 45 and 55cm) and three phosphorus rates (15, 20 and 25kg P₂O₅ dunum⁻¹; 1 dunum = 0.1ha) were tested. Triple superphosphate containing 46% P₂O₅ was the phosphorus source; the three P₂O₅ rates corresponded to approximately 32.6, 43.5 and 54.3kg TSP product dunum⁻¹, respectively. The factorial arrangement therefore comprised 27 experimental plots (3 row spacings × 3 P rates × 3 replications), each approximately 12m². Within-row spacing was fixed at 20 cm.

2.2.2. Crop management

The land was prepared by two perpendicular deep ploughings followed by harrowing, levelling and ridge formation. Triple superphosphate was applied according to the assigned phosphorus treatment, and potassium sulfate (50% K₂O) was applied uniformly at 24 kg product

dunum⁻¹. The field was then divided according to the three row-spacing treatments (35, 45 and 55 cm).

Seeds were sown on the upper third of the ridge at 20 cm between hills within the row, with two to three seeds per hill and a seed rate of 1.5 kg dunum⁻¹. Sowing was carried out on 30 October 2025, and the first irrigation was applied on 1 November 2025. Gap filling was performed 2–3 weeks after sowing, and seedlings were thinned to one plant per hill at the 6–8 true-leaf stage. Hoeing was carried out three times during the season. Irrigation was applied according to crop requirement and was stopped 15 days before lifting. Roots were harvested on 24 June 2026.

2.2.3. Measurements

At harvest, the following traits were determined: mean root weight (g), root yield (t ha⁻¹), soluble solids (°Brix), sucrose content (%), juice purity (%), and theoretical and actual sugar yields (t ha⁻¹). A representative root sample of approximately 1 kg was sliced and homogenized for juice analysis. Sucrose was determined polarimetrically after clarification, while °Brix was measured with a refractometer standardized at 20 °C. Juice purity was calculated as sucrose/°Brix × 100. Theoretical and actual sugar yields were calculated as follows:

$$TSY = RY \times \frac{S}{100} \quad (1)$$

$$ASY = RY \times \frac{S}{100} \times \frac{JP}{100} \quad (2)$$

where TSY and ASY are the theoretical and actual sugar yields (t ha⁻¹), RY is root yield (t ha⁻¹), S is sucrose content (%) and JP is juice purity (%).

2.2.4. Statistical analysis

Data were subjected to analysis of variance appropriate for a split-plot design using GenStat software. Treatment means were compared using the least significant difference (LSD) test at the 5% probability level. Reported LSD values are presented below the corresponding tables where available.

3. RESULTS AND DISCUSSION

3.1. RESULTS

3.1.1. Mean root weight

Mean root weight increased with wider row spacing and higher phosphorus rate (Table 3). The largest row-spacing mean was recorded at 55 cm (803.3 g), while the largest phosphorus-rate mean occurred at 25 kg P₂O₅ dunum⁻¹ (840.0 g). The highest interaction value (870 g) was obtained at 55 cm × 25 kg P₂O₅ dunum⁻¹.

Table 3. Effect of row spacing (A) and phosphorus rate (B) on mean root weight (g).

Row spacing (cm)	15 kg P ₂ O ₅ dunum ⁻¹	20 kg P ₂ O ₅ dunum ⁻¹	25 kg P ₂ O ₅ dunum ⁻¹	Mean (A)
35	590	725	810	708.3
45	645	765	840	750.0
55	715	825	870	803.3
Mean (B)	650.0	771.7	840.0	

3.1.2. Root yield

Root yield responded significantly to the experimental factors (Table 4). The 55 cm row spacing gave the highest mean root yield (75.8 t ha⁻¹), as did the 25 kg P₂O₅ dunum⁻¹ rate (75.8 t ha⁻¹). The maximum interaction value, 79.6 t ha⁻¹, was obtained at 55 cm × 25 kg P₂O₅ dunum⁻¹.

Table 4. Effect of row spacing (A) and phosphorus rate (B) on root yield (t ha⁻¹).

Row spacing (cm)	15 kg P ₂ O ₅ dunum ⁻¹	20 kg P ₂ O ₅ dunum ⁻¹	25 kg P ₂ O ₅ dunum ⁻¹	Mean (A)
35	64.3	68.6	70.6	67.8
45	68.6	72.6	77.3	72.8
55	70.3	77.6	79.6	75.8
Mean (B)	67.7	73.0	75.8	

LSD (0.05): A = 2.89, B = 2.47, A × B = 4.80

3.1.3. Sucrose content

Sucrose content was significantly affected by the experimental factors (Table 5). The 35 cm spacing produced the highest mean sucrose content (14.7%), and the 25 kg P₂O₅ dunum⁻¹ rate produced the highest phosphorus-rate mean (14.9%). The highest interaction value, 15.9%, was recorded at 35 cm × 25 kg P₂O₅ dunum⁻¹.

Table 5. Effect of row spacing (A) and phosphorus rate (B) on sucrose content (%).

Row spacing (cm)	15 kg P ₂ O ₅ dunum ⁻¹	20 kg P ₂ O ₅ dunum ⁻¹	25 kg P ₂ O ₅ dunum ⁻¹	Mean (A)
35	12.5	15.7	15.9	14.7
45	13.3	14.1	14.4	13.9
55	13.4	14.5	14.5	14.1
Mean (B)	13.1	14.8	14.9	

LSD (0.05): A = 0.28, B = 0.51, A × B = 0.315

3.1.4. Brix

Brix values varied among the row-spacing × phosphorus combinations (Table 6). The 20 kg P₂O₅ dunum⁻¹ rate gave the highest mean °Brix (20.01%), while the 35 cm spacing gave the highest row-spacing mean (19.39%). The maximum interaction value, 20.6%, was recorded at 45 cm × 25 kg P₂O₅ dunum⁻¹.

Table 6. Effect of row spacing (A) and phosphorus rate (B) on soluble solids (°Brix).

Row spacing (cm)	15 kg P ₂ O ₅ dunum ⁻¹	20 kg P ₂ O ₅ dunum ⁻¹	25 kg P ₂ O ₅ dunum ⁻¹	Mean (A)
35	18.66	20.39	19.12	19.39
45	17.61	19.42	20.60	19.21
55	17.82	20.23	20.00	19.35
Mean (B)	18.03	20.01	19.91	

3.1.5. Juice purity

Juice purity varied among treatments (Table 7). The 35 cm spacing achieved the highest mean purity (80.8%), while the 20 kg P₂O₅ dunum⁻¹ rate gave the highest phosphorus-rate mean (81.7%). The highest interaction value, 83.5%, was obtained at 35 cm × 20 kg P₂O₅ dunum⁻¹.

Table 7. Effect of row spacing (A) and phosphorus rate (B) on juice purity (%).

Row spacing (cm)	15 kg P ₂ O ₅ dunum ⁻¹	20 kg P ₂ O ₅ dunum ⁻¹	25 kg P ₂ O ₅ dunum ⁻¹	Mean (A)
35	77.1	83.5	81.8	80.8
45	78.9	82.3	79.3	80.2
55	76.8	79.4	83.0	79.7

Mean (B)	77.6	81.7	81.4
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3.1.6. Theoretical sugar yield

Theoretical sugar yield was highest at the 25 kg P₂O₅ dunum⁻¹ rate (10.8 t ha⁻¹) (Table 8). The 35 cm spacing also produced the highest row-spacing mean (10.8 t ha⁻¹), and the maximum interaction value (12.3 t ha⁻¹) was obtained at 35 cm × 25 kg P₂O₅ dunum⁻¹.

Table 8. Effect of row spacing (A) and phosphorus rate (B) on theoretical sugar yield (t ha⁻¹).

Row spacing (cm)	15 kg P ₂ O ₅ dunum ⁻¹	20 kg P ₂ O ₅ dunum ⁻¹	25 kg P ₂ O ₅ dunum ⁻¹	Mean (A)
35	8.2	11.8	12.3	10.8
45	8.7	9.8	10.2	9.6
55	8.5	9.9	9.8	9.4
Mean (B)	8.5	10.5	10.8	

3.1.7. Actual sugar yield

Actual sugar yield was significantly affected by the experimental factors (Table 9). The highest phosphorus-rate mean was obtained at 25 kg P₂O₅ dunum⁻¹ (8.73 t ha⁻¹), and the 35 cm spacing gave the highest row-spacing mean (8.57 t ha⁻¹). The highest interaction value, 9.9 t ha⁻¹, was recorded at 35 cm × 25 kg P₂O₅ dunum⁻¹.

Table 9. Effect of row spacing (A) and phosphorus rate (B) on actual sugar yield (t ha⁻¹).

Row spacing (cm)	15 kg P ₂ O ₅ dunum ⁻¹	20 kg P ₂ O ₅ dunum ⁻¹	25 kg P ₂ O ₅ dunum ⁻¹	Mean (A)
35	6.3	9.5	9.9	8.57
45	6.9	8.2	8.1	7.73
55	6.5	7.9	8.2	7.53
Mean (B)	6.57	8.53	8.73	

LSD (0.05): A = 0.39, B = 0.48, A × B = 0.53

3.2. DISCUSSION

The increase in individual root weight with wider row spacing reflects the greater growing area available to each plant and reduced intra-specific competition. Similar effects of plant population and geometry on individual root growth, canopy development and root yield have been reported in recent sugar beet studies [1], [4], [6], [8]. Under the present conditions, the 55 cm spacing increased individual root size sufficiently to produce the highest root-yield mean despite the lower nominal number of plants per unit area.

In contrast, the narrowest spacing (35 cm) produced the highest mean sucrose content and the highest theoretical and actual sugar-yield means. Denser stands can promote earlier canopy closure and greater light interception per unit land area, while wider spacing may favor larger individual roots. The balance between these responses explains why the spacing that maximizes root mass is not necessarily the spacing that maximizes sugar yield [1], [4], [6], [8].

The favourable response to phosphorus is consistent with the low available-P value reported for the experimental soil and with the established role of phosphorus in root development, energy transfer and assimilate metabolism. Recent studies have shown that sugar beet response to phosphorus depends on soil P status, fertilizer source, application rate and interactions with water and other nutrients [2], [3], [5], [9]. In the present experiment, 25 kg P₂O₅ dunum⁻¹ produced the highest mean root yield, sucrose content and sugar yields, whereas the greatest juice purity occurred at 20 kg P₂O₅ dunum⁻¹. This confirms that fertilizer

management should be evaluated using both biomass and technological-quality criteria rather than root yield alone.

4. CONCLUSIONS

Increasing phosphorus supply up to 25 kg P_2O_5 dunum⁻¹ improved the principal productive traits under the conditions of this experiment. A row spacing of 55 cm was most favourable for mean root weight and root yield, whereas 35 cm was superior for sucrose content and for theoretical and actual sugar yields. The 55 cm $\times$ 25 kg P_2O_5 dunum⁻¹ combination produced the highest root weight (870 g) and root yield (79.6 t ha⁻¹), while the 35 cm $\times$ 25 kg P_2O_5 dunum⁻¹ combination gave the highest sucrose content (15.9%) and the highest theoretical (12.3 t ha⁻¹) and actual (9.9 t ha⁻¹) sugar yields. For maximum root production under conditions similar to those of Deir Ezzor, 55 cm row spacing with 25 kg P_2O_5 dunum⁻¹ is indicated, whereas 35 cm spacing with the same phosphorus rate is indicated when sugar yield per unit area is the main objective. Multi-season and multi-location trials are recommended to confirm the stability and economic efficiency of these responses.

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DECLARATION OF COMPETING INTEREST

None.

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