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Research Article

Effect of Plant Geometry on the Growth and Yield of Sugar Beet (*Beta vulgaris* L) cv. California-KWS: A Study on Inter-row and Intra-row Spacing

Imran Khan[1*], Muhammad Iqbal[1], Malik Muhammad Hashim[2], Muhammad Munir[2], Atiq Ahmad[1], and Abdul Aziz Khakwani[3]

[1]Department of Horticulture, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Pakistan

[2]Institute of Food Science and Nutrition, Gomal University, Dera Ismail Khan, Pakistan

[3]Department of Agronomy, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Pakistan

Abstract: This study was aimed to assess the effect of plant geometry on the growth and yield of sugar beet under the agroclimatic conditions of D. I. Khan, Pakistan. Sugar beet, hybrid cv. California-KWS from Al-Moiz sugar mills (Dera Ismail Khan) was planted two seeds per hole on ridges at an inter-and intra-row spacing: 20 × 50, 20 × 60, 30 × 50, 30 × 60, 40 × 50, 40 × 60, 50 × 50 and 50 × 60 cm. The experiment was carried out in a Randomized Complete Block Design and replicated thrice. The parameters like plant height (cm), number of leaves, leaf area plant^{-1} (cm^2), leaf and root weights per plant, root length and diameter (cm), TSS% (total soluble solids), sucrose (%), root and sugar yields (t ha^{-1}) were studied. Results revealed that significantly maximum plant height, leaf area, leaf and root weights were observed in 40 × 50 cm spacing, number of leaves were maximum in 30 × 50 cm spacing, maximum root diameter was observed in 50 × 50 cm spacing while maximum root length, sucrose content, TSS, root and sugar yield were observed in 20 × 50 cm. Hence, the results showed that 20 × 50 cm is best spacing for obtaining highest yield and quality of sugar beet crop in the area.

Keywords: Sugar Beet, Planting Geometry, Quality, Root Yield, Sugar Yield.

1. INTRODUCTION

Sugar beet (*Beta vulgaris* L.) being an important crop, after sugar cane, produces 30% sugar annually worldwide. Europe contributes more than 60% of the sugar beet production area [1]. In Pakistan, sugar cane is the major source of sugar production while sugar beet share is small. The beet plant contains crown, neck, and root [2]. 16-20% sucrose is present in the roots [3]. Its leaves also contain carbohydrates, protein, vitamin A and green manure [4]. Sugar beet can be cultivated on loam and clay loam soils and it can tolerate alkaline conditions and also resist cold and drought [5]. During 2022-23, the area under sugar beet cultivation was 6426 hectares, producing 480087 tons beets in Pakistan, while in Khyber Pakhtunkhwa, area under its cultivation was 821 hectares with annual production of 32454 tons [6]. In Pakistan, it is cultivated in Peshawar, Charsadda, Mardan and D.I. Khan (Khyber Pakhtunkhwa). However, it has also been cultivated in Punjab, Sindh and parts of Balochistan. Due to decrease in water availability, the area under cultivation of sugar cane is decreasing in Pakistan, therefore, sugar beet is a suitable solution under such circumstances, having potential of giving two-time more sugar yield and more financial returns as compared to sugar cane in a short (5-6 months) period [7]. Factors like environmental conditions, soil, cultural practices, weeds, pests and diseases

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* Corresponding Author: Imran Khan <imrankhan1441@gmail.com>

etc. are critical for sugar beet cultivation. Plant density or plant population is also one of the most crucial factors. Reduced germination, time of sowing, poor field preparation and several biotic and abiotic factors are the main causes which can reduce plant numbers per unit area [8, 9]. Sucrose contents, purity and sugar yield were significantly increased by the increase in plant population from 87,500 to 100,000 plants ha^{-1}[10]. El-Sarag [11], Bhullar *et al*. [12], Shukla and Awasthi [13] and Sadre *et al*. [14] reported maximum yield of both roots and sugar at higher plant density.

Around 90,000 to 110,000 plants ha^{-1} are recommended for sugar crop [15-18]. New varieties have straight leaves that promote growth even in smaller area, so there is a possibility of even higher population. To find out the best plant density for proper development of higher mass and quality under different field conditions is crucial [19]. In Pakistan, agronomic studies especially of plant populations in sugar beet are rare. In Pakistan there are a few studies [20, 21] about sugar beet density, therefore, it is dire need of the day to asses proper plant density of this most important crop of the area. Hence, a study was designed with the objective to find a suitable plant density for such an important crop of the area.

2. MATERIALS AND METHODS

2.1. Study Site

The trial was performed in Faculty of Agriculture, Gomal University D. I. Khan during winter season (2013-14 and 2014-15). The soil properties and the weather data of the research site was same as reported previously [22].

2.2. Design and Treatments

Sugar beet cultivar California-KWS was planted two seeds per hole on ridges, in scheme of RCBD with three replications. Sowing was performed on October 16, 2013 and on October 17, 2014 at an inter-and intra-row spacing: 20 × 50, 20 × 60, 30 × 50, 30 × 60, 40 × 50, 40 × 60, 50 × 50 and 50 × 60 cm. Triple super phosphate and potassium sulphate were supplied at a basal rate of 100 and 62.5 kg ha^{-1}, respectively; while N was applied in two split doses (30 days after sowing and 60 days after sowing) at 120 kg ha^{-1}. Field was immediately irrigated after seeding and then at an interval of fortnight. All field cultural practices were conducted as per requirement.

2.3. Parameters Observed

The data of the following parameters were observed as:

2.3.1. Plant height (cm) was measured with measuring tape by taking ten plants at random from each replication and mean was calculated.

2.3.2. Number of leaves per plant: Mean of randomly counted leaves of ten (10) plants was calculated from each replication.

2.3.3. Leaf area per plant (cm^2): Area of the leaves was assessed as per Ahmad *et al*. [21].

2.3.4. Leaf and root weight $plant^{-1}$ were determined by a digital scale.

2.3.5. Root length (cm)**:** Measuring tape was used to record the length.

2.3.6. Root diameter (cm) was calculated as stated by Ahmad *et al*. [21].

2.3.7. Total soluble solids (%) were measured as per Horwitz and Latimer [23].

2.3.8. Sucrose (%) was determined by Lane and Eynon method as per Horwitz and Latimer [23].

2.3.9. Root and sugar yields (t ha^{-1}) were assessed as per Khan *et al*. [22].

The common cultural practices for growing sugar beet were followed accordingly. Sugar beet crop was harvested at its maturity. Roots were dugout manually by using a commonly used agricultural tool "Khurpa".

2.4. Statistical Analysis

The data was subjected to ANOVA as stated by Steel *et al.* [24] using Statistics 8.1 software. The values were compared by using LSD test at $P \leq 0.05$ levels.

3. RESULTS AND DISCUSSION

3.1. Plant Height (cm)

The plant geometry significantly affected the plant height (cm) during both years (Table 1). The tallest plants (44.68 and 44.66 cm) were recorded in 40 × 50 cm while shortest plants (42.44 and 42.45 cm) were observed in 50 × 60 cm during both years. By increaing space up to a certain limit might improve vegetative growth. Khogali *et al*. [25], Bacha *et al*. [26], Maboko and Du Plooy [27], Imran *et al.* [28], Sharifi and Namwar [29] and Wu *et al.* [30] also reported similar results in various crops.

3.2. Number of Leaves per Plant

The leaves count was significantly affected by plant geometry during both years (Table 1). Higher leaf count plant^{-1} (45.57 and 45. 60) was recorded in 30 × 50 cm while minimum (42.67 and 42.50) was recorded in 50 × 60 cm during both years. By increasing space up to a certain limit might improve top/leaves growth. Results are in line with Khogali *et al.* [25], Imran *et al.* [28] and Zahoor *et al.* [31].

3.3. Leaf Area per Plant (cm^2)

Leaf area was significantly affected by the plant geometry during both years (Table 1). Among all treatments, the maximum leaf area (445.24 and 444.94 cm^2) was recorded in 40 × 50 cm and minimum leaf area (435.41 and 434.60 cm^2) was recorded in 50 × 60 cm during both years. The results might be due to better light use efficiency by plants which resulted in superior vegetative growth (plant height, leaf length). Results agree with those obtained by Soleymani and Shahrajabian [16], Wu *et al.* [30], Zahoor *et al.* [31] and Varga *et al.* [32].

3.4. Leaf Weight (g) per Plant

Leaf weight was significantly affected by the plant geometry during both years (Table 1). Maximum leaf weight (479.66 and 480.20 g) was found in 40 × 50 cm while minimum (478.40 and 477.54 g) was recorded in 50 × 60 cm during both years. It could be due to better vegetative growth and better available resources for plants. The findings strongly agree with Varga *et al.* [33].

Table 1. Effect of plant geometry on plant height (cm), number of leaves, leaf area (cm^2) and leaf weight plant^{-1} (g).

Plant density	Plant height (cm)	Number of leaves	Leaf area (cm^2)	Leaf weight (g)
Year I				
20 × 50	43.72 c	43.57 c	442.45 c	478.79 d
20 × 60	43.69 d	43.53 c	441.79 d	478.69 e
30 × 50	44.41 b	45.57 a	443.47 b	479.46 b
30 × 60	44.43 b	45.50 a	438.81 e	479.29 c
40 × 50	44.68 a	44.43 b	445.24 a	479.66 a
40 × 60	44.66 a	44.53 b	442.44 c	479.46 b
50 × 50	42.44 e	42.73 d	437.45 f	478.48 f
50 × 60	42.44 e	42.67 d	435.41 g	478.40 g
LSD	0.026	0.125	0.100	0.051
Year II				
20 × 50	43.70 e	43.63 c	442.45 c	478.82 d
20 × 60	43.57 f	43.50 c	441.76 d	478.70 e
30 × 50	44.40 c	45.60 a	443.47 b	479.46 b
30 × 60	44.34 d	45.56 a	438.81 e	479.29 c
40 × 50	44.66 a	44.50 b	444.94 a	480.20 a
40 × 60	44.59 b	44.60 b	442.44 c	479.46 b
50 × 50	42.46 g	42.77 d	436.60 f	478.48 f
50 × 60	42.45 g	42.50 e	434.60 g	477.54 g
LSD	0.036	0.146	0.115	0.057

Response of three replicates. Means bearing different letters in the same column (years) are significant ($P \leq 0.05$).

3.5. Root Weight (g) per Plant

Significantly heaviest roots (1331.8 and 1361.8 g) were recorded in 40 × 50 cm while minimum root weight (1148.7 and 1148.1 g) was recorded in 50 × 60 cm during both years (Table 2). It could be due to better root growth and better available resources for plants. The findings agree with Ahmad *et al.* [21], Varga *et al.* [33] and Nafei *et al.* [34].

3.6. Root Length (cm)

The root length was significantly affected by plant geometry during both years (Table 2). The lengthiest roots (36.76 and 36.80 cm) were recorded in 20 × 50 cm while the shortest roots (34.39 and 34.27 cm) were observed in 50 × 60 cm during both years. By decreasing space, roots might have grown vertically to have maximum root length (compared to wider spacing). The results are in agreement with Nafei *et al.* [34] and Hozayn *et al.* [35].

3.7. Root Diameter (cm)

The root diameter (cm) was positively affected by plant geometry during both years (Table 2). Thickest roots (12.62 and 12.64 cm) were observed in 50 × 50 cm while thinnest roots (11.51 and 11.55 cm) were recorded in 20 × 50 cm during both years. It could be due to better utilization of soil and other resources due to less plant density. The results are in accord with Sadre *et al.* [14], Varga *et al.* [33], Hozayn *et al.* [35] and Leilah *et al.* [36].

3.8. Sucrose Content

The plant geometry significantly affected the sucrose content during both years (Table 2). Higher sucrose content (16.40 and 16.45%) was recorded in 20 × 50 cm while minimum (15.96 and 15.87%) was observed in 50 × 60 cm during both years. Findings are in line with Ahmad *et al.* [21], Varga *et al.* [32], Nafei *et al.* [34] and Hozayn *et al.* [35].

3.9. Total Soluble Solids (TSS%)

TSS% was significantly affected by plant geometry during both years (Table 3). Maximum TSS (19.14 and 19.17%) were recorded in 20 × 50 cm while minimum (18.70 and 18.74%) was recorded in

Table 2. Effect of plant geometry on root weight (g), root length (cm), root diameter (cm) and sucrose%.

Plant density	Root weight (g)	Root length (cm)	Root diameter (cm)	Sucrose%
Year I				
20 × 50	1173.6 d	36.76 a	11.51 f	16.40 a
20 × 60	1160.8 e	36.73 ab	11.61 e	16.38 a
30 × 50	1230.9 b	36.66 bc	11.72 d	16.30 b
30 × 60	1213.0 c	36.59 c	11.72 d	16.26 c
40 × 50	1331.8 a	35.56 d	11.94 b	16.22 d
40 × 60	1229.8 b	35.43 e	11.82 c	16.14 e
50 × 50	1149.9 f	34.56 f	12.62 a	16.02 f
50 × 60	1148.7 f	34.39 g	12.60 a	15.96 g
LSD	9.211	0.102	0.076	0.023
Year II				
20 × 50	1173.6 d	36.80 a	11.55 f	16.45 a
20 × 60	1156.2 e	36.75 ab	11.62 e	16.34 b
30 × 50	1230.9 b	36.69 bc	11.72 d	16.30 c
30 × 60	1215.6 c	36.59 c	11.72 d	16.26 d
40 × 50	1361.8 a	35.56 d	11.94 b	16.22 e
40 × 60	1232.5 b	35.43 e	11.84 c	16.14 f
50 × 50	1149.1 e	34.56 f	12.64 a	16.05 g
50 × 60	1148.1 e	34.27 g	12.58 a	15.87 h
LSD	8.741	0.102	0.054	0.033

Response of three replicates. Means bearing different letters in the same column (years) are significant ($P \leq 0.05$).

50 × 60 cm during both years. It might be due to development of poor-quality plants due to decreased population and increased non-sugar contents [36]. The findings agree with Ahmad *et al.* [21], Nafei *et al.* [34] and Hozayn *et al.* [35]. Wu *et al.* [30] reported similar results in Perilla.

3.10. Root Yield (t ha^{-1})

The plant geometry significantly affected root yield (t ha^{-1}) during both years (Table 3). Maximum root yield (63.43 and 63.46 t ha^{-1}) was recorded in 20 × 50 cm whereas, minimum root yield (60.26 and 60.66 t ha^{-1}) was found in 50 × 60 cm during both years. It could be due to high light interception which contributed positively to photosynthesis with relative increase in root numbers per hectare. The findings agree with Bhullar *et al.* [12], Sadre *et al.* [14], Soleymani and Shahrajabian [16], Varga *et al.* [32], Nafei *et al.* [34], Hozayn *et al.* [35], Leilah *et al*. [36] and Xu *et al*. [37].

3.11. Sugar Yield (t ha^{-1})

Sugar yield was also significantly affected by the plant geometry during both years (Table 3). Maximum sugar yield (10.40 and 10.47 t ha^{-1}) was noted in 20 × 50 cm while minimum (9.62 and 9.70 t ha^{-1}) was recorded in 50 × 60 cm during both years. The sugar yield relates with root yield (rather than change of technological quality of roots). Results agree with Masri [10], Bhullar *et al.* [12], Sadre *et al.* [14], Ahmad *et al.* [21], Nafei *et al.* [34], Hozayn *et al*. [35] and Xu *et al*. [37].

4. CONCLUSIONS

Results showed that plant geometry significantly affected almost all the studied characters of sugar beet during the study. In general, the sugar beet plants having higher crop densities produced a higher yield and quality as compared to lower densities. The lengthiest roots, highest sucrose, TSS, root and sugar yield were observed in 20 × 50 cm spacing. Hence, it is concluded that sowing of sugar beet at 20 × 50 cm spacing is recommended for better growth, yield and quality of the crop in the area.

Table 3. Effect of plant geometry on TSS (%), root and sugar yield (t ha^{-1}).

Plant density	TSS%	Root yield (t ha^{-1})	Sugar yield (t ha^{-1})
Year I			
20 × 50	19.14 a	63.43 a	10.40 a
20 × 60	19.12 a	63.35 a	10.38 b
30 × 50	19.05 b	62.72 b	10.22 c
30 × 60	19.00 c	62.70 b	10.16 d
40 × 50	18.95 d	61.76 c	10.02 e
40 × 60	18.87 e	61.46 d	9.92 f
50 × 50	18.73 f	60.28 e	9.66 g
50 × 60	18.70 f	60.26 e	9.62 h
LSD	0.030	0.100	0.020
Year II			
20 × 50	19.17 a	63.46 a	10.47 a
20 × 60	19.08 b	63.40 a	10.36 b
30 × 50	19.05 c	62.72 b	10.23 c
30 × 60	18.97 d	62.70 b	10.19 d
40 × 50	18.95 d	61.66 c	9.99 e
40 × 60	18.87 e	61.70 c	9.96 f
50 × 50	18.77 f	60.69 d	9.74 g
50 × 60	18.74 f	60.66 d	9.70 h
LSD	0.026	0.117	0.026

Response of three replicates. Means bearing different letters in the same column (years) are significant ($P \leq 0.05$).

5. ACKNOWLEDGMENTS

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6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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