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AGRONOMY | ORIGINAL ARTICLE

Optimizing Spacing and Fertilization to Maximize Yield and Quality of Tropical Sugar Beet (*Beta vulgaris* L.) in Bangladesh

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ABSTRACT

Sugar beet, a potential sugar crop in Bangladesh needs to develop an appropriate agronomic package to get maximum yield and quality. Therefore, to study the yield and quality of sugar beet as influenced by spacing and fertilization, an experiment was conducted at the Bangladesh Sugarcrop Research Institute (BSRI) farm, Ishurdi, Pabna, during 2019-20 cropping season. To select the most suitable spacing and fertilizer dose, the experiment was carried out in RCBD using two spacing, viz., S_1: 50 cm× 20 cm and S_2: 60 cm× 20 cm and eight different fertilizer dose viz., F_1: Urea, TSP and MoP @ 195, 75 and 169 kgha^{-1} (2 splits of Urea and MoP), F_2: Urea, TSP and MoP @ 195, 75 and 169 kgha^{-1} (3 splits of Urea and MoP), F_3: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 10 tha^{-1} (2 splits), F_4: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 10 tha^{-1} (3 splits), F_5: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 5 tha^{-1} (2 splits), F_6: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 5 tha^{-1} (3 splits), F_7: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kgha^{-1} and 10 tha^{-1} (2 splits), and F_8: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kgha^{-1} and 10 tha^{-1} (3 splits). The highest leaf number (35.80), shoot length (45.17 cm), root length (38.17 cm), girth (44.33 cm), root dry weight (132.33 g), root yield (86.87 tha^{-1}) and total soluble solid (18.20%) was recorded in the 50cm × 20cm spacing along with application of Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP ($S_1 \times F_4$ combination) followed by 60cm × 20cm spacing along with application of Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP ($S_2 \times F_4$ combination) where leaf number (35.13), shoot length (44.97 cm), root length (38.47 cm), girth (43.90 cm), root dry weight (120.17 g), root yield (88.97 tha^{-1}) and total soluble solid (18.12%) was obtained which were statistically significant and superior as compared to other treatment combinations.

1. Introduction

Sugar beet (*Beta vulgaris* L.) belongs to the Chenopodiaceae family and is acknowledged as the predominant sugar-producing crop worldwide, next only to sugarcane (Abdelrazik & Mahmoud, 2024). It accounts for nearly 20% of global sugar consumption, representing approximately 40% of total worldwide sugar production (Hosseini et al., 2019). Besides, it is an important source for ethanol production in the bioenergy sector and significantly contributes to fodder industries (Abu-Ellail et al., 2021; Abu-Ellail & El-Mansoub, 2020). Sugar beet holds a growth duration approximately half that of sugarcane and demands a smaller amount of water for its cultivation compared to sugarcane (Brar et al., 2015). Sucrose in sugar beet constitutes up to 18% of the plant's fresh weight, serving as the primary form of reduced carbon (Alkahtani et al., 2021). Besides, it is an incredible source of nutrition, containing substantial amounts of fiber, folate, vitamin C, manganese, potassium, and iron (Adaora et al., 2022). Despite these advantages, the output and productiveness of sugar beet cultivation remain quite limited, owing to several constraints. The primary challenges include unsuitable agronomic packages, issues related to soil fertility, and inadequate extension services (Sintayehu et al., 2022). In light of the extended growth period associated with sugarcane, there is a noticeable shift among farmers towards cultivating short-duration crops to enhance their profitability. As a result, in Bangladesh, most sugar mills experience periods of inactivity due to a significant shortage of sugarcane supply (Islam et al., 2012). In this context, sugar beet could be an ideal option to extend the operational lifespan

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of the sugar mill, thus enhances the effectiveness of sugar industries (Paul et al., 2018). Since there has not been any in-depth research done on the topic in Bangladesh up to this point, it is imperative to perform a thorough evaluation of the viability of growing sugar beet there before moving forward (Bithy et al., 2020; Paul et al., 2018).

Agronomic practices like plant spacing and management of fertilizers significantly impact the crop circumstances, thereby influencing growth and eventually yield (Fageria, 2014). Plant spacing plays a crucial role in influencing both the yield and quality of the produce (Mahil & Lokanadhan, 2018). A crucial element of any crop production system is the formation of a crop canopy that maximizes light interception, enhances photosynthesis, and efficiently allocates dry matter to the harvestable components (Ashenafi & Tenaye, 2023). Management of a crop canopy typically involves adjusting the spacing between rows and plant population; a higher population density may contribute to a rise in yield per unit area (Gebretsadik & Dechassa, 2018). In addition to optimal plant density, fertilization serves as a vital element affecting both the ultimate quality and quantity of sugar beet (Hlisnikovský et al., 2021). The response of sugar beet to increased amounts of nitrogen, phosphorus, and potassium is notable, as these elements are crucial for achieving higher yields and maintaining quality (Kadam et al., 2018).Optimum use of fertilizers leads to increased yields and enhanced beet quality (Biondo et al., 2014; El-Mageed et al., 2022; Varga et al., 2021). Nitrogen, phosphorus, and potassium (NPK) plays a vital role as essential element for plant growth, significantly affecting yield, as highlighted by Mandal et al. (2023). The insufficient application of NPK results in reduced beetroot yields and diminished sucrose production, whereas excessive application causes an uneven distribution of assimilates, lower sucrose levels, and heightened concentrations of contaminants, leading to diminished sucrose recovery (Barłóg et al., 2014; Chatterjee et al., 2018; Hergert, 2010; Zarski & Renata Ku´smierek-Tomaszewska, 2020). Consequently, an efficient fertilization with NPK can enhance beetroot growth and yield attributes (Kadam et al., 2018b). Furthermore, a balanced supply of phosphorus and potassium enhances both the sugar and starch proportions in sugar beet, while secondary and micronutrients are crucial for improving crop quality (Idris et al., 2021).

To maximize revenue from sugar beet in the subtropical settings of Bangladesh, it is crucial to adjust agronomic practices to establish an ideal environment for the crop's growth and development. The effective production of sugar beet in subtropical locations requires the careful selection of varieties, optimizing inter and intra-row spacing and fertilization etc. that are highly suited to these particular conditions (Radivojević et al., 2008; Yasin, 2017). By optimizing plant and row spacing along with NPK doses, sugar beet producers can minimize costs related to inputs, labor, and materials. If cultivated effectively with the optimized spacing and NPK doses, sugar beet could be advantageous for us. Bangladesh has considerable potential for sugar beet cultivation, which could enhance sugar production to a satisfactory level, enabling farmers to embrace the possibilities of extensive agricultural expansion. A limited number of studies have been carried out to determine the optimal doses of NPK, as these elements significantly affect the yield and quality of sugar beet. In a similar vein, limited information exists regarding the ideal spacing of sugar beet to enhance yield. In the context of Bangladesh, this figure is more concerning. Therefore, this study seeks to improve both the productivity and the quality of tropical sugar beet by optimizing spacing and fertilization.

2. Materials and Methods

2.1. Site description of the experimental field

The experiment was conducted in the research field of the Agronomy and Farming Systems Division of Bangladesh Sugarcrop Research Institute (24.1156◦ N, 89.0817◦ E, 15.5 m altitude), Ishurdi 6620, Pabna, Bangladesh; during 2019-2020. This location belongs to the High Ganges River Floodplain (AEZ-11) characterized by sandy loam in texture (sand 67%, silt 22%, and clay 11%) with a high pH (7.55), low organic matter (0.9%), and 0.06% total nitrogen content. The physio-chemical properties of the experimental soil have been presented in Table 1. The climate of the experimental site is a subtropical monsoon. It is characterized by heavy rainfall in the monsoon (June to September) and scanty at other times. The climatic conditions such as air temperature, rainfall, and humidity during the study period have been shown in Figure 1.

Table 1. Physio-chemical properties of the experimental soil

Soil Properties	Analytical Values
Texture class	Sandy loam
Sand (%)	67
Silt (%	22
Clay (%)	11
pH	7.55
Organic matter (%)	0.9
Total nitrogen (%)	0.06
Calcium (meq 100 g^{-1})	10.60
Magnesium (meq 100 g^{-1})	0.78
Potassium (meq 100 g^{-1})	0.15
Phosphorus (μg g^{-1})	14.00
Sulphur (μg g^{-1})	18.00
Boron (μg g^{-1})	0.20
Iron (μg g^{-1})	3.60
Zinc (μg g^{-1})	0.60

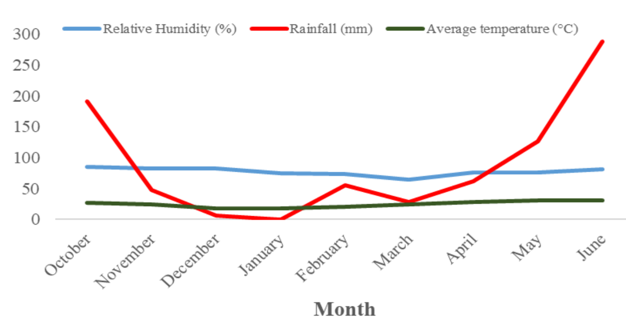

Figure 1. Month-wise air temperature, humidity, and rainfall of Ishurdi during the study period

2.2. Seed material

Sugar beet seeds of the variety "Cauvery" was used as plant material in this experiment. This variety was collected from an international seed company named "Syngenta Bangladesh Limited". This is a monogerm hybrid seed cultivated in tropical and sub-tropical regions as a tropical variety. It is an excellent rotational crop that enhances the yield of the next crop. The variety fully matures at 5-6 months with the requirement of moderate water. Cauvery is characterized by high sucrose content of 14-20% with the yield ranges from 80-100 t ha^{-1}.

2.3. Experimental design and treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) with a factorial combination of two level of spacing [S_1: 50cm ×20cm and S_2: 60cm × 20cm] and eight fertilizer level [F_1: Urea, TSP and MoP @ 195, 75 and 169 $kgha^{-1}$ (2 splits of Urea and MoP), F_2: Urea, TSP and MoP @ 195, 75 and 169 kg ha^{-1} (3 splits of Urea and MoP), F_3: Urea, TSP, MoP and Cowdung @ 260, 100, 225 $kgha^{-1}$ and 10 tha^{-1} (2 splits), F_4: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 10 t ha^{-1} (3 splits), F_5: Urea, TSP, MoP and Cowdung @ 260, 100, 225 $kgha^{-1}$ and 5 tha^{-1} (2 splits), F_6: Urea, TSP, MoP and Cowdung @ 260, 100, 225 $kgha^{-1}$ and 5 tha^{-1} (3 splits), F_7: Urea, TSP, MoP and Cowdung @ 195, 75, 169 $kgha^{-1}$ and 10 tha^{-1} (2 splits), and F_8: Urea, TSP, MoP and Cowdung @ 195, 75, 169 $kgha^{-1}$ and 10 tha^{-1} (3 splits)] with three replications, during 2019–2020 cropping season at Ishurdi. The size of each plot was 4.0 m × 4.0 m i.e. 16 m^2. The whole experimental field was at first divided into three blocks where each of the block was considered as replication. Each replication was again divided into 16 uniform plots where the treatment combinations was applied. The adjacent blocks were separated from one another by keeping 2m space and the adjacent plots by 1m, respectively.

2.4. Land preparation

The land was prepared thoroughly by disc ploughing and harrowing followed by leveling. The land was made ready for laying out the experiment on 02 November, 2019.

2.5. Fertilizer application

The land was uniformly fertilized with the treatment wise doses with 100 kg Gypsum, 10 kg Zinc Sulphate and 7 kg Boric Acid ha^{-1} as per BSRI suggestions. Whole amount of cowdung, TSP, gypsum, zinc sulphate and boric acid were applied at the time of final land preparation. In case of 2 splits, urea and MoP fertilizers respectively were applied as a top dressing in two equal doses, one half after thinning (35 DAS) and the other before the third watering (70 DAS). In case of 3 splits, urea and MoP fertilizer were applied three times as one basal and two equal doses in top dressing at 35 DAS and the other at 70 DAS.

2.6. Seed sowing and intercultural operations

Seeds were sown in 05 November, 2019 with two spacing mentioned above. Fungicide (Vitavax-200) treated seeds were sown followed by line sowing method. Sugar beet balls were hand sown @ 2 balls $hill^{-1}$ using dry sowing method at about 2 cm depth. The seeds were covered by soil just after sowing. Intercultural operations like weeding, gap filling, thinning, earthing-up, irrigation, disease and insect control were done uniformly in each plot to ensure normal growth of the crop. Three hand weeding was done at 30 DAS, 50 DAS and 70 DAS for the study. Plants were thinned at the age of 35 days after sowing to obtain one plant $hill^{-1}$. Necessary gap filling was done after 3 weeks of sowing with seedlings of similar age. Earthing-up was done to cover the root base and to facilitate drainage operation during each time of weeding. Three irrigations applied at 45, 90 and 125 DAS. Plants were infected by *Sclerotium* root rot disease at seedling and later stages of growth which was controlled by spraying fungicide named "Dithane M 45" @ 2.2 kg ha^{-1} at seedling stage and at later stage by applying Tilt @ 1 mlL^{-1} of water followed by raking of soil. Applying Score 250 EC 0.5 mlL^{-1} of water at 15 days interval was applied to control *Cercospora* leaf spot at vegetative stage of sugar beet. At early stages of growth seedlings were infested by the caterpillar of cutworm (*Agrotis ipsilon*), which was controlled by foliar spraying of a systemic insecticide named "Dursban 20EC" @ 2.5 mlL^{-1} of water for 3 times at 15 days interval.

2.7. Data collection and sampling procedure

2.7.1. Number of leaves per plant

After removing dead and dried leaves, the total numbers of fully developed green leaves were counted from five plants at each sampling and were averaged.

2.7.2. Germination percentage

At the completion of germination after 15 days of sowing, the number of seedlings emerged in each plot were counted and then converted into percentage by using the following formula:

$$\text{Germination (\%)} = \frac{\text{Number of normal seedlings}}{\text{Total number of seeds sown}} \times 100.$$

2.7.3. Root length

The root length of five randomly selected plants from each plot was measured. Measurement was done using the unit centimeter (cm).

2.7.4. Shoot length

The shoot length of each five randomly selected plants from each plot was recorded and expressed in centimeter (cm). It was measured from the base of the root to the tip of leaf at each plant.

2.7.5. Root fresh weight

The root fresh weight of five randomly selected plants from each plot was measured. Measured weight was converted to g $plant^{-1}$.

2.7.6. Shoot fresh weight

The shoot fresh weight of five randomly selected plants from each plot was measured. Measured weight was converted to g plant^{-1}.

2.7.7. Root dry weight

To determine root dry weight, all root fractions were air-dried, and then oven dried at 70^{0}C till constant weight obtained which was converted to g plant^{-1}.

2.7.8. Shoot dry weight

To determine shoot dry weight, all shoot fractions were air-dried, and then oven dried at 70^{0}C till constant weight obtained which was converted to gplant-1.

2.7.9. Beet length

The beet length of ten randomly selected plants at maturity from each plot was measured. Measurement was done using the unit centimeter (cm).

2.7.10. Beet girth

The beet girth of ten randomly selected plants at maturity from each plot was recorded. Unit was expressed in centimeter (cm).

2.7.11. Root yield

Sugar beet plants from each plot were harvested for roots and weighed in kilograms, then converted beet yield as tha^{-1} on fresh weight basis.

2.7.12. Top yield

Sugar beet plants from each plot were harvested for top portions and weighed in kilograms, then converted beet yield as tha^{-1} on fresh weight basis.

2.7.13. Root/Top ratio

It was obtained by the following formula:

$$\text{Root/Top ratio} = \frac{\text{Yield of sugar beet root}}{\text{Yield of sugar beet top}}$$

2.7.14. Harvest Index

It was obtained by the following formula:

$$\text{Harvest index (\%)} = \frac{\text{Root yield}}{(\text{Root yield} + \text{Top yield})} \times 100$$

2.7.15. Sugar yield

It was calculated using the following equation:

$$\text{Sugar yield (t/ha)} = \frac{\text{Root yield} \times \text{Sucrose\%}}{100}$$

2.7.16. Total soluble solids (TSS%)

It was measured in juice of fresh roots by using Hand Refractometer or Brix meter.

2.7.17. Sucrose percentage (%)

It was determined in fresh samples of sugar beet roots, polarimetrically by using Automatic Polarimeter (Model: ATAGO AP-300) at Physiology and Sugar Chemistry Division of BSRI, Ishurdi.

2.7.18. Apparent purity percentage (%)

It was calculated using the following equation:

$$\text{Apparent purity (\%)} = \frac{\text{Polarization}}{\text{Brix\%}} \times 100$$

2.8. Statistical analysis

Data obtained were subjected to a two-way analysis of variance (ANOVA) using the software program Statistix10 (Analytical Software, Tallahassee, FL, USA). Means of significant treatment effects were separated by conducting post hoc analysis using Tukey's honest significant difference test. In all analyses, differences were considered significant at $P \leq 0.05$.

3. Results and Discussion

3.1. Effect on number of leaves per plant

The interaction between spacing and fertilization had significant effect on number of leaves plant^{-1} upto 90 days after sowing. After that a non-significant relationship was observed among all of the treatment combinations. The result indicates that the highest leaf (35.80) was obtained from 60×20 cm spacing with F_4 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP) followed by 50×20 cm spacing with F_4 (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP) and 60×20 cm spacing with F_8 (Urea, TSP, MoP and Cowdung @ 195, 75, 169 kg and 10 t ha^{-1}, respectively with 3 splits of Urea & MoP) values were 35.13 and 34.87, respectively. While the lowest leaf (30.00) came from 50×20 cm spacing with F_1 (Urea, TSP and MoP @ 260, 100 and 225 kgha^{-1}, respectively with 2 splits of Urea & MoP) which was similar to 50×20 cm spacing with F_2 (Urea, TSP and MoP @ 260, 100 and 225 kgha^{-1}, respectively with 3 splits of Urea & MoP) treatment (30.93) at 120 DAS. The trend of leaves plant^{-1} gradually increased up to 90 DAS and then started to decline after 120 DAS. Declining of leaves plant^{-1} after 120 DAS might be due to senescence of leaves or drying of older leaves onward. Hoffmann (2010) reported the leaf number of sugar beet exhibited a significant increase up to 15 weeks after sowing, aligning with our findings.

3.2. Effect on germination

Proper germination is a pre-requisite for better plant growth and development at later stages and the percentage of germination is genetically determined, although environmental conditions affect the pace of germination and the vigor of seedlings (Roy et al., 2024; Sadeghian & Khodaii, 1998). The interaction between spacing and fertilization had no significant effect on germination percentage (%) (Table 2). However, the results indicate that the highest germination (91.79%) was obtained from 60×20 cm spacing with F_4 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP) while the lowest germination (89.08%) came from 50×20 cm spacing with F_1 treatment (Urea, TSP and MoP @ 260, 100 and 225 kgha^{-1}, respectively with 2 splits of Urea & MoP). This corresponds with Varga et al. (2021) who indicated no substantial effect of fertilizer dose on sugar beet emergence.

3.3. Effect on shoot length

The interaction between spacing and fertilization had significant effects on shoot length plant^{-1} over the growth period (Table 2). The result shows that the highest shoot length (45.17 cm) was obtained from 60×20 cm spacing with F_4 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 t ha^{-1}, respectively with 3 splits of Urea & MoP) followed by 50×20 cm spacing with F_4 (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 10 tha^{-1} respectively with 3 splits of Urea & MoP) treatment (44.97 cm). While the lowest (33.27 cm) length recorded from 50×20 cm spacing with F_1 (Urea, TSP and MoP @ 260, 100 and 225 kg ha^{-1}, respectively with 2 splits of Urea & MoP). Kiymaz & Ertek (2015) observed that the rise in fertilizer levels led to an enhancement in both root and shoot lengths. The findings align with the current results.

3.4. Effect on root length and girth

The interaction between spacing and fertilization had significant effects on root length and girth plant^{-1} over the growth period (Table 2). The results indicate that the highest root length (38.47 cm) was obtained from 50×20 cm spacing with F_4 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1} respectively with 3 splits of Urea & MoP) followed by 60×20 cm spacing with F_4 (Urea, TSP, MoP and Cowdung @ 195, 75, 169 kg and 10 t ha^{-1}, respectively with 3 splits of Urea & MoP) and the value was 38.17 cm. While the lowest length (28.09 cm) was attained from 50×20 cm spacing with F_1 (Urea, TSP and MoP @ 260, 100 and 225 kgha^{-1}, respectively with 2 splits of Urea & MoP) followed by 60×20 cm spacing with F_1 (Urea, TSP and MoP @ 260, 100 and 225 kg ha^{-1}, respectively with 2 splits of Urea & MoP) (28.08 cm). In case of root girth, there was a significant influence of interaction between spacing and fertilizer at harvest (Table 2). Increasing fertilizer levels with splits application and spacing tended to increase beet girth. The highest values of this trait (44.33 cm) obtained from 60×20 cm spacing with F_4 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP) followed by in 50×20 cm spacing with F_4 treatment (43.90 cm). On the contrary, the lowest beet girth (25.50 cm) was obtained from 50×20 cm spacing with F_1 (Urea, TSP and MoP @ 260, 100 and 225 kg ha^{-1}, respectively with 2 splits of Urea & MoP) followed by 60×20 cm spacing with F_1 treatment (28.90 cm). Generally, root length and girth were gradually increased by increasing fertilizer level. Besides, wider spacing resulted in better beet length and girth. Paul et al. (2018) also reported similar findings in their study which corroborates with our findings.

3.5. Effect on shoot and root fresh weight

The interaction between spacing and fertilizer levels showed no significant effect on shoot fresh weight plant^{-1} (Figure 3a). The highest shoot fresh weight (103.17 g) was obtained from 60×20 cm spacing with F_4 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP) followed by 50×20 cm spacing with F_4 (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 t ha^{-1}, respectively with 3 splits of Urea & MoP) treatment (101.83 g). While the lowest weight (70.20g) was obtained from 50×20 cm spacing with F_1 (Urea, TSP and MoP @ 260, 100 and 225 kg ha^{-1}, respectively with 2 splits of Urea & MoP) followed by same fertilizer dose with 60×20 cm spacing (77.00 g).

The interaction between spacing and fertilizer levels showed significant effect on root fresh weight plant^{-1} (Figure 3b). The highest root fresh weight (909.33 g) was obtained from 60×20 cm spacing with F_4 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP) followed by 50×20 cm spacing with F_4 (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 t ha^{-1}, respectively with 3 splits of Urea & MoP) treatment (905.83 g). While the lowest root fresh weight (703.80 g) was obtained from 50×20 cm spacing with F_1 (Urea, TSP and MoP @ 260, 100 and 225 kgha^{-1}, respectively with 2 splits of Urea & MoP) followed by same fertilizer dose with 60×20 cm spacing (707.33 g) and 50×20 cm spacing with F_2 (Urea, TSP and MoP @ 195, 75 and 169 kgha^{-1} (3 splits of Urea and MoP) treatment (725.00 g). Wider spacing increases the individual root and shoot fresh weights due to lesser plant population which ensures better uptake of resources such as fertilizer and solar radiation. The increase in root and shoot fresh weight resulting from higher fertilizer application may be attributed to nitrogen's role in enhancing root growth through cell division or elongation, as well as potassium's function in activating enzymes associated with carbohydrate accumulation. Chatterjee et al. (2018) found that fresh weight of root and shoot generally increased with increasing fertilizer which aligns with our findings.

3.6. Effect on shoot and root dry weight

The interaction between spacing and fertilizer levels showed significant effect on shoot dry weight plant^{-1} (Figure 4a). The highest shoot dry weight (9.47 g) was obtained from 60×20 cm spacing with F_4 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP) followed by 50×20 cm spacing with F_4 (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP) treatment (8.70 g) and 60×20 cm spacing

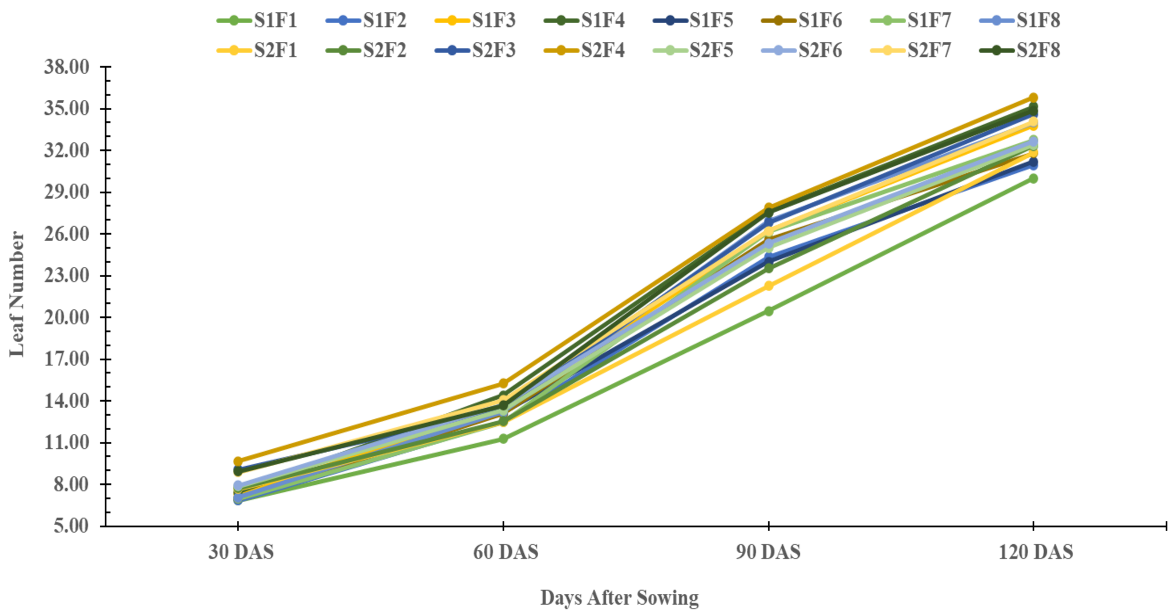

Figure 2. Number of leaves plant^{-1} as affected by spacing and fertilizer over the growth period of 120 DAS. Data are means of three replications. S_1: 50cm × 20cm, S_2: 60cm × 20cm, F_1: Urea, TSP and MoP @ 195, 75 and 169 kg ha^{-1} (2 splits of Urea and MoP), F_2: Urea, TSP and MoP @ 195, 75 and 169 kg ha^{-1} (3 splits of Urea and MoP), F_3: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 10 tha^{-1} (2 splits), F_4: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 10 t ha^{-1} (3 splits), F_5: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 5 tha^{-1} (2 splits), F_6: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 5 t ha^{-1} (3 splits), F_7: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kg ha^{-1} and 10 t ha^{-1} (2 splits), and F_8: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kgha^{-1} and 10 t ha^{-1} (3 splits).

Table 2. Effects of spacing and fertilization on the germination, shoot length, root length and root girth of tropical sugar beet

Treatment	Germination (%)	Shoot Length (cm)	Root Length (cm)	Root Girth (cm)
$S_1 \times F_1$	89.08 ± 0.31	33.27 ± 0.14 i	28.09 ± 0.22 h	25.50 ± 0.36 h
$S_1 \times F_2$	89.58 ± 0.32	35.80 ± 0.15 h	30.69 ± 0.44 g	30.83 ± 0.82 fg
$S_1 \times F_3$	90.50 ± 0.17	41.13 ± 0.17 cd	35.10 ± 0.15 bc	33.95 ± 0.86 ef
$S_1 \times F_4$	90.19 ± 0.35	44.97 ± 0.25 **a**	38.47 ± 0.10 **a**	43.90 ± 0.43 **ab**
$S_1 \times F_5$	90.00 ± 0.43	38.11 ± 0.14 fg	31.67 ± 0.12 e-g	35.32 ± 0.55 de
$S_1 \times F_6$	90.42 ± 0.25	39.88 ± 0.06 de	32.09 ± 0.39 d-g	35.27 ± 0.37 de
$S_1 \times F_7$	90.54 ± 0.06	40.83 ± 0.12 de	33.11 ± 0.26 c-f	36.11 ± 0.11 de
$S_1 \times F_8$	90.62 ± 0.15	42.60 ± 0.10 bc	34.27 ± 0.23 bc	40.43 ± 0.64 bc
$S_2 \times F_1$	90.21 ± 0.16	35.47 ± 0.23 h	28.08 ± 0.18 h	28.90 ± 0.32 gh
$S_2 \times F_2$	90.29 ± 0.10	36.97 ± 0.16 gh	31.15 ± 0.07 fg	33.50 ± 0.48 ef
$S_2 \times F_3$	91.71 ± 0.11	42.40 ± 0.26 bc	35.80 ± 0.24 b	35.35 ± 0.32 de
$S_2 \times F_4$	91.79 ± 0.16	45.17 ± 0.18 **a**	38.17 ± 0.22 **a**	44.33 ± 0.78 **a**
$S_2 \times F_5$	90.71 ± 0.09	39.34 ± 0.15 ef	33.43 ± 0.26 c-e	35.51 ± 0.19 de
$S_2 \times F_6$	90.79 ± 0.13	40.48 ± 0.19 de	33.88 ± 0.25 b-d	36.93 ± 0.08 c-e
$S_2 \times F_7$	91.37 ± 0.04	41.17 ± 0.08 cd	34.57 ± 0.11 bc	37.08 ± 0.04 c-e
$S_2 \times F_8$	91.41 ± 0.13	42.95 ± 0.22 b	33.53 ± 0.10 c-e	38.36 ± 0.22 cd
Sig. level	ns	*	**	*
$HSD_{0.05}$	1.76	1.53	2.09	3.69

Data are means of three replications ± standard error. **, *, and ns indicate $P < 0.01$, $P < 0.05$, and not significant, respectively. Means within a column followed by different letters are significantly different based on Tukey's honest significant difference test at $P \leq 0.05$. S_1: 50cm × 20cm and S_2: 60cm × 20cm; F_1: Urea, TSP and MoP @ 195, 75 and 169 kgha^{-1} (2 splits of Urea and MoP), F_2: Urea, TSP and MoP @ 195, 75 and 169 kg ha^{-1} (3 splits of Urea and MoP), F_3: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 10 tha^{-1} (2 splits), F_4: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 10 tha^{-1} (3 splits), F_5: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 5 t ha^{-1} (2 splits), F_6: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 5 tha^{-1} (3 splits), F_7: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kgha^{-1} and 10 tha^{-1} (2 splits), and F_8: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kg ha^{-1} and 10 t ha^{-1} (3 splits).

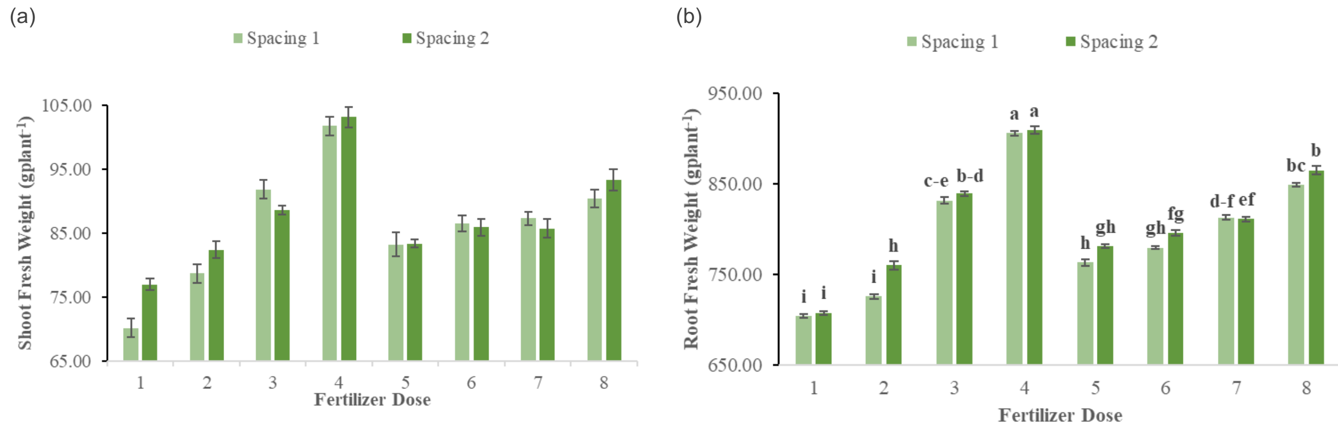

Figure 3. (a) Shoot fresh weight and b) Root fresh weight as affected by spacing and fertilizer. Vertical bars represent standard error values. Columns with different letters are significantly different based on Tukey's honest significant difference test at $P \leq 0.05$. S_1: 50cm × 20cm and S_2: 60cm × 20cm; F_1: Urea, TSP and MoP @ 195, 75 and 169 kgha^{-1} (2 splits of Urea and MoP), F_2: Urea, TSP and MoP @ 195, 75 and 169 kgha^{-1} (3 splits of Urea and MoP), F_3: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 10 t ha^{-1} (2 splits), F_4: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 10 tha^{-1} (3 splits), F_5: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 5 tha^{-1} (2 splits), F_6: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 5 tha^{-1} (3 splits), F_7: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kg ha^{-1} and 10 tha^{-1} (2 splits), and F_8: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kgha^{-1} and 10 tha^{-1} (3 splits).

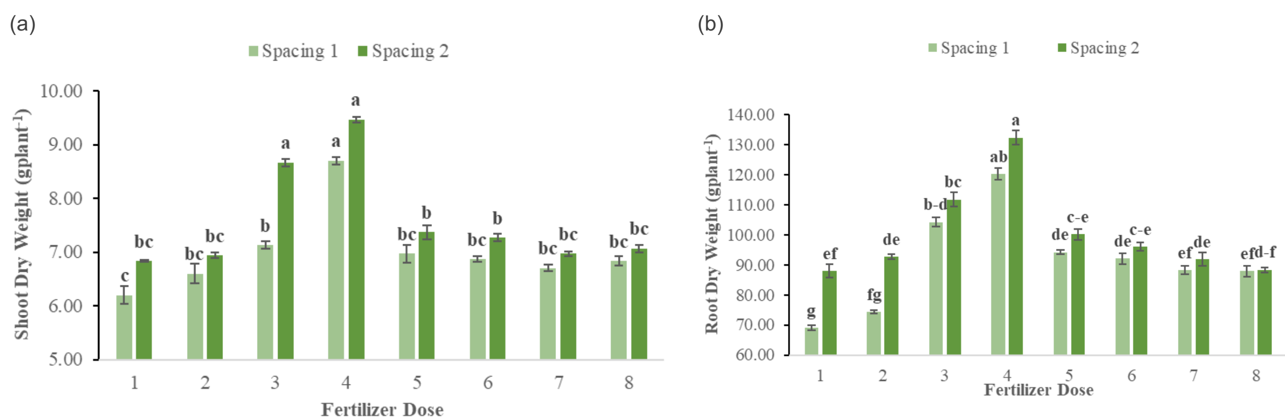

Figure 4. (a) Shoot dry weight and b) Root dry weight as affected by spacing and fertilizer. Columns with different letters are significantly different based on Tukey's honest significant difference test at $P \leq 0.05$. S_1: 50cm × 20cm and S_2: 60cm × 20cm; F_1: Urea, TSP and MoP @ 195, 75 and 169 kgha^{-1} (2 splits of Urea and MoP), F_2: Urea, TSP and MoP @ 195, 75 and 169 kgha^{-1} (3 splits of Urea and MoP), F_3: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 10 t ha^{-1} (2 splits), F_4: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 10 tha^{-1} (3 splits), F_5: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 5 tha^{-1} (2 splits), F_6: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 5 tha^{-1} (3 splits), F_7: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kg ha^{-1} and 10 tha^{-1} (2 splits), and F_8: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kgha^{-1} and 10 tha^{-1} (3 splits).

with F_3 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 10 tha^{-1} (2 splits) (8.67 g). While the lowest weight (6.20 g) was obtained from 50×20 cm spacing with F_1 (Urea, TSP and MoP @ 260, 100 and 225 kgha^{-1}, respectively with 2 splits of Urea & MoP).

The interaction between spacing and fertilizer levels showed significant effect on root dry weight plant^{-1} (Figure 4b). The highest root dry weight (132.33 g) was obtained from 60×20 cm spacing with F_4 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP) followed by 50×20 cm spacing with F_4 (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP) treatment (120.17 g). While the lowest weight (69.00 g) was obtained from 50×20 cm spacing with F_1 (Urea, TSP and MoP @ 260, 100 and 225 kgha^{-1}, respectively with 2 splits of Urea & MoP). Kadam et al. (2018) determined that the dry matter content of fodder beet rose proportionately with the extent of fertilization. This result corroborates with our present results.

3.7. Effect on root and top yield

The interaction between spacing and fertilizer level was significant on root yield at harvest (Table 3). The highest root yield (88.97 t ha^{-1}) was received from 50×20 cm spacing with F_4 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 t ha^{-1}, respectively with 3 splits of Urea & MoP) followed by 60×20 cm spacing with F_4 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP) (86.87 t ha^{-1}). On the contrary, the lowest one (71.24 t ha^{-1}) accompanied from 60×20 cm spacing with F_7 (Urea, TSP, MoP and Cowdung @ 195, 75, 169 kg ha^{-1} and 10 tha^{-1} (2 splits) treatment followed by 50 cm × 20 cm spacing with F_1 treatment (71.69 t ha^{-1}) and 72.44 t ha^{-1} from 60×20 cm spacing with F_6 treatment.

The interaction between spacing and fertilizer level was significant on top yield at harvest (Table 3). The highest top yield (9.24 tha^{-1}) was received from 60 sm ×20 cm spacing with F_4 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP) followed by 50 cm × 20 cm spacing with F_4 treatment (Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 t ha^{-1}, respectively with 3 splits of Urea & MoP) (9.04 t ha^{-1}). On the contrary, the lowest one (6.63 t ha^{-1}) accompanied from 50 cm × 20 cm spacing with F_1 treatment. Sintayehu et al. (2022) discovered that augmenting the distance between hills from 15 to 20 cm markedly enhanced the size and weight of individual beets, as well as the top yield and beetroot yield per acre, which aligns with our findings.

3.8. Effect on Root/Top Ratio and Harvest Index (%)

The interaction between spacing and fertilizer level was non-significant on both root/top ratio and harvest index at harvest (Table 3). But, numerically the highest root/top ratio (10.89) was received from 50×20 cm spacing with F_1 treatment. On the contrary, the lowest one (9.22) accompanied from 50×20 cm spacing with F_6 treatment. The highest harvest index (91.54%) was also found from 50×20 cm spacing with F_1 treatment. On the contrary, the lowest one (90.21%) was found from 50×20 cm spacing with F_6 treatment.

3.9. Effect on total soluble solid (TSS%) and sucrose percentage

The interaction between spacing and fertilizer level showed significant effect on TSS % at harvest (Table 4). Increasing fertilizer levels and spacing tended to decrease TSS %. The highest values of this trait 18.20% was obtained from 60×20 cm spacing with F_4 treatment followed by 50×20 cm spacing with F_4 treatment (18.12%). A statistically similar to this finding also observed in $S_2 \times F_2$ (17.99%), $S_1 \times F_3$ (17.87%), $S_2 \times F_1$ (17.86%), $S_1 \times F_2$ (17.83%) and $S_1 \times F_8$ (17.77%). On the contrary, the lowest TSS % (16.61) was obtained from $S_2 \times F_5$ treatment combination.

The interaction between spacing and fertilizer level showed significant effect on sucrose % at harvest also (Table 4). The highest values of this trait 12.70% was obtained from 50×20 cm spacing with F_4 treatment followed by 60×20 cm spacing with F_4 treatment (12.50%). A statistically similar to this finding also observed in $S_1 \times F_3$ (12.47%), $S_2 \times F_1$ (17.86%) and $S_1 \times F_6$ (12.40%) On the contrary, the lowest sucrose% (10.53) was obtained from $S_2 \times F_7$ treatment combination. The enhanced sugar production per unit area resulting from fertilizer application can be attributed to the essential roles of nitrogen and potassium in augmenting growth characteristics and sucrose percentage, hence elevating sugar yield per unit area. Our findings is at par with the findings of Hergert (2010).

3.10. Effect on sugar yield (t ha^{-1}) and apparent purity percentage

The interaction between spacing and fertilizer level showed significant effect on sugar yield (Table 4). The highest values of this trait 10.35 tha^{-1} was obtained from 50 cm × 20 cm spacing with F_4 treatment. The lowest sugar yield of 7.50 tha^{-1} was obtained from $S_2 \times F_7$ treatment combination followed by $S_2 \times F_6$ (7.62 t ha^{-1}) treatment combination.

With regard to the interaction between spacing and fertilizer level on apparent purity %, it was non-significant (Table 4). The highest apparent purity% (66.71) resulted from 50×20 cm spacing with F_4 fertilizer application while the lowest (63.68%) was obtained from $S_2 \times F_3$ treatment combination. The increased sugar yield per unit area due to application of fertilizers can be explained through the fact that nitrogen and potassium has a vital role in improving all growth attributes, consequently increasing sugar yield per unit area. Our findings are consistent with those of Hergert (2010).

Table 3. Effects of spacing and fertilization on yield and yield contributing parameters of tropical sugar beet

Treatments	Root Yield (t ha^{-1})	Top Yield (t ha^{-1})	Root/Top Ratio	Harvest Index (%)
$S_1 \times F_1$	71.69 ± 0.41 **h**	6.63 ± 0.21 **g**	10.89 ± 0.38	91.54 ± 0.003
$S_1 \times F_2$	73.77 ± 0.36 gh	7.55 ± 0.09 d-g	9.77 ± 0.07	90.71± 0.001
$S_1 \times F_3$	83.51 ± 0.55 bc	8.87 ± 0.06 a-c	9.42 ± 0.12	90.40 ± 0.001
$S_1 \times F_4$	88.97 ± 0.67 **a**	9.04 ± 0.08 **a**	9.84 ± 0.06	90.78 ± 0.000
$S_1 \times F_5$	80.00 ± 0.67 c-e	8.59 ± 0.12 a-e	9.32 ± 0.11	90.30 ± 0.001
$S_1 \times F_6$	78.20 ± 0.18 d-g	8.49 ± 0.13 a-e	9.22 ± 0.12	90.21 ± 0.001
$S_1 \times F_7$	79.19 ± 0.40 c-f	8.40 ± 0.09 a-e	9.43 ± 0.09	90.41 ± 0.001
$S_1 \times F_8$	82.20 ± 0.35 b-d	8.71 ± 0.07 a-d	9.44 ± 0.06	90.42 ± 0.001
$S_2 \times F_1$	73.43 ± 0.77 gh	6.81 ± 0.11 fg	10.80 ± 0.20	91.51 ± 0.001
$S_2 \times F_2$	74.90 ± 0.34 f-h	7.68 ± 0.13 c-g	9.78 ± 0.19	90.70 ± 0.002
$S_2 \times F_3$	75.47 ± 0.51 e-h	8.00 ± 0.10 b-f	9.43 ± 0.08	90.41 ± 0.001
$S_2 \times F_4$	86.87 ± 0.60 **ab**	9.24 ± 0.23 **a**	9.44 ± 0.30	90.38 ± 0.003
$S_2 \times F_5$	79.17 ± 0.82 c-f	8.01 ± 0.24 b-f	9.93 ± 0.31	90.81 ± 0.003
$S_2 \times F_6$	72.44 ± 0.63 **h**	7.51 ± 0.03 d-g	9.64 ± 0.09	90.60 ± 0.001
$S_2 \times F_7$	71.24 ± 0.30 **h**	7.44 ± 0.14 e-g	9.60 ± 0.21	90.54 ± 0.002
$S_2 \times F_8$	75.69 ± 0.38 e-h	7.89 ± 0.07 b-f	9.60 ± 0.13	90.56 ± 0.001
Sig. level	**	*	ns	ns
HSD $_{0.05}$	4.94	1.22	1.67	1.4

Data are means of three replications ± standard error. **, *, and ns indicate $P < 0.01$, $P < 0.05$, and not significant, respectively. Means within a column followed by different letters are significantly different based on Tukey's honest significant difference test at $P \leq 0.05$. S_1: 50cm × 20cm and S_2: 60cm × 20cm; F_1: Urea, TSP and MoP @ 195, 75 and 169 kgha^{-1} (2 splits of Urea and MoP), F_2: Urea, TSP and MoP @ 195, 75 and 169 kgha^{-1} (3 splits of Urea and MoP), F_3: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 10 tha^{-1} (2 splits), F_4: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 10 t ha^{-1} (3 splits), F_5: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 5 t ha^{-1} (2 splits), F_6: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 5 tha^{-1} (3 splits), F_7: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kgha^{-1} and 10 tha^{-1} (2 splits), and F_8: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kgha^{-1} and 10 tha^{-1} (3 splits).

Table 4. Effects of spacing and fertilization on quality parameters of tropical sugar beet

Treatments	TSS (%)	Sucrose (%)	Sugar Yield (tha^{-1})	Apparent Purity (%)
$S_1 \times F_1$	17.43 ± 0.05 a-d	12.23 ± 0.02 ab	8.50 ± 0.03 cd	65.91 ± 0.03
$S_1 \times F_2$	17.83 ± 0.10 **a**	12.37 ± 0.02 ab	9.12 ± 0.05 bc	65.97 ± 0.15
$S_1 \times F_3$	17.87 ± 0.02 **a**	12.47 ± 0.19 **a**	9.30 ± 0.05 b	65.51 ± 0.78
$S_1 \times F_4$	18.12 ± 0.13 **a**	12.70 ± 0.03 **a**	10.35 ± 0.06 **a**	66.71 ± 0.31
$S_1 \times F_5$	17.42 ± 0.12 a-e	12.17 ± 0.25 ab	9.29 ± 0.24 bc	65.69 ± 0.15
$S_1 \times F_6$	17.70 ± 0.13 ab	12.40 ± 0.23 **a**	9.31 ± 0.03 b	65.75 ± 0.18
$S_1 \times F_7$	17.55 ± 0.06 a-c	11.67 ± 0.02 a-c	9.16 ± 0.01 bc	66.03 ± 0.13
$S_1 \times F_8$	17.77 ± 0.03 **a**	11.83 ± 0.02 a-c	9.69 ± 0.16 ab	66.18 ± 0.21
$S_2 \times F_1$	17.86 ± 0.07 **a**	12.10 ± 0.18 ab	7.78 ± 0.02 de	65.80 ± 0.14
$S_2 \times F_2$	17.99 ± 0.10 **a**	11.87 ± 0.02 a-c	7.95 ± 0.05 de	65.96 ± 0.26
$S_2 \times F_3$	17.53 ± 0.02 a-c	11.30 ± 0.15 b-d	8.03 ± 0.12 de	63.68 ± 0.43
$S_2 \times F_4$	18.20 ± 0.15 **a**	12.50 ± 0.03 **a**	9.50 ± 0.03 b	65.08 ± 0.08
$S_2 \times F_5$	16.61 ± 0.08 **e**	10.93 ± 0.14 cd	7.77 ± 0.05 de	64.40 ± 0.15
$S_2 \times F_6$	16.77 ± 0.03 c-e	10.87 ± 0.02 cd	7.62 ± 0.03 **e**	64.79 ± 0.01
$S_2 \times F_7$	16.63 ± 0.12 de	10.53 ± 0.02 **d**	7.50 ± 0.04 **e**	63.37 ± 0.41
$S_2 \times F_8$	16.92 ± 0.05 b-e	10.90 ± 0.00 cd	8.25 ± 0.04 de	64.42 ± 0.20
Sig. level	**	**	*	ns
HSD $_{0.05}$	0.82	1.06	0.79	2.56

Data are means of three replications ± standard error. **, *, and ns indicate $P < 0.01$, $P < 0.05$, and not significant, respectively. Means within a column followed by different letters are significantly different based on Tukey's honest significant difference test at $P \leq 0.05$. S_1: 50cm × 20cm and S_2: 60cm × 20cm; F_1: Urea, TSP and MoP @ 195, 75 and 169 kgha^{-1} (2 splits of Urea and MoP), F_2: Urea, TSP and MoP @ 195, 75 and 169 kgha^{-1} (3 splits of Urea and MoP), F_3: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 10 tha^{-1} (2 splits), F_4: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 10 tha^{-1} (3 splits), F_5: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 5 tha^{-1} (2 splits), F_6: Urea, TSP, MoP and Cowdung @ 260, 100, 225 kgha^{-1} and 5 tha^{-1} (3 splits), F_7: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kg ha^{-1} and 10 tha^{-1} (2 splits), and F_8: Urea, TSP, MoP and Cowdung @ 195, 75, 169 kgha^{-1} and 10 tha^{-1} (3 splits)

4. Conclusion

From the above results and discussion, it was found that highest germination, leaf number, shoot fresh and dry weight, root fresh and dry weight, root girth, root length, yield, TSS% and sucrose% was the highest in 50cm × 20cm spacing along with application of Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoP ($S_1 \times F_4$ combination) followed by 60cm × 20cm spacing along with application of Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg and 10 tha^{-1}, respectively with 3 splits of Urea & MoPtreatment combinations. Therefore, it may be concluded that 50cm×20cm or 60cm×20cm spacing along with fertilization of Urea, TSP, MoP and Cowdung @ 260, 100, 225 kg ha^{-1} and 10 t ha^{-1} in 3 splits appears as the most promising treatment combinations for cultivating tropical sugar beet successfully in Bangladesh.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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