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Foliar Application of Boron Boosts the Performance of Tropical Sugar Beet

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ABSTRACT

The experiment was conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh to find out the effect of foliar application of boron on the growth, yield and quality of tropical sugar beet. The treatments included foliar application of boron at four concentrations viz. 0, 50, 100 and 150 ppm, and three application times viz. once at 40 days after emergence (DAE), twice at 40 and 65 DAE and thrice at 40, 65 and 90 DAE. The experiment was laid out in a randomized complete block design with three replications. The SPAD values were increased with advancement of time and reached the maximum (55.99) at 90 DAS with 150 ppm boron applied thrice at 40, 65 and 90 DAE and thereafter declined. Crown rot infestation was suppressed properly when 100 ppm or 150 ppm boron was applied thrice at 40, 65 and 90 DAE. The highest beet length (28.92 cm) was obtained from150 ppm boron applied twice at 40 and 65 DAE while the highest beet girth (36.25 cm), beet yield (104 t ha^{-1}) and shoot yield (6.40 t ha^{-1}) were recorded when 150 ppm boron was foliar applied thrice at 40, 65 and 90 DAE whereas the lowest values were recorded in control treatment. The highest brix percentage (16.33%) was recorded with 100 ppm boron applied thrice at 40, 65 and 90 DAE which was at par with 150 ppm boron applied thrice at 40, 65 and 90 DAE, twice at 40, 65 DAE and once at 40 DAE while the highest purity (75.53 %) was recorded in 150 ppm boron applied thrice at 40, 65 and 90 DAE. Therefore, it can be concluded that foliar spray of 150 ppm boron thrice at 40, 65 and 90 DAE appears as the most effective for maximizing the yield and juice quality of sugar beet.

Introduction

Sugar beet (*Beta vulgaris* L.) belongs to chenopodiaceae family whose tap root contains a high concentration of sucrose. Sugar beet is second vital sugar crops which covers 30% of the world's sugar (Dom *et al.*, 2014). In addition to sugar production, sugar beet is also used for syrup, spirit and bio-fuel production as well as livestock feed. Sugar beet is generally considered as a temperate region crop but due to development of new tropical sugar beet (TSB) varieties it has become a potential cash crop for tropical and subtropical environment (Cosyn *et al.,* 2011). The main sugar beet producing countries are France, Russia, USA, Ukraine, Germany, Turkey, Poland, Italy, Britain, etc. In Bangladesh, sugar beet was introduced by Bangladesh Sugarcrop Research Institute (BSRI) in the year of 2002 which has already been proved as a promising sugarcrop in Bangladesh with some challenges.

Sugar is an essential commodity and an integral part of the 'food chain' and the cheapest source of energy. The Food and Agriculture Organization recommends per capita consumption of sugar 13 kg for physical and mental fitness (FAO, 1982). Therefore, Bangladesh requires about two million tons of sugar/*goor* per year. But currently it produces about 0.6 million tons (0.068 million tons of sugar and 0.532 million tons of *goor* (BBS, 2017). The main causes of lower sugar production of the industry include less supply of sugarcane in the factories and very poor sugar recovery (Paul *et al.,* 2018). The area of sugarcane cultivation in Bangladesh dropping gradually due to its long span and dietary demand of over increasing population to short duration cereals and vegetables. So, sugar mills remain inoperative for longer period of time due to insufficient delivery of sugarcane to longer the crushing period. Most farmers want to produce more than one crop in a year from a field and, therefore, are not interested in producing sugarcane. Sugar beet has got many benefits compared to

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sugarcane such as short duration, less water and fertilizer requirement, and high sucrose contents (Ahmad *et al.,* 2012). In this regards, sugar beet might be an excellent source of raw material to continue sugar production in mills by little modification of processing facilities in the existing sugar mills.

Boron plays an essential role in promoting cell wall formation, carbohydrate metabolism, and has been associated with sugar translocation. Boron deficiency has been understood as the second most vital micronutrients constraints in crop production after zinc. Sugar beet generally considered having relatively high requirements of boron as compared to other commodities (Tlili *et al.,* 2018). It is primarily associated with production and transport of sugars to actively growing and developing roots of sugar beet (Barker and Pilbeama, 2007). Application of boron on sugar beet significantly increased the yield components, root yield, recoverable sugar percent and sugar yield (Cooke and Scott, 1993; Mirvat and Mekki, 2005). Foliar application of boron @ 0.20 to 0.25 g L^{-1} increased beet yield and juice quality when applied twice at 80 and 110 days after planting (Abbas *et al.,* 2014). Boron deficiency in the root can decrease yield dramatically and the quality will deteriorate in storage. Al-Mohmmad and Al-Geddawi (2001) reported that boron consumption in sugar beet significantly reduced heart rot, increasing sugar yield due to increased glucose levels in roots and phloem sap. Boron application in soil @ 1.5 kg ha^{-1} increased beet yield, juice quality and suppression of crown rot incidence of tropical sugar beet (Islam *et al.,* 2015). Despite the important role of boron to increase yield and quality of sugar beet, there is still a lack of information on the effect of boron application on sugar beet yield and quality particularly under Bangladesh condition. Therefore, the present study was undertaken to assess the foliar application of boron on the performance tropical sugar beet.

Materials and Methods

Experimental site and experimentation

The research work was done at the Agronomy Field Laboratory (24° 75' N latitude and 90° 50' E longitude and at an altitude of 18 meter above the sea level), Bangladesh Agricultural University, Mymensingh, Bangladesh during November 2018 to May 2019. The experimental site belongs to the Sonatola series of the dark grey floodplain soil type under Old Brahmaputra Floodplain Agro-Ecological Zone (AEZ-9). The experimental plot is medium high land having silty loam texture with pH 6.9, electrical conductivity (EC) 0.4 ds/m, organic carbon 1.00%, N 0.09%, P 1.60 ppm, K 0.10% meq/100g soil, Ca 8.30 meq/100 g soil, Mg 3.29 meq/100 g soil, S 2.98 ppm, Zn 0.21 ppm and B 0.23 ppm. The experimental area is under the sub-tropical climate. The minimum and maximum temperature 12.16°C and 31.69 °C, relative humidity 67.76 % and 83% and total rainfall 0.00 mm and 66.80 mm, respectively were prevailing at the experimental site during experimentation. The experiment consisted of four foliar application of boron concentrations viz. 0 ppm (B_0) 50 ppm (B_1), 100 ppm (B_2), 150 ppm (B_3) and three times foliar application viz. once at 40 days after emergence (T_1), twice at 40 and 65 days after emergence (T_2) and thrice at 40, 65 and 90 days after emergence (T_3). The experiment was laid out in a factorial randomized complete block design with three replications. The size of the unit plot was 5.0 m^2 (2.5 m × 2.0 m). The distance between two adjacent plots was 50 cm and plant to plant distances was 20 cm. Tropical sugar beet variety 'KWS Allayana, was used as test crop for the study.

Crop husbandry

The experimental land was opened with a power tiller. Ploughing and cross ploughing were done with country plough followed by laddering. The land was fertilized with urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum and zinc sulphate at the rate of 260, 100, 225, 100 and 10 kg ha^{-1}, respectively. One third urea, total amount of triple super phosphate, muriate of potash, gypsum and zinc sulphate were applied at final land preparation and mixed well with soil. Two-third urea was applied in two equal splits at 40 and 70 days after sowing (DAS). Seeds were sown on 23 November 2018 (after soaking in water) in rows on the ridge with 50 cm × 20 cm spacing @ two seeds $hill^{-1}$ for protecting the germination failure. Some seeds were broadcast separately by the side of the experimental field for necessary gap filling operation. To encourage seed germination the first flood irrigation was applied in the field just after seed sowing and later the crop was irrigated four times at 45, 70, 95 and 120 DAS. The excess water was drained out properly to avoid root damage. Sugar beet is a poor competitor with weeds from emergence until the sugar beet leaves provide shade over the ground. Uncontrolled growth of weeds may reduce sugar beet yield up to 30-54% (BSRI 2010). So weeds were removed from the plot up to 60 DAS (days after sowing). Special precaution was taken during weeding in the early stage because the seedlings were less vigorous, soft, and thin. Four hand weeding were done with "*niri*" at 15, 30, 45 and 60 DAS. The optimum plant population was maintained by thinning at 35 DAS in each plot as two seeds were placed $hill^{-1}$. Earthing-up was done at 60 DAS to facilitate soil moisture to the root for its maximum growth. Some plots were infected by *Sclerotium* root rot disease. The fungicide Amister top 0.5 ml L^{-1} water + Provax 1g L^{-1} water was sprayed at 15 days intervals after 30 days by Knapsack sprayer. Sevin dust (500 g) was used with 5 kg wheat bran and *citagoor* 1 kg for cutworm, Zinc phosphide was also used for rat. Pheromone trap (commercial name: Spodo-Lure, generic name: (Z, E)-9, 11Tetradecadien-1-yl acetate 97.52% w/w) was used to control the lepidopteran insect (leaf eater).

Data collection

Measurement of leaf chlorophyll content

Greenness or chlorophyll content of leaves were measured by SPAD meter (Model SPAD-502, Minolta crop, Ramsey, NJ) at 25-day intervals, beginning from 40 DAS up to 140 DAS.

Five new fully expanded leaves that adjacent to a similar leaf about to emerge were selected for recording SPAD values. The mean data was taken from middle point of the five leaves planit^{-1} in between 9:00 and 10.00 am.

Harvesting and juice quality measurement

After harvesting, plants were washed and cleaned by removing dead and dried leaves and soil adhering to beets. The harvested 10 plants plot^{-1} were bundled separately and tagged properly for recording data on different plant parameters. Beet yield was recorded from the whole plot harvest.

Brix (%) in beet juice

Percent brix were measured by hand refractometer (ATAGO, MASTER-53α, Japan) at harvest. Five beets of each plot were collected. A sharp knife was used to remove the outer skin of sugar beet root and sliced into small pieces as well as to extract a drop of juice by using mortar and pestle. Then the juice was transferred into the prism of the refractometer and also closed the day light plate to get the accurate measurement of brix (%) observed by eyepiece and then averaged to get mean data per plot.

Pol /Sucrose concentration

It was determined in fresh samples of sugar beet roots, polarimeterically by using Automatic Polarimeter (Model: ATAGO AP-300, Japan) standardized at 20°C by Horne's dry lead method at Physiology and Sugar Chemistry Division of BSRI (Bangladesh Sugarcrop Research Institute), Ishurdi, Pabna.

Purity percentage

It was determined as a ratio between sucrose % and total soluble solids % (TSS) of roots.

Purity (%): = (Pol/Brix) x 100

Crown rot incidence

Crown rot infected plants were measured against the total number of plant in each plot at 140 days after sowing.

Statistical analysis

All the collected data were analyzed for analysis of variance (ANOVA) using the computer package MSTAT (Power, 1985). The mean differences among the treatments were adjudged by Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984).

Results and Discussion

SPAD value

Chlorophyll is the most important photosynthetic pigment and base material for photosynthesis. The content of chlorophyll is one of main index reflecting leaf photosynthesis capacity and plant health condition. Traditional ways to measure chlorophyll content usually need to extract leaf tissue with various organic solvents. The chlorophyll meter (SPAD-502) readings have been positively correlated with destructive chlorophyll measurements in many crop species (Zhu *et al.*, 2012). Table 1 indicates that the SPAD value was significantly influenced by the interaction between boron concentration and frequency of foliar application at all dates of sampling. The SPAD value showed an increasing trend and reached the maximum at 90 DAS and thereafter declined irrespective of treatment differences. Similar trend of SPAD value of various crop was reported elsewhere (Tajul *et al.,* 2013; Islam et al. 2014; Paul et al. 2018). The SPAD reading ranged from 30.60 to 42.62 (unitless) at 40 DAS and 40.99 to 48.25 at 65 DAS. The highest SPAD values (55.99, 48.24 and 43.37 at 90, 115 and 140 DAS, respectively) were recorded in plants grown in $B_3 \times T_3$ (150 ppm boron × foliar application thrice at 40, 60 and 90 DAE) while the corresponding lowest values were recorded in $B_0 \times T_1$ (0 ppm × foliar application once at 40 DAE). This result was associated with the findings by Abido (2012) who noted that foliar application of boron in sugar beet significantly increased leaf chlorophyll content (SPAD value) over control. Foliar application of B at various growth stages along with recommended dose of NPK as basal might be responsible for higher chlorophyll content in leaves compared to control. Similar observation was noted by Wasaya *et al.* (2017) who reported that foliar application of micronutrient increased SPAD chlorophyll value in maize with minimum SPAD chlorophyll grown in control treatment.

Crop characters, yield components, yield and quality

Shoot length was significantly influenced by the interaction between boron concentration and time of application at harvest (Table 2). The longest shoot (42.08

cm) was obtained from the plants grown in $B_3 \times T_3$ (150 ppm boron × foliar application thrice at 40, 65 and 90 DAE) which was at par with $B_3 \times T_2$ (150 ppm boron × foliar application twice at 40 and 65 DAE) and the shortest one (25.33 cm) was obtained from the plants grown in $B_0 \times T_1$ (0 ppm boron × foliar application once at 40 DAE) (Table 2).

The interaction of boron concentration and application frequency for beet length was significant (Table 2). The beet length ranged from 21.92 cm to 28.92 cm. The highest beet length (28.92 cm) was observed when in plants grown in $B_3 \times T_2$ (150 ppm boron × foliar application twice at 40 and 65 DAE) which was at par with $B_1 \times T_1$, $B_2 \times T_2$, $B_2 \times T_3$ and $B_3 \times T_3$ while shortest beet (21.92 cm) was found in plants grown in $B_0 \times T_2$ (0 ppm boron × foliar application once at 40 DAE). Similar result was reported by El-Geddawy and Makhlouf (2015) who found that there was a significant positive increase in root diameter and beet length of sugar beet due to the gradual increase in the spraying concentration of boron from 105 to 210 ppm.

The interaction between boron concentration and application frequency on beet girth showed a significant variation. The beet girth ranged from 25.33 cm to 36.25 cm (Table 2). The maximum beet girth (36.25 cm) was observed in plants grown in $B_3 \times T_3$ (150 ppm boron × foliar application thrice at 40, 65 and 90 DAE), which was as good as in plants grown in $B_2 \times T_3$ (100 ppm boron × foliar application thrice at 40, 65 and 90 DAE), $B_2 \times T_2$, $B_2 \times T_3$ and the lowest one (25.33 cm) was recorded in plants grown in $B_0 \times T_2$ (0 ppm boron × foliar application twice at 40 and 65 DAE). Application of boron significantly increase in root diameter which might be attributed to the increase in activities of certain enzymes essential for cell division thus ultimately increased root diameter (Abido, 2012; Abbas *et al.,* 2014).

The interaction of boron concentration and application frequency had significant influence on beet yield. The highest beet yield (104.0 t ha^{-1}) and shoot yield (6.40 t ha^{-1}) were found in plants grown in $B_3 \times T_3$ (150 ppm boron × foliar application thrice at 40, 65 and 90 DAE) followed by plants grown in $B_2 \times T_3$ (100 ppm boron × foliar application thrice at 40, 65 and 90 DAE) while the lowest beet yield (28 t ha^{-1}) and shoot yield (1.38 t ha^{-1}) were recorded in $B_0 \times T_2$ (0 ppm boron × foliar application twice at 40 and 65 DAE). The highest beet yield and shoot yield in $B_3 \times T_3$ were mostly the outcome of the highest beet girth and longer shoot grown under the treatment, respectively. Beet yield was gradually increased due to increasing boron concentration with application frequency. Foliar application of boron increased beet yield was reported elsewhere (Abido, 2012, Armin and Asgharipour, 2012; Mohamed and Yasin, 2013, Abbas *et al.,* 2014, Abdel-Motagally, 2015). Boron application promoted the formation of new leaves on sugar beet plants thus might be responsible for higher foliage in plants grown under boron application treatments. There was an increase in foliage yield of sugar beet with the successive increment of boron over control was reported by Singh (2016). Foliar application of B at earlier, middle and later growth stages might be an efficient method because nutrients are easily absorbed through leaves and is best option to compensate micronutrient requirement in shorter period of time and ultimately increased root and foliage yield. Similar result was reported in maize food and fodder yield (Soomro *et al*., 2011). Boron participates in the carbohydrate metabolism, directly influencing plant development and indirectly affecting the photosynthetic efficiency (Cakmak and Römheld, 1997).

Juice quality

Brix (%)

The highest brix percentage (16.33%) was observed in $B_2 \times T_3$ (100 ppm boron × foliar application thrice at 40, 65 and 90 DAE) which was statistically identical with $B_3 \times T_3$, $B_3 \times T_1$ and $B_3 \times T_2$ while the lowest one (13.83 %) was observed in $B_0 \times T_2$ (0 ppm boron × foliar application twice at 40 and 65 DAE) was at par with $B_1 \times T_2$, $B_0 \times T_1$, $B_0 \times T_3$ (Table 2). Abd El-Motagly (2015) showed that spraying of boron at 70 days from sowing on sugar beet had a significant positive effect on yield and quality traits of sugar beet. Mirvat and Mekki (2005) stated that application of boron fertilizer on sugar beet cultivars significantly increased the root yield and yield components and also increased recoverable sugar percent and sugar yield. Pospisil et al. (2005) reported that the application of 50 L ha^{-1} of Fertina B (3% N + 4% B) increased the root and sugar yield of sugar beet crop. Similar finding was also reported by Kristek *et al.* (2006) who found that application of Fertina B @ 1.0 kg ha^{-1} increased root and sugar yields by 19.4% and 39.5%, respectively compared with control treatment (without boron).

Pol/Sucrose

The highest pol percentage (12.85%) was observed in $B_1 \times T_2$ (50 ppm boron × foliar application twice at 40 and 65 DAE) which was statistically identical with $B_3 \times T_2$ (150 ppm boron × foliar application twice at 40 and 65 DAE) while the lowest pol percentage (9.96%) was observed in $B_2 \times T_1$ (100 ppm boron × foliar application once at 40 DAE) (Table 2). This result corroborates with that of Armin and Asgharipour (2012) who reported that foliar application of boron increased sucrose concentration by 26.35% compared to control. Sugar yield increased due to boron application was reported elsewhere (El-Hawary, 1994; Bondok, 1996; Islam *et al*., 2015).

Table 1. Interaction effects between boron concentration and frequency of application on chlorophyll content (SPAD Value) of tropical sugar beet at different days after sowing

Interaction (Concentration of boron × frequency of application)	Chlorophyll content (SPAD Value) at different days after sowing (DAS)				
	40	65	90	115	140
$B_0 \times T_1$	36.35c-g	42.07bc	46.13f	38.81e	31.39g
$B_1 \times T_1$	30.6h	46.97a	47.90ef	41.77cd	38.58cd
$B_2 \times T_1$	36.26d-g	46.44ab	49.98de	44.03bc	36.40de
$B_3 \times T_1$	39.06b-d	45.17a-c	54.51ab	42.31b-d	34.06f
$B_0 \times T_2$	37.01b-f	48.25a	54.14a-c	39.10e	31.30g
$B_1 \times T_2$	39.49bc	44.53a-c	54.67ab	41.25de	36.16ef
$B_2 \times T_2$	37.74 b-e	47.63a	49.45de	44.28bc	40.49bc
$B_3 \times T_2$	42.62a	46.62ab	51.96b-d	47.07a	41.31ab
$B_0 \times T_3$	40.01ab	40.99c	47.00ef	44.64b	29.56g
$B_1 \times T_3$	33.24gh	48.16a	55.85a	41.35de	40.26bc
$B_2 \times T_3$	35.83eg	48.22a	51.46cd	47.55a	43.12a
$B_3 \times T_3$	34.39fg	48.04a	55.99a	48.24a	43.37a
Level of sig.	**	*	**	**	**
CV (%)	4.55	5.55	3.16	3.24	3.51

Table 2. Interaction effects between boron concentration and frequency of application on yield components and yield of tropical sugar beet

Interaction (B conc. × application freq.)	Shoot length (cm)	Beet length (cm)	Beet girth (cm)	Beet yield (t ha^{-1})	Shoot weight (t ha^{-1})	Brix (%)	Pol (%)	Purity (%)
$B_0 \times T_1$	25.33g	22.92e	27.58ef	35.33h	2.70fg	14.33e-g	10.61e	72.74cd
$B_1 \times T_1$	29.42ef	27.42ab	30.75cd	51.34fg	2.60f-h	14.67d-f	11.09d	72.96b-d
$B_2 \times T_1$	28.75ef	25.58cd	32.08b-d	54.6ef	3.22e	15.00c-e	9.96f	72.57cd
$B_3 \times T_1$	30.42e	26.50bc	29.67de	58.00e	2.78f	15.67a-c	10.60e	71.62de
$B_0 \times T_2$	28.25f	21.92e	25.33f	28.00i	1.38i	13.83g	11.64c	72.60cd
$B_1 \times T_2$	36.92c	26.75bc	32.00b-d	47.34g	2.30gh	14.00fg	12.85a	75.54a
$B_2 \times T_2$	39.58b	27.83ab	33.92ab	90.00c	5.10c	15.33cd	10.39e	76.39a
$B_3 \times T_2$	40.83ab	28.92a	33.92ab	91.33bc	5.66b	16.17ab	12.76a	75.06ab
$B_0 \times T_3$	36.00c	24.67d	33.00bc	31.34hi	2.18h	14.50efg	11.21d	70.06e
$B_1 \times T_3$	37.50c	26.92bc	31.08cd	66.00d	4.10d	15.50bc	11.34cd	70.50e
$B_2 \times T_3$	34.08d	27.83ab	35.75a	96.67b	5.66b	16.33a	12.07b	75.44a
$B_3 \times T_3$	42.08a	27.75ab	36.25a	104.0a	6.40a	16.17ab	12.34b	75.53a
Level of sig.	**	**	**	**	**	*	**	**
CV (%)	3.22	3.59	4.49	5.05	7.06	2.76	1.73	1.75

In a column, figures with same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT); ** =Significant at 1% level of probability, * =Significant at 5% level of probability; B_0 = 0 ppm, B_1 = 50 ppm, B_2 = 100 ppm, B_3 = 150 ppm; T_1 = Once at 40 days after emergence, T_2 = Twice at 40 and 65 days after emergence, T_3 =Thrice at 40, 65 and 90 days after emergence

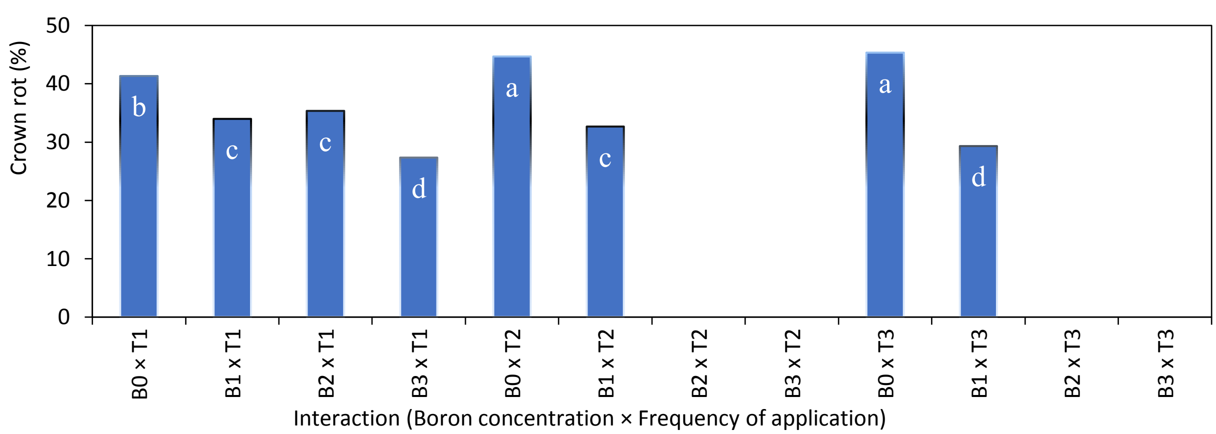

Figure 1. Effect of interaction between boron concentration and application frequency on crown rot incidence at 140 DAS of tropical sugar beet. B_0 = 0 ppm, B_1 = 50 ppm, B_2 = 100 ppm, B_3 = 150 ppm, T_1 = Once at 40 days after emergence, T_2 = Twice at 40 and 65 days after emergence, T_3 =Thrice at 40, 65 and 90 days after emergence

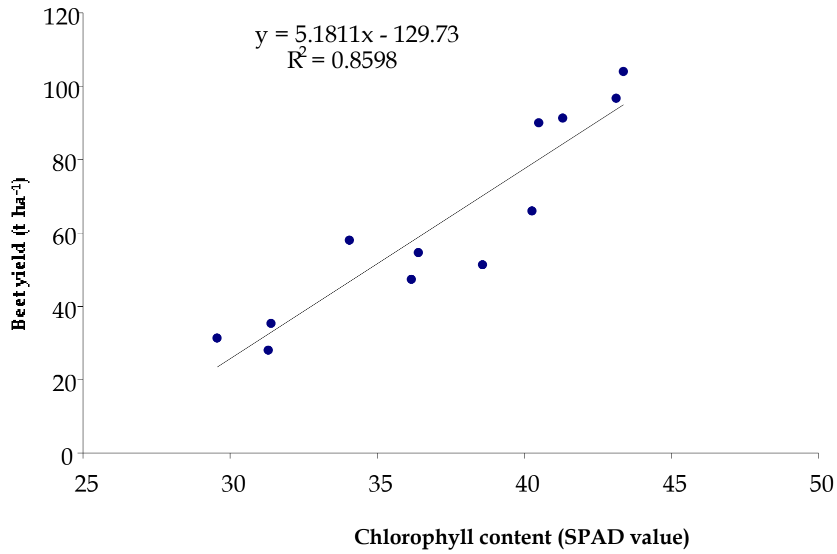

Figure 2: Functional relationship between beet yield and chlorophyll content (SPAD value) of tropical sugar beet

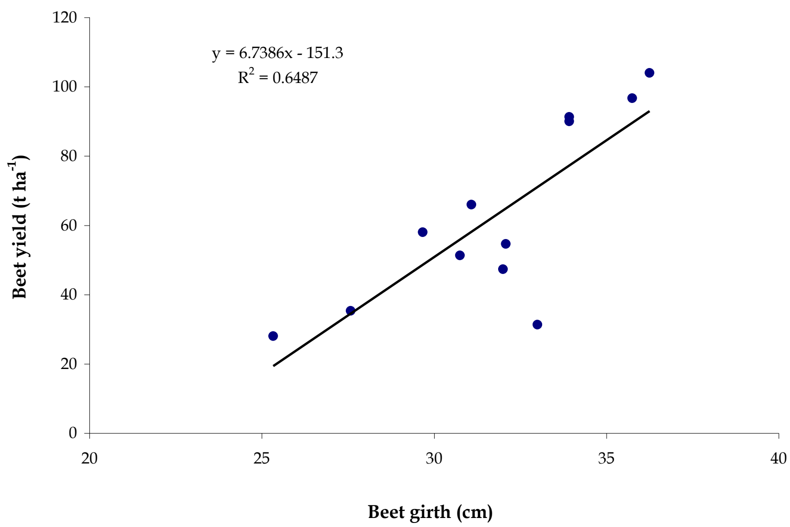

Figure 3. Functional relationship between beet yield and beet girth of tropical sugar beet

Purity

The highest purity percentage (76.39%) was observed in $B_2 \times T_2$ (100 ppm boron × foliar application twice at 40 and 65 DAE) which was statistically identical with $B_3 \times T_3$, $B_2 \times T_3$, $B_3 \times T_2$ and $B_1 \times T_2$ and the lowest purity (70.06%) was observed in $B_0 \times T_3$ (0 ppm boron × foliar application thrice at 40, 65 and 90 DAE) which was at par with $B_1 \times T_3$, and, $B_3 \times T_1$ (Table 2). Foliar application of B at various growth stages of crop ontogeny might be supply requirements of B rapidly through absorption which is may be responsible for higher sugar content as well as purity in juice. Similar results was reported by Mohmmad and Al-Geddawi (2001) who reported that foliar or soil application of boron increased sugar content and purity (%) in beet juice. Micronutrients had significant effect on juice purity (%) was also reported by Gobarah *et al.* (2014).

Crown rot incidence

Crown rot incidence of tropical sugar beet was significantly influenced by the interaction between boron concentration and application frequency at 140 DAS. The highest number of plants (45.33%) showed crown rot like symptoms in plants grown in $B_0 \times T_3$(0 ppm boron × foliar application thrice at 40, 65 and 90 DAE) which was at par with $B_0 \times T_2$ followed by $B_0 \times T_2$ while the lowest value (0.00%) was obtained in $B_3 \times T_3$ (150 ppm × foliar application thrice at 40, 65 and 90 DAE), $B_2 \times T_3$ (100 ppm × foliar application thrice at 40, 65 and 90 DAE), $B_3 \times T_2$ (150 ppm boron × foliar application twice at 40 and 65 DAE), $B_2 \times T_2$ (100 ppm boron × foliar application twice at 40 and 65 DAE) (Figure 1). The higher crown rot symptom might be occurred due to boron deficiency because sugar beet plants need relatively higher requirement of boron (Tlili *et al.,* 2018). If the deficiency becomes severe, transverse cracking of the petioles develops and new leaves on the growing points may turn black (Armin and Asgaripur 2012). So, boron application at various growth phases in plants readily absorbed through leaves that might be solve the additional requirements in sugar beet crops and suppressed crown rot symptoms. This finding is an agreement with that of Islam *et al.* (2015) who noticed that higher boron application may led lower incidence of crown rot in sugar beet.

Functional relationship

Chlorophyll content (SPAD value) and yield

Chlorophyll content is the most important yield contributing characters of sugar beet. Regression analysis was done to quantify the relationship between chlorophyll content and yield. A positive relationship between chlorophyll content and yield of tropical sugar beet was observed which indicated that higher the chlorophyll content, higher the beet yields. The regression equation indicates that an increase in chlorophyll content would lead to an increase in the beet yield of sugar beet (Figure 2). The functional relationship was significant at $p \leq 0.01$. The functional relationship can be determined by the regression equation Y=5.1811x – 129.73 (R^2 = 0.8598). It was expressed that 85% of the variation in yield could be explained from the variation in beet length at 90 DAS. This finding is in agreement with that of Paul *et al.* (2018) who reported that 87% of beet yield could be explained by the chlorophyll content (SPAD value) at 100 DAS.

Beet girth and yield

Beet girth is the most important yield contributing characters of tropical sugar beet (TSB). Regression analysis was done to quantify the relationship between beet girth (at harvest) and yield of TSB. The relationship of beet girth and beet yield of TSB was determined by using the respective interaction data between boron concentration and application time which indicated that higher the beet girth, higher the beet yields of TSB (Figure 3). The functional relationship was significant at $p \leq 0.01$. The functional relationship can be determined by the regression equation Y= 6.7386x – 151.3 (R^2 = 0.6487). It was revealed that 64% of the variation in yield could be explained from the variation in beet girth at harvest. This finding is an agreement with that of Bairagi *et al.* (2013) who reported that 78% of the variation of beet yield could be explained by beet girth.

Conclusion

Results revealed that the highest beet yield (104 t ha^{-1}) was recorded with 150 ppm boron foliar applied thrice at 40, 65 and 90 DAE. The highest brix (16.33 %) was recorded in 100 ppm boron applied thrice at 40, 65 and 90 DAE which was as good as 150 ppm boron applied thrice at 40, 65 and 90 DAE while the highest purity (75.53 %) was recorded with 150 ppm boron applied thrice at 40, 65 and 90 DAE. Therefore, 150 ppm boron applied thrice at 40, 65 and 90 DAE appears as the promising combination in terms of beet yield and juice quality. However, the further trail is required in various agro-ecological zones of Bangladesh to make a precise recommendation.

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Conflict of Interests

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

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