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FOLIAR APPLICATION OF BORON ENHANCES SUGAR BEET YIELD AND INDUSTRIAL SUGAR CONTENT BY PROMOTING INDIGENOUS SOIL-BORON UPTAKE

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Abstract

Soil boron (B) deficiency has been identified in different parts of world in alkaline and low organic matter soils. However, B application is very tricky as a very small amount of B is required to be applied. Two pot experiments were conducted to evaluate B effect on sugar beet yield, industrial sugar content and B uptake. In first experiment, five treatments carrying different B application methods were used. After harvesting, results revealed that B application significantly increased beet yield, sugar content and B uptake. Another experiment was conducted with four different treatments to test how foliar B promotes soil-B uptake via roots. Boron uptake was significantly improved owing to foliar B spray (1.14 mg pot^{-1}) in treatment where B was applied as foliar plus soil as compared to (0.08 mg pot^{-1}) where only foliage B was applied after subtracting B value from their respective controls. The amount of B taken up by plant from soil was calculated higher in treatment where foliar B was applied relative to only soil-B applied, which suggests that foliar B application induced indigenous soil-B uptake. It was concluded that foliar B application upregulated B transporters which enhanced B uptake from soil.

Keywords: Boron, Foliar application, Soil-B uptake, Sugar beet, Sugar yield.

Introduction

Sugar beet (*Beta vulgaris* L.) belongs to family *Amaranthaceae* and its underground part, beet root contains high sucrose content. It is an important crop among *B. vulgaris* species cultivated in Europe, America, Asia and Africa. France and Germany are the leading counties for its production (Anon., 2009; Eurostat, 2017). It has 25% share in total sugar production, 140 million tons, world-wide and the European Union was the leading producer of the sugar beet all over the world (Marlander *et al*., 2003; Anon., 2014). It is also used to produce ethanol in different parts of the world (Anon., 2005). Short growing period and low water requirements with average yield of 50-60 tons ha^{-1} in many humid parts of the world (Marx, 2012; Khodadadi *et al*., 2020) have developed attractions for growing of sugar beet for tropical regions (Chakauya *et al*., 2009).

Boron (B) is an essential micronutrient required by the plants for optimum growth and development. It has significant role in plant cell wall formation and cell division (Wu *et al*., 2020; Miah *et al*., 2020; Wu *et al*., 2021). It is considered important for the yield as well as the quality of crops (Kakar *et al*., 2002; Tariq & Mott 2006; Azeem & Ahmad, 2011) and affects the translocation of carbohydrates too (Ewais *et al*., 2020; Kandil *et al*., 2020). Its deficiency affects both the quality and quantity of agricultural products (Klikocka, 2020). Boron has variable availability (2 to 200 mg kg^{-1} soil) in different textured soils (Mengel & Kirkby, 1987; Sonmez *et al*., 2009) and generally more deficiency has been reported in sandy and calcareous soils (Valenciano *et al*., 2011; Tarar *et al*., 2020). Exhaustive cultivation and without fertilization have reduced the B availability to crops in many agricultural soils in tropics and subtropics (Mengel & Kirkby, 2001; Ariraman *et al*., 2020). Other factors affecting B uptake from soil by plant roots, may include soil pH, organic matter content and crop varieties (Padbhushan & Kumar, 2017). Crops show B deficiency symptoms in the soils having B less than 0.5 mg kg^{-1}; however, the soils having B less than 1.0 mg kg^{-1} should be fertilized with B (Mousavi & Motesharezadeh, 2020). Boron deficiency not only reduces the plant growth, but also affects the yield (Brown *et al*., 2002; Zhang *et al*., 2014; Qin *et al*., 2021). It is relatively immobile micronutrient inside plants and its continuous availability is very important at different stages of plant growth. The production losses in cotton and reduced fiber quality have been reported due to B deficiency in various parts of the world including Pakistan (Zia *et al*., 2006; Ahmed *et al*., 2011; Wahid *et al*., 2020).

Like other crops, sugar beet also requires B for better yield and quality as it accelerates the translocation of sugars to the storage and growing parts (Allen *et al*., 2007). The growing parts of the plants (young leaves and root tips) require sugars, synthesize in the older leaves of the plants, and are transported by B in the plant body. Beneficial results of B application on sugar beet have been observed and foliar application of 0.5 kg B ha^{-1} increased the yield and quality of sugar beet (Song *et al*., 2019; Dordas *et al*., 2007). Boron significantly increased the length and diameter of sugar beet (Tombo *et al*., 2008) and enhanced beet yield, concentration of sucrose and white sugar yield (Kandil *et al*., 2020). Soil application of borax at the rate of 10 kg ha^{-1} improved the beet yield and sucrose content of sugar beet (Malakouti & Tehrani, 2000). Application of B on sugar beet also decreases impurities like Na^+ and K^+ in beet (Artyszak *et al*., 2015), thus enhancing the industrial sugar yield (Armin & Asgharipour, 2012). Plant parts accumulate a significant amount of B as its mobility is considerably slow in plant tissue. In broccoli, the floral parts were concentrated with B and the small amount of it was transferred through phloem in the florets (Shelp *et al*., 1995). In case of foliar application of B, it can be transferred from mature leaves to the other parts (Aziz *et al*., 2019). Plant species having sorbitol complexes show better mobility of B (Hu *et al*., 1997). The mobility of B in the plant body is an apparent problem and leads to determine the application method (Sen & Chalk, 2009). Boron is considered as an essential micronutrient for plants but its deficiency and sufficiency range in plant body is very narrow. Under deficient condition of B, plants are unable to complete metabolic processes. There are various factors which reduce the absorption of B from soil like soil texture, liming, organic matter contents and nature of clay minerals (Padbhushan & Kumar, 2017). In addition, calcium carbonate is another factor which affects the B availability in soil owing to strong absorbent in calcareous soils, like in Pakistan (Rashid & Rayan, 2004).

Due to these reasons, it is very important to use alternate methods of B application along with soil application. Hence, foliar spray of B could be an instant solution to remedy B availability issue in soil. So, it was hypothesized that foliar B application would minimize B deficiency and it will improve sugar contents and soil-B absorption via roots by activating plant B transporters. The experiments were conducted to evaluate significant effect of different B application methods on sugar beet considering beet yield and beet sugar contents. In addition to test how foliar B triggers plant roots to uptake soil-B activating B transporters in plant body.

Materials and Methods

Plant growth conditions

Experiment: Two research studies were conducted in the rain protected wire house at the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad to evaluate the effect of soil and foliar applied B on B uptake and beet sugar contents of sugar beet. The pots were filled sieved soil (45 kg each) and arranged these under completely randomized design. Texture of the soil used in the experiment was sandy clay loam with 7.7 pH, 2.57 dS m^{-1} EC_e, 7.86 (mmol L^{-1})$^{1/2}$ sodium adsorption ratio (SAR) and saturation percentage 30% with the deficient level of plant available B (0.33 mg kg^{-1}). Seeds of sugar beet cultivar Bond (Strube, Germany) were sown in sand to grow nursery for one week. At three leaves stage, seedlings were transplanted in to pots already filled with soil. The basal doses of nitrogen (N), phosphorus (P) and potassium (K) equivalent to 125-125-150 kg ha^{-1} were uniformly applied as urea (contain 46% N), diammonium phosphate (DAP having 46% P_2O_5 and 18% N) and potassium sulfate (50% K_2O) respectively. Five different B treatments were applied i.e., soil application (46.3 mg pot^{-1}) at rate of 6 kg B ha^{-1} at the time of sowing, foliar B (60 mg L^{-1}) was applied at 6th week of plant growth stage, foliar B was applied at 13th week of plant growth stage and foliar B at 6th as well as at 13th week of plant growth stage along with control (foliar spray of distilled water) were applied. Boric Acid (H_3BO_3) was used as a source of B. The crop was irrigated with distilled water at 60% of soil water-holding capacity. The crop was harvested 200 days after sowing the seeds.

Experiment: It was noticed that in our first experiment that B uptake from soil was improved after foliar B applied on sugar beet plants 80 days after sowing the seeds. Second pot experiment was conducted to test how foliar B application triggered sugar beet plant roots to take up soil-B. It was conducted in earthen pots with 15 kg soil each and soil was collected from the research farm University of Agriculture, Faisalabad Pakistan. Soil was air-dried and made it into powder form and sieved it through 2 mm sieve. Texture of the soil was sandy clay loam and pH was 7.4, with electrical conductivity of soil saturated extract (EC_e) 2.3 dS m^{-1}, saturation percentage 35% and available B content were 0.35 mg kg^{-1}. Sugar beet cultivar Bond (Strube, Germany) were sown in nursery trays filled with washed sand. Distilled water was applied regularly, maintaining the water level at 60% of sand water-holding capacity. The recommended nutrients of fertilizers NPK for sugar beet were applied as a source of Urea, DAP and SOP respectively. All doses were applied at the time of transplanting except N, it was applied into three splits. Seedlings were transplanted at three leaves stage to pots after 10 days of sowing in the sand and one plant was maintained in each pot. The treatments as foliar B at rate of 60 mg L^{-1}, soil-B at a rate of 6 kg ha^{-1}, soil-B at rate of 6 kg ha^{-1} plus foliar B at rate of 60 mg L^{-1} and control (no B) were assigned in completely randomized manner with four replications. Foliar spray of B solution having concentration of 60 mg L^{-1} (5 mL) on each pot was applied before 10 days of harvesting the crop. It was assured that exactly 5 mL was applied to foliage and wasted drops were measured and no drop was let fallen on soil covered with tissue paper to avoid B accumulation in soil through foliar application. The exact value of B uptake due to foliar B from soil via roots was calculated through subtracting foliar B from respective controls. The crop was harvested 90 days after sowing the seeds.

Agronomic parameters: Beet root size, including length and diameter was measured with the help of measuring scale and Vernier caliper respectively. Fresh weight of shoot and beet were recorded. The plant samples (shoot and beet) were placed at 65^{o}C in an oven (Red line by BINDER) for drying until constant weight and grinding was done.

Physiological parameters: Chlorophyll contents (*SPAD* value) were estimated at 90 days after sowing using chlorophyll meter (SPAD 502 P). *Chemical analyses (Na^+, K^+ and B).*

Table 1. Effect of B fertilization on plant height, beet diameter, beet length, Na^+, K^+ and B concentration in plant of sugar beet, quality parameters (brix, polarization and recoverable sugar) in sugar beet.

Treatments	Plant height (cm)	Beet diameter (cm)	Beet length (cm)	Na^+ (mg kg^{-1})		K^+ (mg kg^{-1})		B (mg kg^{-1})		Brix (%)	Polarization (%)	Recoverable sugar (%)
				Shoot	Beet	Shoot	Beet	Shoot	Beet			
Control	49.9 ± 1.42d	49.8 ± 0.67d	11.0 ± 0.40c	113.5 ± 0.92b	18.3±0.49b	8767±9.0e	1712±4.16c	31.32±1.71d	36.1±1.51d	15.28±0.90c	13.11±0.31c	8.69±0.45c
SB	68.2 ± 1.49c	65.0 ± 1.00b	16.0 ± 0.64b	88.4 ± 1.12c	14.6±0.76c	14229±12.3c	1423±4.48d	41.0±0.65c	50.2±0.86c	18.4±0.57b	15.64±0.66b	10.30±0.49b
FB-6W	91.1 ± 1.78a	80.0 ± 0.67a	19.0 ± 0.64a	58.9 ± 0.71e	4.8±0.65e	20474±11.8a	941±2.85e	45.6±041b	54.0±1.17b	22.15±0.56a	18.6±0.35a	12.15±0.33a
FB-13W	86.5 ± 0.87b	77.7 ± 0.92a	16.8 ± 0.47b	62.4 ± 0.65d	6.8±0.29d	17742±11.2b	11522±4.3b	43.5±0.41bc	53.0±1.17bc	20.75±0.45a	16.27±0.63b	10.10±0.49b
FB-6W+13W	50.8 ± 1.10d	59.7 ± 0.61c	12.3 ± 0.47c	118.8 ± 1.39a	22.2±0.49a	10839±11.3d	22554±4.9a	63.9±1.10a	78.5±6.37a	15.55±0.33c	13.59±0.32c	9.12±0.39bc
LSD value	**4.13**	**2.39**	**1.62**	**3.00**	**1.68**	**35.31**	**13.25**	**2.99**	**3.17**	**1.88**	**1.52**	**1.33**

*Mean in a column followed by same letters are not significant at p <0.05 by least significant difference test ± MSE

SB=Soil boron , FB= Foliar boron , 6W= 6^{th} week after transplanting the plants to pots and 13W= 13^{th} week after transplanting the plants to pots

Oven-dried and fine ground shoot and beet samples were digested using dry ashing method (Chapman & Pratt, 1961) and B was determined by colorimetric method using Azomethine-H (Bingham, 1982) as an indicator. The ground plant samples were placed in furnace at 550°C for 6 hours for burning the samples. During preparation of the final volume of filtrate after ashing the plastic volumetric flasks were used to avoid the contamination of borax in glassware. The samples were analyzed on spectrophotometer at 420 nm wavelength for B determination. Na^+ and K^+ in shoot and beet were determined by wet digestion procedure using the mixture of nitric and perchloric acids in 2:1 ratio (Rashid, 1999) using flame photometer according to the method described by Chapman & Pratt (1961).

Industrial sugar analysis: Industrial sugar contents were determined by chopping the fresh slices of sugar beet and extracting the juice in a blender. Few drops of juice were taken on refractometer to determine brix % and then added 2-3 g of lead acetate in 100 mL juice. Samples were shaken vigorously with stirrer and were kept for 5 minutes at 20ºC to stabilize it. Filtered-juice was filled in the polarimeter tube and polarization was determined at 24ºC and 589 nm wavelength using polarimeter (POL-1/2, ATAGO, Japan). The sugar recovery in percentage was determined using following formula practiced by sugar industry in different countries (Mubarak *et al*., 2016).

$$\text{Sugar recovery (\%)} = \left[\frac{3P}{2\left\{1-\frac{F+5}{100}\right\}} - \frac{B}{2\left\{1-\frac{F+3}{100}\right\}}\right] \times 0.93$$

where P = Pol % of juice
B = Brix % of juice
F = Fiber % beet (16% constant)
0.93 = Recovery factor

Statistical analysis

Data collected were analyzed by one-way analysis of variance (ANOVA) using Rx64 4.0.3 software. Least significant difference (*LSD*) test was applied to differentiate effect among treatments means, as prescribed by Steel *et al*., (1997). Treatment effect was compared with the critical difference at 5% level of probability. Bar graphs were constructed using Microsoft Excel Worksheet 2019.

Results

Plant growth and beet yield attributes mediated by B application: Boron fertilization significantly improved plant height, beet diameter and beet length (p<0.05; Table 1). Maximum plant height, beet size and beet length were recorded in treatment where B was foliar applied at 6^{th} week of plant growth. Almost same trend was found in dry shoot weight, fresh and dry beet weight. Boron application increased dry beet weight about 32% higher as compared to control. Soil application of B at rate of 6 kg ha^{-1} significantly increased plant height as compared to control but less than foliar appplications. Highest beet weight was recorded in treatment where B was applied as foliar spray at 6th week of plant growth, which was almost at par with foliar application at 13th week. Foliar spraying at two different growth stages (6th and 13th week of plant growth) did not show significant difference to each other. Similar results were found for dry shoot weight as well as dry and fresh beet weight. Maximum fresh and dry beet weights were recorded 796 g beet^{-1} and 265.5 g beet^{-1}, respectively, in the treatment where B was foliar applied at 6th week of plant growth (Fig. 1). In the second experiment, statistical analysis showed significant (p<0.05) effect of foliar application of B on plant height of sugar beet as compared to control (Table 1). Soil plus foliar applied-B significantly improved plant height (45 cm) at rate of 60 mg L^{-1} of B as foliage and 6 kg ha^{-1} B as soil application as compared to no B application (control). The reduced plant height was recorded in treatment where sole B was applied as foliar spray on sugar beet at rate of 60 mg L^{-1}. In this experiment, there was a significance difference was observed between foliar and soil application of B.

Both experiments showed foliar application of B improved the plant height, plant biomass and root yield of sugar beet. Foliar along with soil application of B provided the better results for agronomic parameters instead of sole B application as soil or foliage.

Boron, potassium and sodium uptake mediated by B application: The results showed that concentration of B in sugar beet plants increased with applications of B. The highest concentration of B in shoot and beet (63.9 mg kg^{-1} and 78.5 mg kg^{-1}, respectively) was observed when two foliar B were applied at 6th and 13th week of plant growth (Table 1). Results also revealed that B application as foliar or soil significantly affected K^+ and Na^+ concentration in shoot and beet (Table 1). Maximum K^+ concentration, i.e., 2049.5 mg kg^{-1} was determined in shoot where B was applied as foliar spray at 6th week of plant growth. Non-significant difference was found for beet K^+ concentration between foliar B application at 6th and 13th week of plant growth. Highest K^+ concentration was determined as 2256.4 mg kg^{-1} of beet dry weight in two foliar applications of B during plant growth. Minimum value for beet K^+ concentration was reported as 944 mg kg^{-1} of beet dry matter where B was applied as foliar spray at 6th week of plant growth.

Foliar B considerably reduced Na^+ concentration in shoot of sugar beet crop. Analysis of variance showed that lowest Na^+ concentration in beet (4.8 mg kg^{-1}) and shoot (58.9 mg kg^{-1}) was determined where foliar B at 6th week of plant growth was applied.

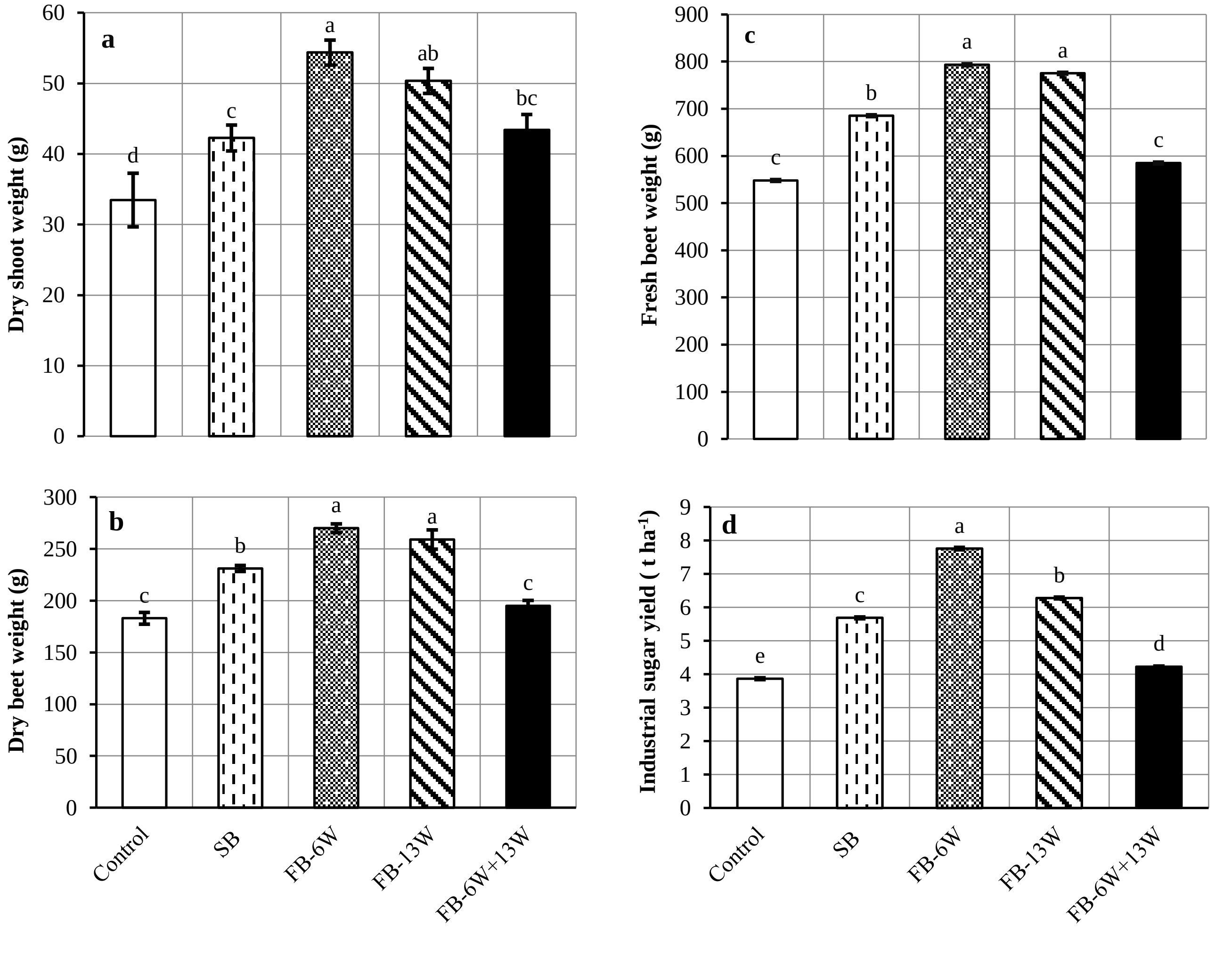

Fig. 1. Effect of different B applications on dry shoot weight (a), dry (b) and fresh beet (c) weight, and industrial sugar yield (d) of sugar beet plant. Column shows means of four replications while bars show standard error. Means sharing the similar letter (s) do not differ significantly at p≤0.05 according to *LSD* test. *LSD value* for dry shoot weight=7.20, dry beet weight=17.87, fresh beet weight=58.04 and industrial sugar yield=0.08.

Table 2. Response of various B application methods on total B uptake by sugar beet plant, B uptake from soil induced by foliar B in plant and remaining soil-B after harvesting the sugar beet plants.

Treatments	B application	Foliage B	Total B uptake	Foliar B induced indigenous soil- B uptake	B in soil after harvesting (mg kg^{-1})
	mg pot^{-1}				
Control			2.75 ± 0.24b		1.53 ± 0.19c
FB		0.28	3.11 ± 0.15b	0.08	1.12 ± 0.07d
SB	46.3		2.93 ± 0.21b		5.82 ± 0.23a
SB + FB	46.3	0.28	4.35 ± 0.11a	1.14	4.59 ± 0.07b
LSD value			**1.24**		**0.41**

B= Boron, FB= Foliar boron, SB= Soil boron

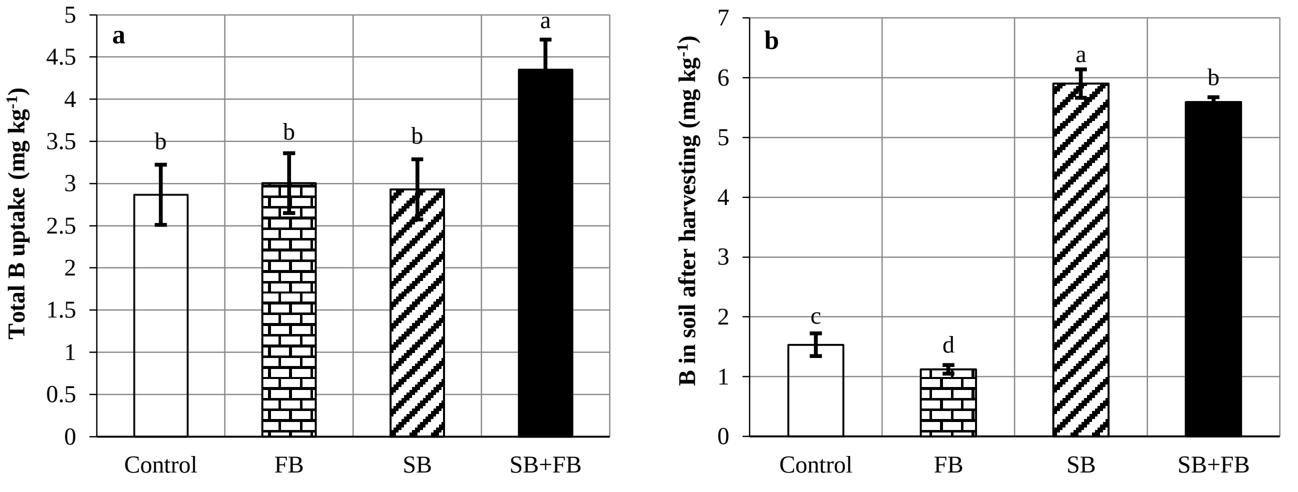

Fig. 2. Effect of foliar B applications on total B uptake (a) of sugar beet plants (mg pot^{-1}) and B concentration in soil (b) after harvesting. Control (no B application), B foliar application 0.28 mg pot^{-1} at rate of 60 mg L^{-1}, B soil application 46.3 mg pot^{-1} at rate of 6 kg ha^{-1}, B foliar 0.28 mg pot^{-1} at rate of 60 mg L^{-1} + Soil application B 46.3 mg pot^{-1} at rate of 6 kg ha^{-1}. Values in columns show the mean of four replications, whereas bars show the standard errors. Columns sharing similar letters are non-significant at $P \leq 0.05$ according to *LSD* test. *LSD value* for total B uptake=1.35, B in soil after harvesting=0.31.

Industrial sugar content (%) and sugar yield mediated by B supply: From first experiment the results revealed that the maximum industrial sugar contents (12.1%) in beet were recorded where B was foliar applied at 6th week of plant growth (Table 1). Soil-B application also increased beet sugar content and minimum value was determined in control where no B was applied. Industrial sugar contents were significantly reduced when two foliar applications were done at 6th and 13th week of plant growth as compared to one foliar B application at 6th or 13th week of plant growth. Industrial sugar yield was calculated by considering 80,000 plants per hectare. Analysis of variance showed the significant (p<0.05) effect of B fertilization on industrial sugar yield of sugar beet plants compared to control (Fig. 1). The maximum industrial sugar yield (7.7-ton ha^{-1}) of sugar beet crop was calculated where foliar B was applied at 6th week of plant growth. Similar trend was observed in beet yield.

Soil-B concentration after harvesting: Boron concentration in soil was determined in second experiment after harvesting the crop at 90 days after sowing (Fig. 2). Different B application methods as soil and foliar on sugar beet plants revealed that exogenous B application affected soil-B uptake significantly (Table 2). Significant results were found after interpretation of data. More soil-B concentration (5.82 mg kg^{-1}) was determined after harvesting the crop where only B was applied as soil at rate of 6 kg ha^{-1}. Low B concentration (1.12 mg kg^{-1}) was determined in soil where foliar B spray was applied at rate of 60 mg L^{-1}. The results showed that foliar B application induced B transporters in the plants that helped the indegenous soil B absorption by plant roots as compared to control.

Total B uptake by sugar beet mediated by B supply: Statistical analysis shows higher B uptake (4.35 mg pot^{-1}) was recorded in treatments where soil-B along with foliar at the time of sowing at rate of 6 kg ha^{-1} and at rate of 60 mL^{-1} respectively was applied (Table 2). This value was significantly different comparatively from all other treatments. This showed that combined soil and foliar B application promoted the sugar beet plants to take up B from the soil (Fig. 2). Only soil or foliar B application was not improved B uptake significantly as compared to control.

Discussion

Boron is an essential micronutrient which is mainly required for formation of cell wall, and it is involved in many metabolic processes in the plant cell (Hu & Brown, 1994). Similarly, it plays an essential role in vegetative growth of all higher plants (Brown *et al*., 2002; Kaya *et al*., 2019). Present research describes the effect of foliar and soil application of B on various parameters of sugar beet growth, sugar contents and its translocation in the plant body from roots to aerial parts. In general, B fertilization showed the positive effects on plant growth and beet yield as reported by Tombo *et al*., (2008). Boron significantly increased dry shoot weight while plant leaves were found smaller under B deficient conditions (Nadeem *et al*., 2019). However, in this study, the response was variable and was not increased in all treatments. Plants require very small amount of B for their growth as the higher concentration of B is toxic. The optimum range in soil is 0.5 to 5.0 mg B kg^{-1} soil (Jones, 2003). Soils having B more than 5.0 mg kg^{-1} can cause B toxicity in plants because plants sufficient range starts from 3.0 mg kg^{-1} dry weight. However, sugar beet requires more B and its sufficient range is 31-200 mg kg^{-1} of dry weight (Jones, 2003). Soil application of B improved the plant growth as well as shoot B concentration (41 mg kg^{-1}), however one foliar B application improved B concentration up to 45 mg kg^{-1} dry shoot weight with better plant growth as well beet yield (Fig. & Table 1). Two applications of B increased its concentration > 60 mg kg^{-1} dry shoot weight with less shoot growth and beet yield. The harmful effect of higher B concentration i.e. on double application may be because of toxic effects of B on plant growth, although no toxicity symptoms were observed. Ebru *et al*., (2003) also reported the negative effect of high B concentration on beet dry matter. On the other hand, soil application of B may not provide sufficient B to plants for optimum plant growth. Better plant growth and beet yield with only one foliar B application supported well chlorophyll contents, B concentration in shoot as discussed above shoot, beet diameter and beet length. Boron fertilization significantly increased the length and diameter of beet (Tombo *et al*., 2008; Enan *et al*., 2016). Similarly, Jaszczolt (1998) also reported that diameter of beet gave the lowest value without B application due to its essential role for providing sugars for root growth. Foliar B application was found more advantageous than soil because of the direct absorbance of micronutrients by plants rather than losses due to soil application (Rimar *et al*., 1996; Parveen & Rehman, 2000; Asad *et al*., 2002; Curtin *et al*., 2008). Boron application significantly increased the diameter of sugar crops (Madhuri *et al*., 2013). Interestingly, extractable sugar contents were also higher in beets supplied with only one foliar B application at 6^{th} week of plant growth. However, sugar contents in the treatment having two foliar sprays had less extractable sugar due to increased K^+ and Na^+ concentration in beets (Table 1). Higher K^+ and Na^+ concentration has molassegenic effect, decrease the extraction of sugar from beets as described by Wakeel *et al*., 2010; Wakeel *et al*., 2011; Wu *et al*., 2020. The sugar contents were improved by synergetic effects of B and Ca in an apple as reported by Lu *et al*., (2013). One foliar B application at 6^{th} week of plant growth reduced K^+ and Na^+ content (Table 1) in beet as compared to all other treatments including control, which have positive effects on sugar extraction.

Boron absorption from soil was increased in shoot and root by foliar B application as compared to control (without B) after subtracting the exogeneous B applied (foliar B from control and foliar along with soil-B application from solely soil-B) (Table 2). It provided the exact picture absorbed B from soil. Three pathways have been found to take up B by the plants across the plasma membrane including passive diffusion of boric acid, facilitated diffusion of boric acid via channels and borate anion exporter (Fig. 3). Under B deficient conditions boric acid channels and borate exporters help the plants to take up B and translocate from soil to aerial parts. NIP 5;1 and BOR1 are located in the plasma membrane and various cells of roots in *Arabidopsis thaliana* support B translocation from soil to shoot under B limiting conditions and downregulation of NIP 5;1 and BOR1 starts under sufficient level of B owing to degradation of mRNA and proteolysis. In addition to BOR4 and BOR1 in *A. thaliana* and barley play a vital role for exclusion of B from cells and tissues under excess condition (Takada *et al*., 2014; Yoshinari & Takano, 2017). Application of foliage B on plants, it helps the B complexes to move easily in the phloem of plant. The high membrane permeability for boric acid, the similar results were found after foliar B application on broccoli (*Brassica oleracea*), canola (*Brassica napus* L.) and wheat (*Triticum aestivum*) aided B concentration in plant tissues. The translocation of B was reported in plant shoots tissue of the above-mentioned crops, that was due to exogenous B application enhanced the mobility of B complexes in the shoot as reported by Oertli (1994). In curent experiment foliar B application on sugar beet activate B trasporters under suffient condition of B supply and triggers plant roots to take up soil-B.

Total B uptake was increased significaltly where B was applied as soil along with foliar spray owing to absorbtion of B via roots from soil as well as from external application (foliage B). Low B concentration was found significantly in soil where foliar B was applied as compared to relevent control after harvesting the crop. This shows that application of foliar B spray induces more absorption of B from soil media, the root exudates could be mineralized indegenous soil-B on the other hand, and it releases in lebile pool and plant takes up it easily under high B affininity transporters as BOR1. The foliar application of nutrients enhanced the exudates which alteres the microflora in rhizosphere and helped solublization of unavailable nutrients for plant uptake (Balasubramanian & Rangaswami, 1973). Foliar B application also altered the root rhizosphere microflora population could be enhanced B-soil availability for plants as similar results were obtained in current experiment. On the other hand, application of nutrients as foliar increases the root architure and it helps for absorption of nutrients from the soil which are far off from the roots and are taken up easily but root prolefiration helps to absorb them easily (Ishfaq *et al.*, 2022). In addition to application of B as foliar on plants activates the B transporters in plant system considered as a major contributor which aids for uptake of B. The similar results were found that foliar N application activates N transporters in plants and helped soil-N uptake via plant roots as mentioned by Reid *et al*., (2020). Sen & Chalk (2009) found that foliar application of urea on wheat and sunflower helped the uptake of N via plant roots from soil. The same case was found for foliar B application on sugar beet in current experiment. In soyabean plants at the time of seed filling foliar application of N, P, K and S showed the effective results (Gracia, 1976).

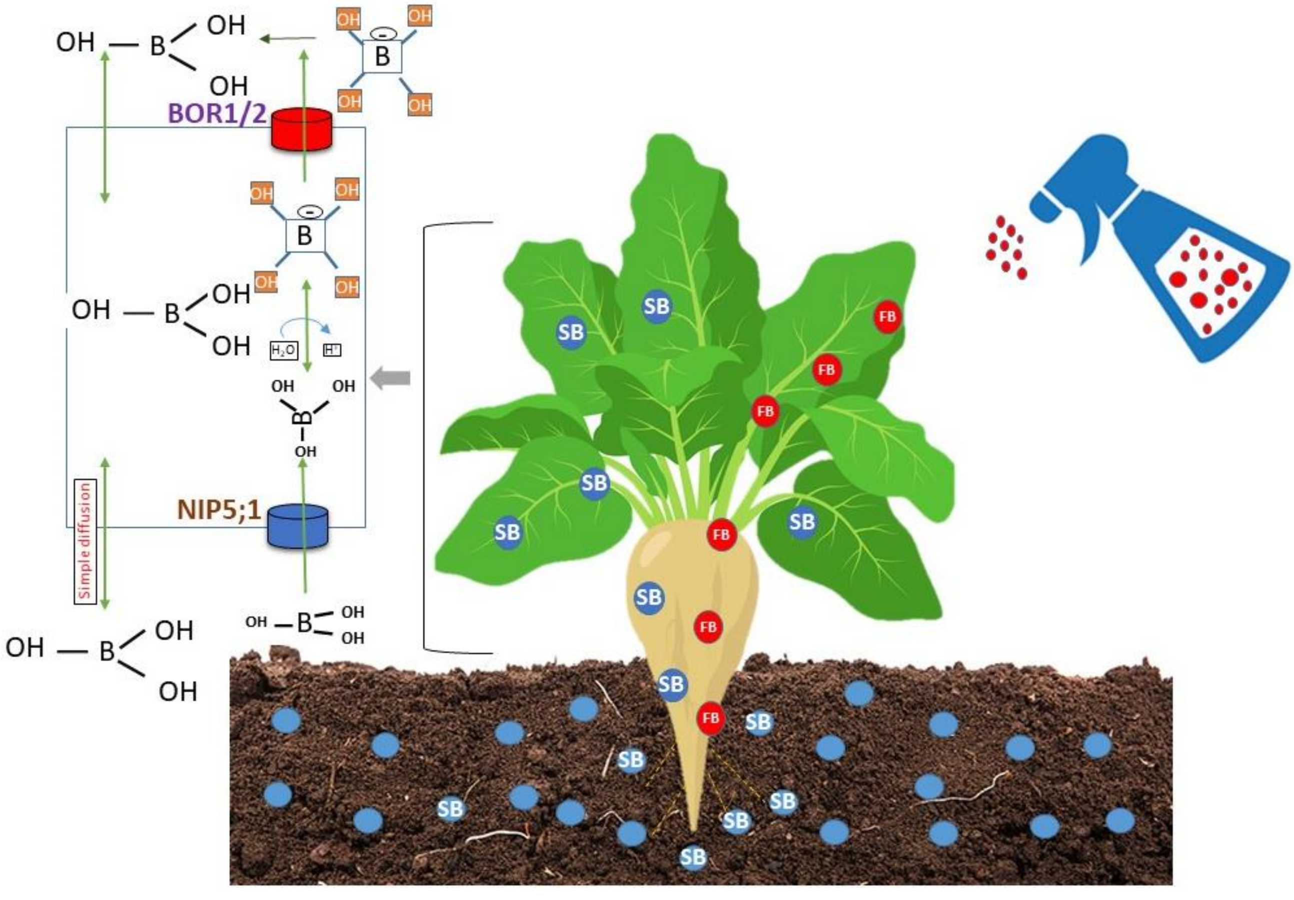

Fig. 3. Foliar application of B induces uptake of soil-boron via roots. Three boron transport pathways in plants. Foliar B application on sugar beet activates B transporters for soil-boron uptake. Simple diffusion of uncharged boric acid via plasma membrane across lipid bilayer, facilitated diffusion mediates under B deficient condition via boric acid channels (NIPs) and borate anion transporters (BORs) activate under sufficient B, FS= Foliar boron, SB= Soil boron

Conclusion

It is concluded that one foliar spray of B improved the sugar contents as well as agronomic parameters. It also induced soil-B uptake through sugar beet roots activating B transporters in sugar beet plants under high affinity B like BOR1 and proliferating the root architecture for nutrient acquisition. However, underling pathways of B uptake via plant roots mediated by foliar application of B remains open to unmask.

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