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Physiological and morphological responses of sugar beet (*Beta vulgaris* L.) subjected to nano-boron oxide at different growth stages

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ABSTRACT   The deficiency and toxicity of boron may lead to noticeable yield reduction and quality loss of sugar beet. To evaluate the effects of nano-boron on the root yield and quality of sugar beet, factorial experiment was conducted based on a randomized complete block design with three replications at Urmia University. Treatments were spraying of nano-boron oxide (0, 2, 3 and 4 g L^{-1}) at different growth stages (20, 40, 60, 80 and 100% of ground cover). Increasing levels of boron up to 3 g L^{-1} resulted in the highest SPAD (Soil Plant Analysis Development) value, leaf number and relative water content. With optimal leaf area (86.47 cm^2), the highest yields of root, sugar, white sugar, and technological sugar (144.53, 28.23, 26.19 and 25.32 t ha^{-1}) were determined in the treatment of 4 g L^{-1} boron at 40% of ground covered. Increasing nano-boron level under different growth stages increased sugar and white sugar contents, on contrary impurities (Na, K and α-amino-N) loss and molasses sugar percentage were decreased. More than 3 g L^{-1} nano-boron exhibited the highest values of purity. Application of 3 g L^{-1} boron at 40% of ground cover increased sugar and white sugar contents by 12.45 and 18.72%, respectively.   **Acta Biol Szeged 63(2):103-111 (2019)**

Introduction

Sugar beet (*Beta vulgaris* L., Amaranthaceae) is one of the important sugar crops with high yield, high adaptability and high biological activity. It is also rich in minerals and organic nutrients (Grzegorzewski et al. 2017). Although sugar beet is well adapted to a wide range of growing conditions and soils, nutritional disorders caused by boron deficiency are quite common (Dordas 2007). Sustainable production requires the efficient use of inputs including adequate and balanced fertilization of both macro- and micro-nutrients (Singh et al. 2017). Deficiency of soil nutrients such as nitrogen (N), phosphorus (P), potassium (K), zinc (Zn) and boron (B) should be added to the rhizosphere according to plant needs and has been known as the major limitations in beet crop production (Abidow 2012). Boron is unique among the essential mineral micronutrients because of normal presence in soil solution as a non-ionized molecule over the vast pH range (Hirparan et al. 2018). It is also essential for plant in development and growth (Abido 2012) through the cell wall structure, membrane integrity and function (Nyomora et al. 2019), sugar translocation from source to sink

(Rawashdeh and Sala 2013) physiological functions such as carbohydrates metabolism, indole acetic acid metabolism, formation amino acid (Singh et al. 2017), nitrogen fixation (Rawashdeh and Sala 2013) and photosynthetic pigments (Abd El-hady 2017).

Deficiency of boron causes reduction in photosynthesis due to disturbs the activities of proton pumping ATPase and electron transport chain (Nadeem et al. 2019; Rehman et al. 2018), inhibition of leaf expansion, inhibitions root elongation through limiting mitosis and cell enlargement and division (Gemici et al. 2003), early enlargement due to clear limitation of its phloem mobility and reduced growth of new shoots and leaf (Ullah et al. 2013; Ali et al. 2015). Without an adequate supply and consumption of boron in large quantities, it may lead to marked yield reduction and quality loss of sugar production in soil application (Abbas et al. 2014; Tlili et al. 2017; Armin and Asgharipour 2012). Because boron has been considered to have only limited phloem mobility and cannot readily be redistributed within the plant (Brown et al. 1999), the amount of yield losses directly depends upon the duration of deficiency and the plant growth stage at which it occurs (Ali et al. 2015). Deficiencies of boron result in many anatomical, biochemical and physiological changes

in plants (Ali et al. 2015). Therefore, the management of boron in soil has become a worldwide agricultural problem in the recent years (Tlili et al. 2017).

Foliar fertilization has the advantage of low application rates, treated rapidly, uniform distribution and quick plant responses to applied nutrients (Asad et al. 2003; Saadati et al. 2013). Moreover, a number of previous studies have increased the significance of the role of foliar boron application in the productivity of crop plants (Perica et al. 2001; Dordas 2006; Abido 2012; Kristek et al. 2006). Also, to get the desired results, nanomaterial can be utilized by foliar application with much-decreased concentration (Prasad et al. 2012). After entering the cells the nanoparticles transport from one cell to another through plasmodesmata. The chemical and biological activities of most substances increase at the nanoscale (Dewdar et al. 2018). Root yield, sugar percentage significantly increased by increasing boron doses (Abbas et al. 2014). Dordas et al. (2006) reported that spraying of boron lead to a higher quality of sugar and root yield compared to the time using boric acid mixed with soil. El-Geddawy and Makhlouf (2015) found that there was a significant positive increase in root diameter and root length of sugar beet due to the gradual increase in the spraying concentration of boron from 105 to 210 ppm. Armin and Asgharipour (2012) reported that the maximum root yield and sugar percentage was achieved by foliar application of 12% boric acid. Abd El-hady (2017) reported that root and sugar yields were increased by 19.4% and 39.5% compared with control treatment.

A better understanding of the physiological basis of the response of sugar beet may help in programs aiming to evaluate yield. Therefore, this work aimed to evaluate the effects of different amounts and time of nano-boron oxide spraying on the quantitative and qualitative aspects of sugar beet.

Materials and Methods

Site and experimentation

All experiments were conducted during 2011-2012 cropping seasons in North-Western Iran Iran, i.e. Naghadeh (27°45' N latitude and 22°37' E longitude; Alt 1300 m) and were situated in the wet zone with moderate winter and hot summer. The experimental design was randomized factorial experiment based on a randomized complete block design with three replications. The soil type was silty loam and possessed around 7.95 pH, EC about 2.3 dS m^{-1}, total organic C = 1.20% and Zn = 32 mg kg^{-1}. The experimental soil was fertilized with 250 kg N ha^{-1} in the form of urea (was applied as ½ at sowing, ½ at 6-8 leaf), 250 kg P ha^{-1} in the form of triple superphosphate, and 100 kg K ha^{-1} in the potassium nitrate at planting time. Experiment factors were the amount of nano-boron (Nano-B) oxide concentration (0, 2, 3 and 4 g L^{-1} of nano chelate powder, with 99.5% of purity and 80 nm particle size, obtained from Khazra Company containing 9% chelated boron, absorbable at pH 3-11, and completely soluble in water) and spraying time included (20, 40, 60, 80 and 100 of ground cover by plant canopy). Each plot was consisted of 5 rows with 5 m long. The inter row and intra-row spacing was 10 and 15 cm, respectively. The sugar beet cultivar (Montarosa cv. a commonly grown cultivar of sugar beet in Naghdeh area) was sown at the depth of 20 cm on May 10.

Measurements of quantity and quality parameters of sugar beet

Harvesting was done manually 180 days after sowing (DAS). In order to measure the root length (cm), root diameter (cm) and leaf number traits, 10 plants in each plot were randomly harvested. Root yield (t ha^{-1}) was obtained from plants harvested of 5 m^2 in each experimental unit and juice quality characteristics were analyzed. The percentage of sucrose was determined according to Le-Docte (1927). Sodium and potassium (%) were determined by using a flame photometer (Model 410 Classic), nitrogen was determined according to the semi-micro Kjeldahl method (Model NA 1500) (Edwards 2014). Total soluble solids (TSS%) was measured in fresh roots using hand refractometer (model REF-113ATC). Juice purity% was also determined as a ratio between sucrose% and TSS% according to Carruthers and Oldfield (1961).

Sugar yield and root quality were calculated via the following equations:

$$SY \ (t \ ha^{-1}) = RY \ (t \ ha^{-1}) \times SC(\%)$$

Where, SY: sugar yield; RY: root yield; SC: sugar content.

$$MS = 0.12 \ (K + Na) + 0.24(\alpha\text{-amino-N}) + 0.48$$

Where, MS: molasses sugar (%); K: potassium (mmol/100 g root), Na: sodium (mmol/100 g root); α-amino-N: alpha-amino-nitrogen (mmol/100 g root) (Buchholz et al. 1995).

$$AC: (K + Na)/ \ N.$$

Where, AC: alkalinity coefficient.

$$WSC(\%) = SC\% - MS\%$$

Where, WSC: white sugar content.

$$WSY \ (t \ ha^{-1}) = RY \times WSC \ \%$$

Where, WSY: white sugar yield.

$$TSY\ (t\ ha^{-1}) = RY\ (t\ ha^{-1}) \times [SC\ (\%) - loss\ of\ sugar\ productivity\ (\%)]$$

Where, TSY: technological sugar yield (Buchholz et al. 1995).

$$LSP\ (\%) = MS\ (\%) + 0.6$$

Where, LSP: loss of sugar productivity (Carruthers et al.1961).

$$Sugar\ productivity\ (SP) = \frac{SC - loss\ of\ sugar\ productivity}{SC}$$

Where, SP: sugar productivity.

The leaf length was measured as the distance between the beginning of leaf formation on the leaf stem and the top of the leaf. The leaf width was measured at its widest point with a ruler. Based on measured leaf width (W, mm) and leaf length (L, mm) the area of each leaf (A, mm²) is calculated using the following relationship (Mirschel 2018):

$$A = W \times L \times 0.675$$

The chlorophyll content of leaves was estimated with a SPAD-502 (Konica Minolta Sensing, Osaka, Japan) (Jifon et al. 2019). Relative water content was estimated according to the method of Tambussi et al. (2005).

Analysis of variance (ANOVA) and means comparison on data was performed using the SAS Statistical Package Program. Least Significant Difference (LSD) method was used to test the differences between means comparison of main effects and interactions.

Results

Analysis of variance showed that the significant interaction effect between Nano-B concentration and spraying stage on the relative water content (RWC), leaf area, root length, root and sugar yield, white and technological sugar yield, sugar content, white sugar content, sugar productivity, loss of sugar productivity, sodium, potassium, α-amino-N and molasses sugar. There was a significant effect of Nano-B foliar application on the alkalinity coefficient (Table 1). SPAD, leaf number, root diameter, purity% and TSS% were affected by the Nano-B concentration and spraying stage (Table 1).

Chlorophyll index, relative water content, leaf area and leaf number

The maximum of SPAD (73.50) and leaf number (52.26) was obtained in B_3 and B_4, respectively (Table 1). Chlorophyll index was increased about by 34.71% in 3 g L^{-1} Nano-B (Table 1). The highest content of SPAD and leaf number markedly increased from spraying of Nano-B at 80 of ground cover as G_4 (Table 1). However, the difference in mention traits was not statistically significant in a comparison between G_2, G_3 and G_4. The increasing of Nano-B at all growing stages up to 3 g L^{-1} resulted in the highest RWC. The highest and lowest RWC was respectively achieved in B_3G_2 and B_1G_5 (Table 2). A gradual increase in leaf area as growth stages improved up to G_4 was recorded regardless of boron levels. The application of B_3G_4 caused an increase in leaf area of 60% in comparison with B_1G_4.

Root length and diameter

It could be noticed that increasing boron rates significantly increased root diameter. The plant sprayed with 3 g L^{-1} of nano- boric acid revealed the highest root diameter (12.70 cm). Data also cleared that the late application of boron (G_4) recorded the highest value of root diameter (12.79 cm). Results showed that, the crops were fertilized early or late at different rates of boron, had any considerable differences on root length. Application of 2 g L^{-1} at 100% of ground covered (B_2G_5), produced the highest root length (38.16 cm), while the lowest value (25.50 cm) was recorded in the B_1G_1 (Table 2).

Sugar beet yields

Application of 4 g boron L^{-1} at the early stage of plant (40% ground cover), can significantly increase root yield (144.53 t ha^{-1}), sugar yield (28.23 t ha^{-1}), white sugar yield (26.19 t ha^{-1}), and technological sugar yield (25.32 t ha^{-1}) to the highest amounts. Spraying nano-boric acid at the levels of B_2, B_3 and B_4 increased root yield by about 29%, 48% and 79% at early growth stage (G_2), as compared to control treatment (B_1), respectively. However, Abd El-hady (2017) reported that B element (1.0 kg B/ha) was increased root and sugar yields by 19.4% and 39.5% compared with control treatment.

Quality of sugar beet

The highest sugar and white sugar content were found to be in the B_3G_2 treatment with average of 19.86% and 18.39%, respectively. However, their effects were also similar to B_4G_2. Also, the lowest of SC and WSC are related to B_1G_1 treatment with an average of 15.80% and 14.14%, respectively (Table 3). Compared to the control, spraying 3 g L^{-1} Nano-B at 40% of ground covered improved SC and WSC by 12.45% and 15.37%, respectively. Data in Table 1

Table 1. Effects of nano-boron oxide concentration and spraying time (growth stage) on growth and yield of sugar beet.

Nano-B (B)	SPAD	RWC (%)	Leaf number	Leaf area (mm²)	Root length (cm)	Root diameter (cm)	Root yield	Sugar yield	WSY	TSY
								(t ha⁻¹)		
B_1 = no nano-B as control	54.56b	73.98b	33.73c	49.52c	26.70c	10.73b	88.77d	14.93d	13.39d	12.86d
B_2 = 2 g L⁻¹	59.55b	82.07a	41.46b	67.63b	30.53b	11.23b	108.25c	18.92c	17.26c	16.61c
B_3 = 3 g L⁻¹	73.50a	84.82a	52.26a	74.55ab	31.00b	11.36b	117.09b	21.73b	20.05b	19.35b
B_4 = 4 g L⁻¹	68.35a	83.27a	49.33a	82.85a	34.68a	12.70a	127.65a	24.15a	22.42a	21.65a
LSD (p<0.05)	5.20	4.08	4.96	10.47	2.49	1.24	8.05	1.70	1.60	1.55
Growth stage (G)										
G_1 = 20% of ground cover	58.89b	81.74ab	41.58b	55.65c	28.87cd	10.25c	98.94b	17.28b	15.82b	15.23b
G_2 = 40% of ground cover	64.38a	83.48a	44.16ab	69.57abc	27.91d	11.04bc	114.39a	21.36a	19.65a	18.96a
G_3 = 60% of ground cover	65.70a	81.59ab	46.16ab	73.80ab	30.26bc	11.26bc	113.007ab	20.69a	19.09a	18.41a
G_4 = 80% of ground cover	66.92a	81.68ab	48.08a	80.15a	31.20b	12.79a	115.52a	20.40ab	18.66ab	17.96ab
G_5 = 100% of ground cover	64.07ab	76.69b	41b	64.03bc	35.37a	12.18ab	110.35ab	19.94ab	18.19ab	17.53ab
LSD (p<0.05)	5.36	5.53	5.30	14.18	2.10	1.33	14.49	3.33	3.24	3.16
B × G	ns	**	ns	*	**	ns	**	*	**	*
C.V.	10.14	5.18	14.51	14.96	8.28	11.89	7.12	8.31	8.55	8.65

ns: show no significant differences.
* and **: show significant differences at 0.05 and 0.01 probability level, respectively.
RWC: relative water content; WSY: white sugar yield; TSY: technological sugar yield.

Table 1 (Continued). Effects of nano-boron oxide concentration and spraying time (growth stage) on growth and yield of sugar beet.

Nano-B (B)	SC (%)	WSC (%)	Purity %	SP	LSP	Na	K	α-amino-N	AC	MS	TSS %
						(mmol/100 g root)					
B_1 = no nano-B as control	16.84b	15.11c	75.92c	0.861d	2.33a	1.20a	6.84a	1.18a	6.99c	1.73a	22.20a
B_2 = 2 g L⁻¹	17.50b	15.96b	82.83b	0.877c	2.13b	0.79b	6.27b	0.85b	8.46b	1.53b	21.15b
B_3 = 3 g L⁻¹	18.54a	17.11a	92.12a	0.890b	2.03c	0.68b	5.77c	0.74b	8.97b	1.43c	20.18bc
B_4 = 4 g L⁻¹	18.90a	17.54a	95.72a	0.896a	1.96d	0.52c	5.61c	0.60c	10.44a	1.36d	19.91c
LSD (p<0.05)	0.69	0.67	4.90	0.005	0.07	0.117	0.45	0.118	1.12	0.07	0.96
Growth stage (G)											
G_1 = 20% of ground cover	17.40b	15.92b	88.42a	0.879b	2.08ab	0.69b	7.07abc	0.77a	9.00a	1.47ab	19.95c
G_2 = 40% of ground cover	18.53a	17.009a	88.30a	0.884a	2.12ab	0.70b	6.30ab	0.84a	8.71a	1.52ab	21.09abc
G_3 = 60% of ground cover	18.21ab	16.77ab	85.26ab	0.886a	2.044b	0.82a	5.61c	0.80a	8.73a	1.44b	21.43ab
G_4 = 80% of ground cover	17.58ab	16.06ab	81.89b	0.878b	2.11ab	0.90a	6.00bc	0.87a	8.44a	1.51ab	21.54a
G_5 = 100% of ground cover	18.01	16.41ab	89.38a	0.877b	2.20a	0.87a	6.63a	0.93a	8.70a	1.60a	20.30bc
LSD (p<0.05)	0.99	1.072	4.68	0.0043	0.137	0.094	0.59	0.22	1.65	0.137	1.22
B × G	**	*	ns	*	**	**	**	*	ns	**	ns
C.V.	4.06	4.42	6.54	0.58	2.63	14.23	6.56	16.43	17.11	3.66	5.20

ns: show no significant differences.
* and **: show significant differences at 0.05 and 0.01 probability level, respectively.
SC: sugar content; WSC: white sugar content; K: potassium; Na: sodium; α-amino-N: alpha-amino-nitrogen; AC: alkalinity coefficient; TSS: total soluble solids; SP: sugar productivity; LSP: loss of sugar productivity MS: molasses sugar.

noticeably showed that B_4 and B_3 treatments recorded the highest values of purity percentage by 95.72% and 92.12%, respectively. It is worth mentioning that, considerable differences in purity% were not significant (Table 1). The later application at G_5 insignificantly surpassed the earlier application at G_5 in effecting purity%. Increasing the doses of B application from 0 to 4 g L⁻¹ provided the lowest LSP

and MS 1.79 and 1.19 % with a decrease of 20.44% and 27.87%, respectively at the 60% of ground covered.

Root impurities (K, Na and α-amino-N) and AC

The values of impurities differed greatly due to the different treatments of time and boron rates (Table 3). There was a negative relationship between impurities and boron

Table 2. Means comparison the effects of Nano-B concentration and spraying time (growth stage) on RWC, leaf area, root length, root yield, sugar yield, WSY and TSY of sugar beet.

Treatment		RWC (%)	Leaf area (mm^2)	Root length (cm)	Root yield	Sugar yield	WSY	TSY
Nano-B	Growth stage				(t ha^{-1})			
B$_1$	G$_1$	77.34±3.65	52.10±6.53	25.50±2.50	82.87±7.17	13.08±1.055	11.17±0.89	11.21±0.85
	G$_2$	79.18±2.06	50.66±2.51	26.66±1.52	80.93±1.88	14.28±0.42	12.90±0.39	12.41±0.39
	G$_3$	75.65±2.64	58.61±6.88	25.33±1.52	90.56±9.19	15.06±1.72	13.55±1.54	13.01±1.49
	G$_4$	79.16±3.50	57.57±2.97	27.50±2.17	100.88±8.64	16.39±1.17	14.68±1.09	14.08±1.04
	G$_5$	58.57±5.09	28.69±1.69	36.16±1.89	88.61±8.10	15.84±1.66	14.13±1.47	13.60±1.42
B$_2$	G$_1$	81.64±3.22	51.49±6.04	31.33±1.25	98.36±6.93	17.43±1.02	15.99±0.96	15.40±0.92
	G$_2$	82.22±3.87	66.32±10.35	27.50±2.00	112.21±5.77	19.13±0.73	17.46±0.67	16.79±0.65
	G$_3$	82.33±1.86	74.23±15	34.56±3.84	106.85±10.80	19.51±1.46	17.91±1.36	17.26±1.30
	G$_4$	81.25±1.16	84.36±5.99	34.83±2.84	115.25±10.36	19.68±2.05	17.87±1.99	17.18±1.93
	G$_5$	82.93±2.44	61.78±17.16	38.16±2.25	108.61±7.77	18.87±2.30	17.09±2.10	16.44±2.05
B$_3$	G$_1$	85.23±4.76	53.45±4.49	29.16±1.52	111.17±3.47	19.11±0.85	17.58±0.78	16.92±0.78
	G$_2$	88.86±9.10	74.83±9.15	25.66±2.36	119.89±10.14	23.81±2.23	22.05±2.10	21.34±2.05
	G$_3$	85.41±1.38	76.06±12.47	33.00±4.35	119.06±13.26	22.97±2.30	21.28±2.19	20.57±2.13
	G$_4$	83.56±10.56	92.13±18.71	32.16±2.75	118.42±5.98	21.37±0.59	19.59±0.46	18.88±0.43
	G$_5$	83.51±2.20	79.30±15.30	30.83±2.84	116.90±6.79	21.38±1.89	19.74±1.77	19.04±1.73
B$_4$	G$_1$	82.78±2.47	65.57±9.14	29.50±1.32	103.38±7.20	19.49±1.16	18.02±1.10	17.40±1.07
	G$_2$	83.66±0.31	86.47±10.87	31.83±1.75	144.53±6.95	28.23±2.026	26.19±2.01	25.32±1.98
	G$_3$	82.99±0.46	86.29±8.96	28.16±1.15	135.54±6.011	25.24±2.89	23.62±2.85	22.80±2.82
	G$_4$	82.74±1.99	89.36±8.50	30.33±2.75	127.54±2.52	24.14±0.60	22.49±0.56	21.72±0.54
	G$_5$	81.74±2.03	86.56±14.19	36.33±4.01	127.28±7.60	23.67±1.56	21.81±1.44	21.04±1.40
LSD$_{0.05}$		6.94	16.97	4.21	13.01	2.73	2.58	2.52

B$_1$ indicates no application; B$_2$, B$_3$ and B$_4$ indicate application of 2, 3 and 4 g L^{-1} of Nano-B, respectively.
G$_1$, G$_2$, G$_3$, G$_4$ and G$_5$ indicate foliar application Nano-B at 20, 40, 60, 80 and 100% of ground cover, respectively.

foliar application. Data in Table 3 exposed that, increasing the boron concentrations from 0 to 4 g L^{-1} contributed the last potassium and α-amino-N content of 4.58 and 0.45 mmol/100 g root at 60% growth stage. On the other hand, without the application of boron (B$_1$) resulted in the maximum mean values of K (7.69) and α-amino-N (1.47) content at B$_1$G$_5$. The significant lowest sodium content 0.50 and 0.49 mmol/100 g root related to a reduction in impurity 60.37% and 66.66%, at the application of B$_4$G$_3$ and B$_4$G$_4$, respectively.

Discussion

Foliar application of Nano-B at 3 g L^{-1} resulted in a consistent improvement in vegetative growth of sugar beet, but on increasing Nano-B concentration up to B$_4$, vegetative growth decreased compared with B$_3$. In addition, the increases of yield-related responses like chlorophylls and leaf area (Table 2) of sugar beet at high Nano-B concentration (B$_3$ and B$_4$) could be reflected upon the increase of sugars percentage and reduction of impurities (Table 3), so, the optimal leaf area value for root and sugar yields

was 86.47 cm^2 at B$_4$G$_2$. Leaf number and low chlorophyll content at high boron concentration are associated with toxicity of this element (Armin and Asgharipour 2012). Adequate boron supply through foliar application improved the chlorophyll content, leaf number and leaf area enabling them to capture more light and produce more assimilate for loading to root. Ullah et al. (2013) reported that B deficiency causes to reduced growth of new leaf and shoot due to clear limitation of boric acid phloem mobility. Such enhancement effect of B could be related to the favorable influence of them on photosynthetic pigments (Wanas 2002; Abd El-hady et al. 2017), metabolism, enzyme activity (El-Sherbeny et al. 2007), photosynthesis efficiency (Abou El-Yazied and Mady 2012) which in turn encourage vegetative growth and increasing dry matter production. Also, this enhancement could be an indicator of expectable high sugar beet yield. Also, Abd El-hady et al. (2017) informed that these results might be attributed to that B is an essential element for photosynthetic pigments, where it increases CO$_2$ fixation, rates of photosynthetic O$_2$ evolution and decreases respiration and the activities of oxidative pentose phosphate enzymes.

It seems that the increase in root diameter at 3 g L^{-1} of

Table 3. Means comparison the effects of Nano-B concentration and spraying time (growth stage) on sugar content, WSC, SP, loss of sugar productivity, Na, K, N and MS of sugar beet.

Treatment		SC (%)	WSC (%)	SP	LSP	Na	K	N	MS
Nano-B	Growth stage					(mmol/100g root)			
B₁	G₁	15.80±0.20	14.14±0.27	0.857±0.006	2.25±0.085	0.94±0.16	6.93±0.71	0.96±0.11	1.65±0.081
	G₂	17.66±0.83	15.94±0.74	0.868±0.0025	2.32±0.094	0.96±0.27	7.03±0.87	1.17±0.24	1.72±0.096
	G₃	16.63±0.73	14.97±0.75	0.863±0.0077	2.25±0.058	1.26±0.22	6.33±0.59	1.11±0.19	1.65±0.060
	G₄	16.26±0.41	14.56±0.37	0.859±0.003	2.29±0.070	1.47±0.101	6.23±0.24	1.22±0.14	1.69±0.067
	G₅	17.86±0.64	15.94±0.58	0.859±0.002	2.52±0.070	1.37±0.061	7.69±0.79	1.47±0.14	1.92±0.068
B₂	G₁	17.73±0.30	16.26±0.23	0.883±0.002	2.07±0.072	0.66±0.047	5.84±0.28	0.85±0.21	1.46±0.071
	G₂	17.06±0.64	15.58±0.65	0.877±0.0049	2.08±0.011	0.76±0.035	5.93±0.13	0.84±0.03	1.48±0.011
	G₃	18.30±0.79	16.79±0.77	0.885±0.0045	2.10±0.043	0.83±0.100	5.96±0.19	0.86±0.19	1.50±0.045
	G₄	17.06±0.50	15.49±0.54	0.872±0.0073	2.17±0.081	0.81±0.081	9.56±0.32	0.86±0.14	1.57±0.081
	G₅	17.33±0.90	15.69±0.83	0.871±0.0034	2.23±0.075	0.91±0.085	7.05±0.52	0.83±0.05	1.63±0.072
B₃	G₁	17.20±0.80	15.82±0.78	0.885±0.0049	1.97±0.055	0.63±0.062	5.59±0.30	0.60±0.09	1.37±0.057
	G₂	19.86±0.80	18.39±0.79	0.896±0.0040	2.06±0.025	0.57±0.028	6.30±0.24	0.67±0.07	1.46±0.021
	G₃	19.33±0.98	17.90±0.98	0.894±0.0061	2.02±0.050	0.69±0.060	5.56±0.27	0.80±0.20	1.42±0.052
	G₄	18.06±0.50	16.56±0.50	0.883±0.0040	2.10±0.052	0.83±015	5.99±0.36	0.84±0.09	1.50±0.052
	G₅	18.26±0.57	16.86±0.55	0.890±0.0023	2.00±0.20	0.67±0.105	5.41±0.21	0.78±0.12	1.39±0.019
B₄	G₁	18.86±0.64	17.44±0.66	0.893±0.0050	2.02±0.034	0.53±0.041	5.92±0.11	0.69±0.10	1.42±0.035
	G₂	19.53±0.90	18.11±0.91	0.896±0.0050	2.02±0.052	0.52±0.058	5.94±0.48	0.68±0.03	1.41±0.054
	G₃	18.60±1.56	17.40±1.58	0.903±0.0091	1.79±0.046	0.50±0.073	4.58±0.33	0.45±0.08	1.19±0.047
	G₄	18.93±0.23	17.63±0.25	0.899±0.0030	1.90±0.043	0.49±0.072	5.23±0.20	0.55±0.18	1.30±0.043
	G₅	18.60±0.52	17.13±0.55	0.888±0.0047	2.06±0.041	0.54±0.032	6.37±0.03	0.64±0.15	1.46±0.039
LSD₀.₀₅		1.207	1.20	0.0085	0.092	0.188	0.66	0.22	0.091

B₁ indicates no application; B₂, B₃ and B₄ indicate application of 2, 3 and 4 g L⁻¹ of Nano-B, respectively.
G₁, G₂, G₃, G₄ and G₅ indicate foliar application Nano-B at 20, 40, 60, 80 and 100% of ground cover, respectively.

Nano-B by means of high leaf number and chlorophyll content and efficient assimilates portioning towards sink parts. These results could be explained by the role of boron in plant metabolism, development and growth (Rawashdeh and Sala 2013; Abido 2012), cell wall formation and meristematic tissue extension and cell elongation the root (Nalini et al. 2013). Cell enlargement and increase in a number of cells contribute to the increase of yield can be due to the role of boron in the biosynthesis of auxin in the meristematic activity and increase in the IAA-oxidase activity. Similar observations were recorded by Abdelaal et al. (2015) and Dugger (1973) in sugar beet.

Armin and Asgharipour (2012) stated that the maximum root yield and sugar percentage was achieved by foliar application of 12% boric acid. Considering this, Nano-B spraying may be used to enhance root and sugar yield, resulting in reduce boron fertilizer. Foliar Nano-B application predominantly affects at vegetative growth compared with reproductive growth in sugar beet. Results in Table 2 exhibited that sugar yield and white sugar yield was significantly improved by increasing of B from B₁ to B₄. These results were true in the five growth stages. While that sugar content was decreased by B₄ when compared with B₃ treated plants (Table 2), the increase in sugar yield accompanying high boron level might have been due to the increase in root yield as well as sucrose content. These results are in agreement by those of Gezgin et al. (2001).

It seems that, better translocation of photosynthates from high leaf area (Table 2) and higher dry matter accumulation with high root length led to increasing in root yield (Table 2). The increase in tops and roots fresh and dry weights, caused by boron application, could be attributed to the stimulating effect of boron on the photosynthesis process in the plants such as translocation of sugar and carbohydrates of assimilates from the top to root, which leads to increase in root and sugar yield. On the other hand, when photosynthetic activity is high, any factor that increases the leaf area may have a positive effect on WSY. The enhancement of dry matter in sugar beet roots may be attributed to the improvement of leaf area, leaf number, RWC and chlorophyll content which results in improvement of growth-related traits such as root length and root diameter, and consequently root yield sugar yield (Table 2). Similar results were also observed by Abdel-Motagally (2015) and Mohammadian et al. (2014) who reported that early beginning of photosynthetic

transmission from leaf to root and consequently, it would increase WSY at the harvest time.

The rise of WSC may be due to the increase in sugar percentage and the reduction of impurities in terms of sodium, potassium and α-amino-N content (Table 3). Further, if optimum B is available at the early growth stage, the plant continues to partition it in the sink part as have been observed in this study. This finding suggested that sugar content is the key factor conferring B phloem mobility due to the bonding of sugar and boric acid (Liakopoulos et al. 2005). The Nano-boron facilitates the transport of sugars in the plants because it had a crucial role in the biosynthesis of auxin (Dugger 1973; Ullah et al. 2013). The high amount of juice purity would be desirable to provide sugar content. The important role of the boron element on the percentage of purity comes through its beneficial effect on the values of sucrose content (Table 3). Boron dominates in the early-stage, building up the highest TSS for the sugar beets (Table 1).

The result showed that, at low concentration of boron, a lower percentage of sugar had been achieved. Therefore, sugar in the form of molasses in these plants is higher in amount than that which has received enough boron (Table 3). Reduction of impurities like sodium, potassium and α-amino-N content in beet roots cause to decrease of sucrose molasses under application of a higher rate of boron application. These results are an agreement with the finging of Abbas et al. (2014) who reported that increasing the concentration of B cause to the reduction of sugar molasses. Hellal et al. (2009) showed that juice purity, sugar and root yield of sugar beet improved by increasing of B spraying which could be related to the reduction of sodium and potassium uptake in root juice.

The reasons for the improvement in sugar beet quality could be due to the fact that B plays a role in cell division, enhanced enzymatic activity, the membrane integrity, calcium uptake and carbohydrate metabolism (Nalini et al. 2013; Rawashdeh and Sala 2013). An increased boron supply decreases the nitrate levels via inhibiting transcript level in the roots and altering the nitrate transporter activity, leading to reduced plasma membrane enzymes activities (Camacho-Cristobal and Gonzalez-Fontes 2007). Evidence proposes that sugar alcohols synthesis and the later transport of the B-sugar alcohol compound in the phloem to sink tissues is the main factor that confers phloem B mobility to a plant species (Brown et al. 1999). The least accumulation of sodium at the later application (G_3 and G_4) could be due to the increased of leaf area at this time and facilitate the improvement of B absorption. Similar results were obtained by Abbas et al. (2014) who reported that spraying dates lead to significantly different in sodium content. Also, Armin and Asgharipour (2012) and Abbas et al. (2014) showed that boron application improved juice quality by declining K and Na content.

Conclusion

Application of Nano-B rates showed a significant increase in quantitative and qualitative sugar beet traits under study. The highest SPAD and RWC, leaf area and leaf number were observed in 3 g L^{-1} of Nano-B resulted in a consistent improvement in vegetative growth of sugar beet but with increasing concentration of Nano-B mentioned parameters were decreased. The increasing of boron fertilizer at all growing stages resulting in the highest root yield, sugar content and white sugar content thus led to increasing sugar yield, white and technological sugar yield. The decrease in sucrose molasses in a high level of boron accompanying due to the reduction in impurities in terms of sodium, potassium and α-amino-N content in sugar beet roots. Therefore, B_4G_2 treatment (4 g L^{-1} boron at 40% of ground covered) with the highest root and sugar yield may be recommended for the cultivation of sugar beet in terms of time and fertilizer saving.

Acknowledgements

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