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RESEARCH ARTICLE

Efficacy of Nanofertilizer, Fulvic Acid and Boron Fertilizer on Sugar Beet (*Beta vulgaris* L.) Yield and Quality

Essam E. Kandil[1] · Nader R. Abdelsalam[2] · Ashraf A. Abd EL Aziz[3] · Hayssam M. Ali[4,5] · Manzer H. Siddiqui[4]

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Abstract Sugar beet (*Beta vulgaris* L.) is the second most abundant sugar crop after sugarcane. Two field experiments were conducted at the research farm of the Faculty of Agriculture, Saba Basha, Alexandria, Egypt, to study the effects of foliar application treatments and boron (B) fertilizer applications on monogerm sugar beet plants (cultivar classic) during the 2017/2018 and 2018/2019 seasons. The treatments were replicated three times in a split-plot design. Four foliar applications [fulvic acid (FvA), NPK nanoparticles (NPK NPs), FvA + NPK NPs, and a control (water)] were randomly allocated to the main plots. Different numbers of foliar spray applications of B [one application at 120 days after sowing or two applications at 120 and 150 days after sowing, as well as a control (water)] were assigned within the subplots. FvA + NPK NPs significantly increased the root length, root diameter, root weight, and root/shoot ratio of the sugar beet plants; the greatest values were obtained by spraying FvA + NPK NPs during both seasons. B significantly increased the root yield, shoot yield, and biological yield, and two applications of B resulted in the greatest values of root yield, shoot yield, biological yield, and quality of sugar beet. The interaction between FvA or NPK NPs and B significantly affected the yield and quality parameters of the sugar beet plants. However, the greatest mean values of these traits resulted from foliar applications of FvA + NPK NPs in conjunction with applications of B under the conditions at Alexandria, Egypt.

Keywords Sugar beet · Improvement · Nanofertilizer · Yield · Quality

✉ Essam E. Kandil
essam.kandil@alexu.edu.eg

✉ Nader R. Abdelsalam
nader.wheat@alexu.edu.eg

Ashraf A. Abd EL Aziz
nkhily@yahoo.com

Hayssam M. Ali
hayhassan@ksu.edu.sa

Manzer H. Siddiqui
mhsiddiqui@ksu.edu.sa

1 Plant Production Department, Faculty of Agriculture (Saba Basha), Alexandria University, Alexandria 21531, Egypt

2 Agricultural Botany Department, Faculty of Agriculture (Saba Basha), Alexandria University, Alexandria 21531, Egypt

3 Faculty of Agriculture (Saba Basha), Alexandria University, Alexandria 21531, Egypt

4 Botany and Microbiology Department, College of Science, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia

5 Timber Trees Research Department, Sabahia Horticulture Research Station, Horticulture Research Institute, Agriculture Research Center, Alexandria 21526, Egypt

Introduction

Sugar is considered a strategic good that is an inexpensive source of energy, and it is produced by two main crop species, i.e., sugarcane and sugar beet (*Beta vulgaris* L.). Sugar beet is the second most vital sugar crop species after sugarcane. Sugar beet has become the main source of sugar in Egypt. In Egypt, the total production of sugar from sugar beet reached 56.61% (1.27 million tons), while the production of sugarcane constituted 43.39% (0.931 million tons) (Sayed and Omar 2018). Currently, nanotechnology affects almost all aspects of agricultural production, including fertilizers, insecticides, and pesticides (Biswas and Wu 2005; Abdelsalam et al. 2019). Therefore, the application of nanoparticles to plants can be increased growth because of their high absorbance and high reactivity (Liu and Lal 2015). Studies conducted by Dewdar et al. (2018) on sugar beet plants treated with 200 mg/L nano-microelements + urea 1% revealed that this combination was the most effective in terms of the effects on root length (cm), root diameter (cm), and yield, followed by the 160 mg/L + urea 1% combination; the former combination produced significantly increased yields, improved sugar beet quality, and reduced plant requirements for supplemental micronutrients and N. Additionally, foliar application of nanofertilizers combined with mineral fertilizers improved the total yield and various yield components in many crop species, including maize, wheat, bean, and sugar beet (Moghaddasi et al. 2013; Sabir et al. 2014; Jakienė et al. 2015; Abdelsalam et al. 2019).

Fulvic acid (FvA) can help transport trace elements through the cell membrane for release inside cells. Thus, FvA can be considered appropriate for foliar application, allowing micronutrients such as Cu, Fe, Mn, and Zn to be better absorbed by leaves (El-Hassanin et al. 2016). FvA is a subclass of various mixtures recognized as humic substances (Senesi and Loffredo 2018). Humic substances can improve nutrient applications, improve chlorophyll production, improve seed germination, and enhance fertilizers, ultimately strengthening plants. Researchers have investigated the use of foliar applications of FvA; for example, Suh et al. (2014) reported that 0.8 g/L FvA enhanced the growth and yield of tomato plants. El-Hassanin et al. (2016) studied sugar beet and reported that FvA improved the contents of other humic substances as well as sucrose, extractable sugars, and their purity. FvA also can increase crop yield and quality. Justi et al. (2019) reported that humic acid and FvA improved nutrient availability in and uptake by coffee seedlings. Additionally, those authors demonstrated the effects of soil applications of humic acid and foliar applications FvA on plant growth.

B is a critical trace element necessary for the physiological function of higher plants. B deficiency can cause nutritional disorders that negatively affect plant metabolism and growth, and B is among the essential nutrients needed for the ideal growth, development, and yield quality of several crop species (Brown et al. 2002). B promotes vital functions in sugar beet, such as maintaining the balance between sugar and starch and K^+ transport (Kobayashi et al. 2004; Camacho-Cristóbal and González-Fontes 2007). Adding B to sugar beet during the growth stage had a great effect on sucrose concentration, root yield, K^+, Na^+, and molasses sugar. Dewdar et al. (2018) added B (0.25 g/L) via foliar spray twice (at 80 and 110 days after sowing) to sugar beet and detected significant differences in root, shoot, and yield traits. Additionally, El-Sherief et al. (2016) and Aly et al. (2017) showed that foliar applications of B enhanced root characteristics and sugar yields and also improved the percentages of sugar, total soluble solid (TSS), and purity. Nemeata Alla (2017) revealed that increasing the concentration of B in foliar sprays from 100 to 150 ppm resulted in greater values of root characteristics and yield quality at harvest. The greatest demand for B occurs during the stage of intense leaf development, and B application resulted in leaf surface areas that were greater for treated plants than for control plants; in fact, compared with the control treatment, two different B fertilization treatments (1 or 2 kg B/ha) caused significantly greater yield, sugar percentage, and pure sugar yield. Last, Rehab et al. (2019) indicated that the increase in B fertilization from 0 to 960 g/ha to 1920 g/ha and 2880 g/ha significantly increased the growth and yield of sugar beet. In addition, the greatest values were recorded in response to 2880 g/ha. Therefore, the objective of the present work was to study the effects of foliar applications of combinations of FvA and NPK NPs and the number of B fertilizer applications on sugar beet in the Alexandria region; additionally, we investigated the effects of their interaction on both the yield and quality of sugar beet.

Materials and Methods

Two experiments were performed at the agricultural farm in the Abis region, Alexandria, Egypt, during the seasons of 2017/2018 and 2017/2019. The experiments involved the monogerm sugar beet (*Beta vulgaris* L.) cultivar Classic, which was obtained from the Agricultural Research Center of the Sugar Crop Research Institute. The previous crop in both seasons was *Zea mays* L. The physical and chemical properties of the soil before sowing were analyzed by Fazal et al. (2016) and are listed in Table 1. The treatments were established as part of a split-plot system with three replicates. Four foliar application treatments (FvA, NPK NPs, FvA + NPK NPs, and a control) were allocated randomly to the main plots. The number of foliar applications of B, in the form of boric acid (control, one application at 120 days after sowing and two applications at 120 and 150 days after sowing), was assigned within the subplots. The experimental field was first plowed, and calcium superphosphate (12.5% P_2O_5) was applied during tillage at a rate of 840 kg/ha, and potassium sulfate (48% K_2O) was applied at a rate of 120 kg/ha (57.6 kg K_2O/ha). N fertilizer was applied in the form of urea (46% N) at a rate of 240 kg N/ha in two equal doses: The first half was applied after thinning (before the first irrigation), and the second half was applied before the second irrigation. Seeds of the monogerm cultivar Classic

Table 1 Soil chemical and physical properties of the field sites in the 2017/2018 and 2018/2019 seasons

Season	Clay (%)	Silt (%)	Sand (%)	Organic matter (%)	Texture class
Physical property analysis					
2017/2018	23.4	21.2	52.2	0.78	Sandy clay loam
2018/2019	22.6	23.6	53.4	0.81	

Season	pH	EC (dS/m)	HCO_3 (%)	$CaCO_3$ (%)	Element availability (mg/kg)							
					N	P	K	Fe	B	Zn	Cu	Mn
Chemical property analysis												
2017/2018	8.0	2.1	12.2	24.8	28.2	7.4	199.1	5.3	0.9	0.75	1.2	4.5
2018/2019	8.1	2.0	11.7	24.4	25.7	6.5	186.9	4.2	0.8	0.96	2.5	5.6

Table 2 Analysis of nanofertilizer used

Element	Nanopotassium fertilizer (amino-mineral) (%)
K_2O	3.0
Amino acids (AA)	5.0
Vitamins	1.0
Total N	8.0
Micronutrients (Br, Zn, Mn, Co, and Mo)	10.0
Seaweed extract	5.0

*Contents are available on the state website (www.bionano-egypt.com)

were sown by hand on the 8th and 6th of October in the 2017/2018 and 2018/2019 seasons, respectively, at the rate of 1 seed/hill on one side of the ridge of the hill, and the seeds were spaced 20 cm apart. The basic experimental unit was a 10.5 m^2 area and included five ridges each; the width of each unit was 60 cm, and the length was 3.5 m. FvA was applied at a rate of 10 mg/L, and NPK NPs were applied at a rate of 4.8 L/ha; both were applied as foliar sprays (Table 2). B was applied as Nutribor® (8% boric acid), Compo Expert, Germany, at a rate of 3600 g/ha (ha = 2.4 fed).

The characterization of the NPK NPs was confirmed by transmission electron microscopy (TEM) (Hitachi, Japan) according to the methods of Elavazhagan and Arunachalam (2011), as shown in Fig. 1. Last, during harvest (180 days after sowing), the plants were harvested and cleaned; afterward, their leaves were removed, and then, the plants were weighed. Various root characteristics were calculated, such as biological yield (t/fed), sugar yield (t/fed), TSSs (%), sucrose (%), and purity (%). Statistical analysis was

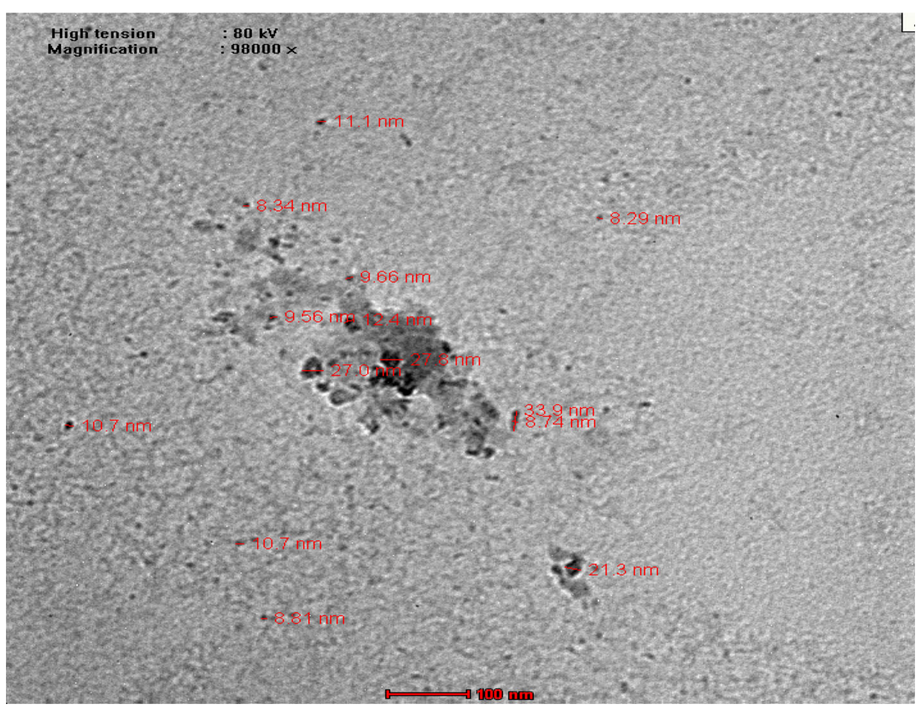

Fig. 1 Transmission electron micrograph (× 7500) of NPK NPs

carried out according to the methods of Steel and Torrie (1981). The treatment means were compared by the least significant difference (LSD) test at the 0.05 level of probability, which was computed using the Ver CoStat (2005) program.

Results and Discussion

The results shown in Table 3 show the effects of foliar applications of NPK NPs and FvA, the effects of different numbers of foliar applications of B, and their interaction effects on the root length, root diameter, root weight, and root/shoot ratio of sugar beet during the 2017/2018 and 2018/2019 seasons.

The foliar application of NPK NPs together with FvA significantly increased the root parameters and root/shoot ratio of sugar beet during both seasons; the maximum values were obtained in response to FvA + NPK NPs, with no significant difference between this treatment and the NPK NP treatment. The lowest mean values were obtained for sugar beet plants under the control treatment (water only) of B in both seasons (Table 3). The increase in these traits was due to the function of NPK NPs in relation to cell

Table 3 Root characteristics of sugar beet plants treated with different combinations of foliar applications of nanofertilizer and fulvic acid and different numbers of foliar applications of B and their interaction effects during both seasons

Traits	Foliar application treatments (A)	Season 2017/2018				Season 2018/2019			
		Boron applications (B)			Average (A)	Boron applications (B)			Average (A)
		Control	Once	Twice		Control	Once	Twice	
Root length (cm)	FvA	18.3	22.3	25.7	22.1	19.0	25.3	28.0	24.1
	NPK NPs	21.3	25.7	29.7	25.6	22.3	28.7	32.0	27.7
	FvA + NPK NPs	23.7	27.7	27.7	26.4	26.0	26.7	30.3	27.7
	Control (water only)	19.0	22.5	22.3	21.3	20.0	24.0	21.7	21.9
Average (C)		20.6	24.6	26.4		21.8	26.2	28.0	
LSD at 0.05	A		1.1				1.4		
	B		1.3				1.3		
	A × B		2.2				2.7		
Root diameter (cm)	FvA	20.1	27.0	27.0	24.7	19.7	25.3	27.7	24.2
	NPK NPs	23.7	26.3	28.3	26.1	23.0	28.0	28.3	26.4
	FvA + NPK NPs	25.0	26.0	31.3	27.4	24.3	24.0	30.0	26.1
	Control (water only)	19.7	20.7	22.0	20.8	19.3	21.7	22.3	21.1
Average (C)		22.1	25.0	27.2		21.6	24.8	27.1	
LSD at 0.05	A		1.6				1.2		
	B		1.3				1.0		
	A × B		2.7				1.9		
Root weight (g)/plant	FvA	1366.7	1620.0	1562.7	1516.5	1377.7	1636.7	1585.3	1533.2
	NPK NPs	1495.7	1710.7	1716.3	1640.9	1502.0	1677.7	1692.3	1624.0
	FvA + NPK NPs	1598.7	1621.7	1777.3	1665.9	1594.3	1707.0	1768.0	1689.8
	Control (water only)	1403.7	1440.7	1444.7	1429.7	1384.7	1455.3	1455.3	1431.8
Average (C)		1466.2	1598.3	1625.3		1464.7	1619.2	1625.2	
LSD at 0.05	A		49.2				80.3		
	B		49.3				46.8		
	A × B		98.6	3.9			93.7		
Root/shoot ratio	FvA	3.5	3.7	3.9	3.7	3.7	4.0	3.8	3.8
	NPK NPs	3.9	3.7	3.7	3.8	3.7	4.0	3.9	3.9
	FvA + NPK NPs	3.5	3.6	3.5	3.6	3.1	3.1	3.7	3.3
	Control (water only)	3.7	3.6		3.6	3.8	3.4	4.0	3.7
Average (C)		3.7	3.7	3.8		3.6	3.6	3.9	
LSD at 0.05	A		0.2				0.2		
	B		0.1				0.2		
	A × B		0.2				0.3		

division and growth, and as a soil amendment and organic acid, FvA plays a vital role in root activation and can reduce the high pH of soils. These results are in agreement with those obtained by previous researchers (Liu and Lal 2015; Dewdar et al. 2018; Abdelsalam et al. 2019), who showed that the applications of NPK NP fertilizer can increase the yield and yield components of numerous crop species. On the other hand, El-Hassanin et al. (2016) indicated that foliar applications of FvA improved the growth, yield, and yield components of several crop species. The results in Table 3 show that increasing the number of B fertilizer applications significantly improved the parameters of sugar beet roots; the greatest values were obtained in response to two applications of B. The lowest values were recorded in the control (water only) treatment during both seasons. These results are in agreement with those obtained by previous researchers (El-Sherief et al. 2016; Aly et al. 2017; Rehab et al. 2019), who reported that foliar applications of B improved the yield and yield components of sugar beet.

The interaction of NPK NPs or FvA and B foliar applications significantly influenced the root length, root diameter, root weight, and root/shoot ratio of sugar beet during both seasons (Table 3). The maximum root length values were obtained in response to foliar application of NPK NPs combined with two applications of B fertilizer. The greatest root diameter and root weight values were obtained in response to FvA + NPK NPs combined with two B foliar applications. However, FvA with two B applications yielded the greatest root/shoot ratio. On the other hand, the lowest values were obtained in response to the control (water only) and two factors (foliar + B fertilizer) in the two seasons. These results demonstrated that the NPK NPs and FvA treatments and the number of B applications acted independently on root yield. The results in Table 3 show the effects of foliar applications of NPK NPs and FvA, the effects of the number of foliar applications of B, and their interaction on the root yield, shoot yield, and biological yield of sugar beet during the two seasons.

Table 4 Yield characteristics of sugar beet plants treated with different combinations of foliar applications of nanofertilizer and fulvic acid and different numbers of foliar applications of B and their interaction during the 2017/2018 and 2018/2019 seasons

Traits	Foliar application treatments (A)	Season 2017/2018				Season 2018/2019			
		Boron applications (B)			Average (A)	Boron applications (B)			Average (A)
		Control	Once	Twice		Control	Once	Twice	
Root yield (t/fed)	FvA	19.1	21.9	21.4	20.8	18.8	21.9	21.7	20.8
	NPK NPs	20.0	22.9	23.4	22.1	21.8	18.3	21.8	20.6
	FvA + NPK NPs	20.6	22.3	24.6	22.5	20.3	22.5	23.2	22.0
	Control (water only)	19.2	20.1	19.9	19.7	18.3	21.4	21.2	20.3
Average (C)		19.725	21.8	22.3		19.8	21.0	22.0	
LSD at 0.05	A		0.8				0.7		
	B		0.6				0.6		
	A × B		1.2				1.3		
Top yield (t/fed)	FvA	5.4	5.7	5.8	5.6	5.0	5.5	5.9	5.5
	NPK NPs	5.1	5.9	6.3	5.8	5.2	5.7	6.3	5.7
	FvA + NPK NPs	5.8	6.1	6.9	6.3	5.8	6.1	7.2	6.4
	Control (water only)	5.1	5.7	5.5	5.4	5.3	5.7	5.8	5.6
Average (C)		5.4	5.9	6.1		5.3	5.8	6.3	
	A		0.3				0.4		
LSD at 0.05	B		0.2				0.3		
	A × B		0.4				0.6		
Biological yield (t/fed)	FvA	24.5	27.6	27.2	26.4	23.8	27.4	27.6	26.3
	NPK NPs	25.1	28.8	29.7	27.9	27.6	24.3	28.1	26.4
	FvA + NPK NPs	26.4	28.4	31.5	28.8	26.1	28.6	30.4	28.4
	Control (water only)	24.3	25.8	25.4	25.2	23.6	27.1	27.0	25.9
Average (C)		25.1	27.7	28.5		25.1	26.8	28.3	
	A		1.0				0.9		
LSD at 0.05	B		0.7				0.8		
	A × B		1.5				1.7		

Foliar applications of NPK NPs and FvA significantly increased the root yield, shoot yield, and biological yield of sugar beet. The maximum mean values of root yield (22.5 and 22.0 t/fed), shoot yield (6.3 and 6.4 t/fed), and biological yield (28.8 and 28.4 t/fed) were obtained in response to the application of FvA + NPK NPs in the first and second seasons, respectively. On the other hand, the lowest mean values of root yield (19.7 and 20.3 t/fed), shoot yield (5.4 and 5.6 t/fed), and biological yield (25.2 and 25.9 t/fed) were obtained by growing sugar beet plants under the control treatment (water only) in both seasons, respectively (Table 4). As an organic acid, FvA plays a vital role in root activation and can be used as a soil amendment. The current results agree with those obtained by previous researchers (Dewdar et al. 2018; Abdelsalam et al. 2019) who showed that the use of NPK NPs increased the yield, and yield components of many crop species. In contrast, El-Hassanin et al. (2016) indicated that the application of FvA increased the growth, yield and yield components of many crop species.

Table 4 shows that increasing the number of B fertilizer applications significantly increased the root yield, shoot yield, and biological yield of the sugar beet plants. Specifically, two foliar applications of B resulted in the greatest mean values of root yield (22.3 and 22.0 t/fed), shoot yield (6.1 and 6.3), and biological yield (28.5 and 28.3 t/fed) of sugar beet. The lowest values were obtained in response to the water (control) treatment in both seasons. These results are in agreement with those of previous researchers (El-Sherief et al. 2016; Rehab et al. 2019) who indicated that foliar applications of B improved yield and yield components. The results in Table 4 and Fig. 2 show the interaction effects between foliar applications of NPK NPs, FvA, and B; there were significant interaction effects on the root yield, shoot yield, and biological yield of sugar beet during both seasons. The maximum mean values of root yield (24.6 and 23.2 t/fed), shoot yield (6.9 and 7.2 t/fed), and biological yield (31.5 and 30.4 t/fed) of sugar beet were obtained in response to foliar application of NPK NPs combined with two applications of B fertilizer. The

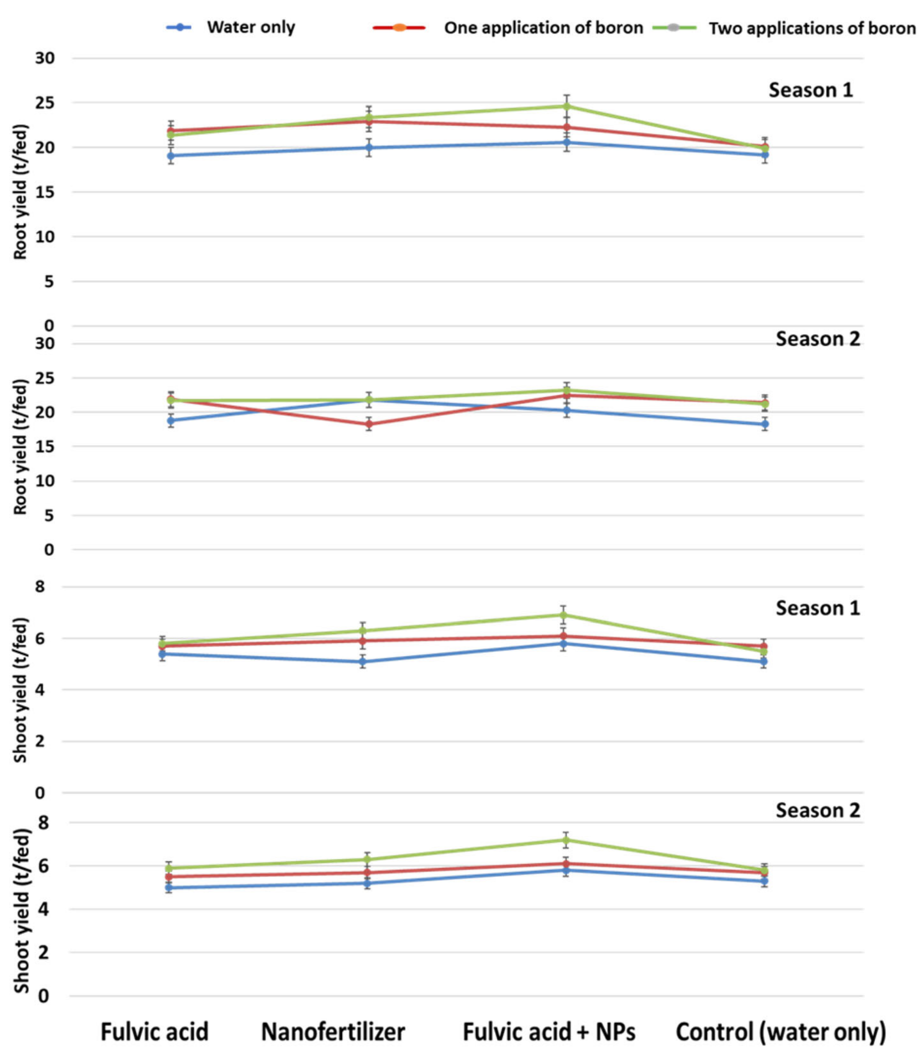

Fig. 2 Root and shoot yield of sugar beet as affected by the interaction between FvA plus nanofertilizer applications and B fertilizer applications in two seasons

Table 5 Sugar yield and percentages of sucrose, TSSs, and purity of sugar beet plants treated with different combinations of foliar applications of nanofertilizer and fulvic acid and different numbers of foliar applications of B and their interaction effects during both seasons

Traits	Foliar application treatments (A)	Season 2017/2018				Season 2018/2019			
		Boron applications (B)			Average (A)	Boron applications (B)			Average (A)
		Control	Once	Twice		Control	Once	Twice	
Sugar yield (t/fed)	FvA	3.2	4.0	3.9	3.7	3.2	3.8	3.9	3.6
	NPK NPs	3.5	4.4	4.7	4.2	3.6	4.3	4.6	4.2
	FvA + NPK NPs	3.8	4.2	4.9	4.3	4.0	3.4	4.1	3.8
	Control (water only)	3.4	3.5	3.7	3.5	3.8	3.4	4.2	3.8
Average (C)		3.5	4.0	4.3		3.7	3.7	4.2	
LSD at 0.05	A		0.2				0.3		
	B		0.1				0.1		
	A × B		0.3				0.3		
Sucrose (%)	FvA	17.0	18.3	18.3	17.9	17.3	17.3	18.3	17.6
	NPK NPs	18.3	18.7	19.7	18.9	18.3	18.6	19.3	18.7
	FvA + NPK NPs	17.7	19.0	20.0	18.9	17.7	19.3	19.6	18.9
	Control (water only)	17.8	17.4	18.8	18.0	18.1	17.4	18.9	18.1
Average (C)		17.7	18.4	19.2		17.9	18.2	19.0	
LSD at 0.05	A		0.4				1.1		
	B		0.6				0.6		
	A × B		1.2				1.3		
TSS (%)	FvA	20.8	25.5	25.4	23.9	21.0	26.9	25.8	24.6
	NPK NPs	22.2	21.2	28.0	23.8	21.9	20.7	28.2	23.6
	FvA + NPK NPs	23.3	24.5	26.4	24.7	23.7	24.5	27.0	25.1
	Control (water only)	19.7	22.0	22.0	21.2	20.0	22.8	21.0	21.3
Average (C)		21.5	23.3	25.5		21.7	23.7	25.5	
LSD at 0.05	A		1.9				2.0		
	B		1.0				1.2		
	A × B		2.0				2.5		
Purity (%)	FvA	79.7	80.7	82.5	81.0	79.2	81.8	82.9	81.3
	NPK NPs	79.8	81.5	83.0	81.4	79.9	81.7	83.0	81.5
	FvA + NPK NPs	80.1	82.8	85.5	82.8	80.8	83.0	86.3	83.4
	Control (water only)	79.5	79.9	80.7	80.0	81.4	80.4	80.6	80.8
Average (C)		79.8	81.2	82.9		80.3	81.7	83.2	
LSD at 0.05	A		1.3				1.4		
	B		0.8				0.8		
	A × B		1.7				1.7		

lowest values were obtained under the control treatment (water only) and two factors (foliar + B fertilizer) in both seasons. These results indicate a significant interaction effect between and NPK NPs and FvA, and the number of times B was sprayed in this study. Overall, the results showed that NPK NP, FvA, and B acted dependently on the shoot yield, biological yield, and sugar yield of sugar beet plants. In addition, the results in Table 4 demonstrate the effects of foliar applications of NPK NPs and FvA and foliar applications of B and their interaction on sugar yield as well as the percentages of sugar, TSSs, and purity of sugar beet during both seasons.

The results in Table 5 show that the foliar application treatments significantly increased the sugar yield as well as the percentages of sucrose, TSSs, and purity of the sugar beet plants during both seasons. However, the maximum mean values of these traits were obtained in response to treating sugar beet plants with foliar applications of FvA + NPK NPs in both seasons. The lowest mean values of these traits were obtained in the control treatment (water only). These results exhibit the same trend as did the results

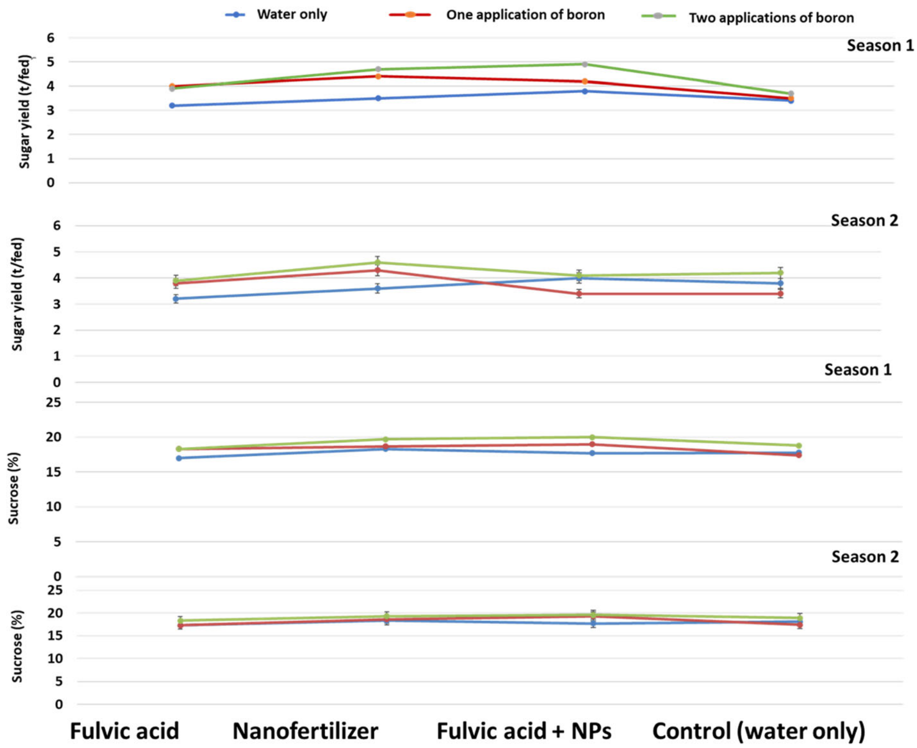

Fig. 3 Sugar yield and sucrose (%) of sugar beet as affected by the interaction between FvA plus nanofertilizer applications and B fertilizer applications in two seasons

obtained by previous researchers (Liu and Lal 2015; Dewdar et al. 2018; Abdelsalam et al. 2019) who showed that the use of NPK NPs increased the yield and yield components in many crop species. Moreover, El-Hassanin et al. (2016) reported that FvA improved the growth, yield, and yield components of many crop species. Foliar application of B significantly increased the sugar yield and the percentages of sucrose, TSSs, and purity of the sugar beet plants in both seasons, as shown in Table 5. The greatest mean values were obtained when B was applied twice. The lowest mean values were obtained under the control treatment (water only) during both seasons. However, there was no significant effect between foliar applications of FvA + NPK NPs and NPK NPs alone on the mean values of these traits in either season. However, the greatest sugar yield was obtained in response to spraying only NPK NPs in the second season. These results are in agreement with those obtained by previous researchers (El-Sherief et al. 2016; Rehab et al. 2019) who indicated that foliar applications of B increased the yield and yield components of sugar beet.

The data in Table 5 and Fig. 3 show that the interaction between foliar application of NPK NPs and FvA and foliar applications of B significantly affected the sugar yield and the percentages of sucrose, TSSs, and purity of the sugar beet plants in the two seasons. These results showed that FvA + two applications of B acted dependently on the sugar yield and the percentages of sucrose, TSSs, and purity of the sugar beet plants in this study. The greatest mean values of these traits were obtained in response to foliar application of FvA + NPK NPs or foliar application of NPK NPs combined with two applications of B in both seasons. The lowest values in both seasons were obtained in the control treatment (water only). Increases in the parameters of sugar beet plants in response to foliar applications of FvA and soil-based applications of NPK NPs can be affected by salinity. FvA may have a greater agronomic efficacy as foliar spray than as a soil amendment (Geilfus 2019; Wang et al. 2019). Moreover, FvA regulates hormone levels and contributes to the generation of secondary metabolites in plants and microalgae (Che et al. 2016). Wang et al. (2019) showed the importance of the effects of FvA on growth properties. FvA also plays an important role in cell signal transduction (Canellas et al. 2015; Liu and Lal 2015; Jarošová et al. 2016). The growth of sugar beet in the field is affected by salinity; as such, the present study investigated the use of foliar applications of B to increase yield, yield components, and quality, and the increases were indeed due to B, which is involved in numerous physiological and biochemical processes in plants (Kabu and Akosman 2013). Additionally, P and K alone or combined was an important factor influencing the availability of B. In fact, B adsorption occurs best in soils whose pH ranges from 3 to 9, but the adsorption decreases as the pH continues to increase (Goldberg et al. 2008). On the basis of previous results, we recommend applying different combinations of NPK NPs and FvA as well as applying two foliar sprays of B to increase sugar beet yield and quality. Additionally, the present results agree with those of previous researchers who studied the effects of foliar applications of Ca and Si on sugar beet plants.

Conclusion

According to the results of the present study, foliar application of NPK NPs with FvA significantly increased the root characteristics of sugar beet plants in two seasons, and the greatest values were obtained by spraying FvA + NPK NPs, with no significant difference between the plants in this treatment and those treated with foliar application of NPK NPs alone. In contrast, the lowest mean values were obtained under the control treatment (water only) in both seasons. The interaction caused by the foliar application of NPK NPs or FvA and foliar application of B significantly affected the root length, root diameter, root weight, and root/shoot ratio of the sugar beet plants in both seasons. Additionally, foliar application of NPK NPs and FvA significantly increased the root yield, shoot yield, and biological yield of sugar beet; the greatest mean values of root yield were obtained in response to the application of the FvA + NPK NPs in both seasons. Moreover, the results revealed that increasing the number of B applications significantly increased the root yield, shoot yield, and biological yield of sugar beet. The greatest mean values of root yield were obtained in response to two B applications, while the lowest values were obtained under the control treatment (water only) in both seasons. These results mean that there were significant responses to NPK NPs and FvA and the number of B applications. These results showed that the shoot yield, biological yield, and sugar yield of the sugar beet plants were dependent on the NPK NPs, FvA, and B fertilizer in this study. In addition, the results showed the effects of foliar applications, the effects of the number of B applications, and their interaction on the sugar yield and the percentages of sucrose, TSSs, and purity of the sugar beet plants in both seasons. Moreover, the data demonstrated that the interaction between foliar applications of NPK NPs and FvA and foliar applications of B significantly affected the sugar yield and the percentages of sucrose, TSSs, and purity of the sugar beet plants in the two seasons. In conclusion, sugar beet treated with the foliar applications of NPK NPs with FvA and two applications of B increased the productivity of sugar beet. This treatment also increased the root and sugar yield and the sugar quality of the plants under the conditions of the Alexandria region and similar regions.

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Availability of Data and Material The data used to support the findings of this study are included within the article.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflicts of interest.

Code Availability The coding of the data is available from the corresponding author upon reasonable request.

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