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IMPACT OF ZEOLITE AND BORON ON YIELD AND QUALITY OF SUGAR BEET IN BORG EL-ARAB REGION

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ABSTRACT: Two field trials were conducted on a private farm in El Gharbaniat, Borg El-Arab (latitude 30°55 N and longitude 29°32 E), Alexandria Governorate, Egypt, in 2021/2022 and 2022/2023 to investigate the influence of zeolite and foliar application with boron on the yield and quality of sugar beet (*Beta vulgaris* var. saccharifera, L.) grown in calcareous soil conditions. The study included twelve treatments that combined four zeolite doses (0, 250, 450, and 650 kg fed^{-1}) and three boron levels applied as boric acid 17% boron (0, 100, and 200 ppm) sprayed at 60 and 80 days after sowing, utilizing a randomized block design in a split-plot arrangement with three replicates. The results revealed that increasing the zeolite level to 650 kg fed^{-1} markedly improved the leaf area index (LAI), relative growth rate (RGR), root fresh weight (RFW), diameter, number of roots fed^{-1}, sucrose percent, quality index, root and sugar yields fed^{-1} (ton) in both seasons. The extracted sugar percentage increased in the first season but remained unaffected in the second one. Applying 200 ppm boron resulted in the highest values for LAI, RGR, root diameter, fresh weight, sucrose, and extracted sugar (ES %) percentages, root and sugar yields/fed, while the sugar lost to molasses (SLM) %, K and Na contents decreased. It is recommended that sugar beets be grown in calcareous sandy soil mixed with 650 kg/fed zeolite and that 200 ppm boron foliar spray be applied to maximize root and sugar yields and reduce root impurities.

Keywords: Boron, quality, sugar beet, zeolite, yield.

INTRODUCTION

Plants in calcareous soils, which have high pH levels and are dominated by CaCO3, experience unavailability of phosphorus and potassium, leading to more severe issues than merely the deficiencies of these nutrients. Remediating this unavailability is a serious objective in plant nourishment (Al-Dubai *et al.*, 2017). Sugar beet is a main economic crop in Egypt, where efforts are being made to close the chronic gap between the sugar needs of nations and their production. The country's sugar production relies on both sugar beet and sugarcane, with sugar beet currently being the primary source, accounting for 63.8% of the total production. In the 2022/2023 season, 658,597 feddans were cultivated with sugar beets, yielding 1.791 million tons of sugar (S.C.C., 2023).

Zeolites are crystalline hydrated aluminosilicates that expose incredible physical and chemical properties. These can reversibly absorb and lose water, adsorb molecules and exchange their essential cations without changing their structural integrity (Eroglu *et al.*, 2017). Recently, zeolites have been used in agriculture for soil management. Zeolites can act as carriers for nutrients, thereby promoting nutrient use efficiency. Given the challenges posed by climate change and rising temperatures, applying zeolites to the soil can conserve water, reduce canopy temperatures and ensure agricultural productivity. Additionally, zeolites can play a key role in minimizing pollution and alleviating anthropogenic pressure over time. As natural cation exchangers, zeolites effectively remove heavy metals, enhance plant productivity, reduce fertilizer addition, and immobilize trace metals (Cataldo *et al.*, 2021).

Boron deficiency is a well-documented nutritional issue affecting over 100 crops, including sugar beet, particularly in calcareous soil regions in more than 80 countries, including

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Egypt. Factors such as high free calcium carbonate levels, excessive phosphorus, low organic matter and high pH can impede boron uptake in plants, limiting the benefits of boron applications (Niaz *et al*., 2016). Although it is a micronutrient, boron plays a significant role in plant growth and development, particularly in cell wall formation, cell division, and carbohydrate translocation (Wu *et al*., 2021). It also facilitates the proper functioning of cell membranes and aids in transporting potassium ions to guard cells, contributing to the control of internal water balance. Deficiencies are typically more pronounced in sandy and calcareous soils. Studies have shown that foliar applications of boron can enhance sugar content and various agronomic parameters (Tayyab *et al*., 2023).

This study aimed to identify the optimal combination of zeolite addition rates and sprayed boron levels to maximize root and sugar yields while improving the quality traits.

MATERIALS AND METHODS

Two field trials were conducted on a private farm in El Gharbaniat, Borg El-Arab (latitude 30°55 N and longitude 29°32 E), Alexandria Governorate, Egypt, in 2021/2022 and 2022/2023 to investigate the influence of zeolite and spraying with boron on the yield and quality of sugar beet (*Beta vulgaris* var. saccharifera, L.) grown in calcareous sandy soil conditions. The present work included twelve treatments that were a combination of four zeolite levels (0, 250, 450, and 650 kg fed^{-1}) and three boron levels applied as boric acid 17% boron (zero, 100 and 200 ppm) sprayed at 60 and 80 days after sowing. A randomized complete block design in a split-plot arrangement with three replicates was used. The four levels of zeolite were assigned to the main plots, while three levels of boron were randomly scattered within the sub-plots. Before plowing, the experimental soil was washed using three consecutive irrigations. It was then plowed deeply three times, incorporating agricultural sulfur at a rate of 300 kg fed^{-1}. The soil was subsequently divided into experimental sub-plots, each measuring 21.0 m² including 7 ridges of 6 m in length and 50 cm in width, with 20 cm between hills. The application of 15 kg P_2O_5 per feddan of calcium super phosphate (15% P_2O_5) was applied as a top dressing next to the plants in two doses, the 1st after emergency and the 2nd after thinning. Natural zeolite levels were mixed with experimental soil at seedbed preparation. Nitrogen fertilizer was applied at 80 kg N fed^{-1} in the form of nitric acid (15% N) in two equal doses; the 1st was applied after thinning (4- true leaf stage) and one month later. Potassium in the form of potassium sulfate (48% K_2O) at the rate of 100 kg fed^{-1} was added with the application of nitrogen fertilizer doses. Zeolite was purchased from El-Ahram Company for Mining and Natural Fertilizers, El-Giza, Egypt, and mixed with experimental calcareous soil at seedbed preparation. The chemical properties of zeolite are shown in Table 1. The multi-germ sugar beet variety" Bts 970" imported from Germany and gained from Sugar Crops Research Institute was sown during the 1st week of September, while harvesting was done 210 days later, in both seasons. Other field practices were done as recommended by the Sugar Crop Research Institute. The physical and chemical properties of the soil experimental site were analyzed using the method described by Black *et al*. (1981) as shown in Table 2.

Table 1: Chemical composition of the soil application of zeolite.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3
64%	12.9%	1.7%	1.44%	0.98 %	2.66%	1.95 %	0.32%

Table 2: Physical and chemical properties of the experimental site 2021/2022 and 2022/2023 seasons.

Physical properties particle size			Soil chemical properties												Available macro and micronutrients (mg kg^{-1} soil)			
Sand %	Silt %	Clay %	pH (1:2.5) soil	E.C ds/m	O.M. %	$CaCO_3^{-2}$ %	Soluble Cations (meq/l)				Soluble Anions (meq/l)							
Texture: sandy soil							Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	CO_3^{-2}	HCO_3^{-}	Cl^{-}	SO_4^{-2}	N	P	K	Boron
2021/2022 season																		
82.90	3.15	13.95	8.0	1.60	0.71	15.30	7.10	1.69	4.90	0.71	--	3.90	8.1	2.40	36.0	5.25	175.2	0.11
2022/2023 season																		
84.00	2.70	13.30	7.9	1.49	0.80	14.95	6.78	1.7	3.82	1.11	--	2.80	7.0	1.54	38.4	5.60	179.1	0.14

The studied traits

At harvest, a random sample of ten guarded plants was taken from the inner ridges of each sub-plot to determine the following traits :

1. Root fresh weight/plant (RFW) (kg).
2. Root diameter (cm).
3. Number of roots (fed^{-1}): the roots of inner rows of each sub-plot were counted and then converted to number of roots per fed.

Five plants were randomly chosen from the middle ridges of each sub-plot at 110 days after sowing to determine:

- Leaf area index (LAI), which was measured as described by Watson (1958) using following formula:

LAI = leaf area per plant (cm^2)/plant ground area (cm^2).

- Relative growth rate (RGR) was calculated in the period between (110-140 days) as described by Aitchison and Brown (1976) according to the following equation:

RGR = (ln W2 - ln W1)/(t2 - t1), where ln W1 and ln W2 are the means of the natural logarithm-transformed plant weights.

- Leaf boron content (meq/100 g dry leaves) was determined according to the method described by Wolf (1974).

4- Quality analysis was done on fresh roots at the Laboratory of Nile Sugar Company, Egypt, including the following characteristics:

- Impurities: sodium, potassium, and α-amino-nitrogen contents in roots, which were estimated as meq/100 g beet, where Na and K were determined using “Flame-photometer”. However, α-amino N was determined according to the method described by Cooke and Scott (1993).
- Sucrose (%) was determined in fresh roots according to Le-Docte (1927):
- Sugar lost to molasses (SLM) % was calculated according to Devillers (1988):

SLM% = 0.14 (Na + K) + 0.25 (α–amino N) + 0.5

- Quality index (QI) was calculated using the formula of Cooke and Scott (1993):

QI = extracted sugar % / sucrose %

- Extracted sugar percentage (ES %) was calculated using the formula of Dexter *et al.* (1967):

ES % = sucrose % - SLM % - 0.6

5. Root yield fed^{-1} (ton).
6. Sugar yield fed^{-1} (ton) was calculated as follows:

Sugar yield fed^{-1} (ton) =
root yield fed^{-1} (ton) x extracted sugar %.

Statistical analysis

The recorded data were statistically analyzed using the “Co-STATC” computer software package, to estimate the analysis of variance (ANOVA) for the split-plot design as published by Gomez and Gomez (1984). The least significant difference (LSD) method was used to check the differences among means of treatment at the 5% level of probability as described by Snedecor and Cochran (1980).

RESULTS AND DISCUSSION

Data in Table 3 demonstrated that applying zeolite to the soil appreciably increased the leaf area index (LAI) and the relative growth rate (RGR) compared to untreated soil. However, increasing zeolite levels up to 650 kg fed^{-1} failed to reach a significant level in their effect on leaf boron content, in both seasons. The higher values of LAI and RGR were associated with increased addition of zeolite up to 650 kg, compared to the absence of zeolite. These results suggest that zeolite improves water retention capacity and facilitates water distribution in the soil. It also contains some nutrients for sugar in the beet plants' growth stages. These results agreed with Akbari *et al.* (2011), who reported that applying 500 kg/ha zeolite appreciably enhanced leaf area compared to untreated soil.

Results showed that spraying beets with boron markedly improved the LAI, RGR and leaf boron content during the two seasons (Table 3). Applying 200 ppm of boric acid resulted in a notable and gradual improvement in the above-mentioned traits across both seasons. These findings align with those reported by Tayyab *et al.* (2023).

Table 3: Influence of zeolite and boron levels on LAI, RGR and leaf boron content of sugar beet in 2021/2022 and 2022/2023 seasons

Treatments	LAI		RGR		Leaf B content (mg/100 g dry leaves)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Zeolite levels (kg fed^{-1})						
Without	2.55	2.59	1.99	2.02	0.66	0.63
250	2.68	2.74	2.23	2.24	0.72	0.71
450	2.69	2.72	2.23	2.22	0.71	0.69
650	2.91	2.95	2.45	2.37	0.80	0.76
LSD at 5%	**0.11**	**0.12**	**0.16**	**0.12**	**NS**	**NS**
Boron sprayed levels (ppm)						
Zero	2.57	2.62	2.09	2.06	0.59	0.57
100	2.69	2.73	2.22	2.24	0.72	0.69
200	2.87	2.91	2.36	2.34	0.86	0.83
LSD at 5%	**0.09**	**0.08**	**0.11**	**0.10**	**0.12**	**0.11**

Significant interaction effect

The leaf area index and leaf boron content were considerably impacted by the interaction between zeolite addition and boron spraying levels (Table 4). The differences between sprayed beet canopies with 100 or 200 ppm boron were insignificant when sown in mixed soil with 450 kg of zeolite fed^{-1}. However, the differences between those plants reached significance when sown in untreated soil and those planted in soil mixed with 250 and/or 650 kg zeolite, in the 1st season. In the 2nd one, the result was similar to the first season. Regarding leaf boron content, there was an insignificant difference between the beet tops sprayed with 100 ppm boron and those untreated when fertilized with 650 kg zeolite, in 1st season. Nevertheless, the differences between beet plants sprayed with 100 ppm and those non-spraying boron reached a significant level when adding the highest dose of zeolite and then decreased to 450 kg fed^{-1}. The highest values for both LAI and leaf boron content were recorded when beets were grown in soil mixed with 650 kg zeolite and sprayed with 200 ppm boron.

Table 4: Significant interaction effect between zeolite and boron fertilization levels on LAI and leaf B content of sugar beet in 2021/2022 and 2022/2023 seasons

Zeolite levels (kg fed^{-1})	Boron levels (ppm)	Leaf area index		Boron in leaves (mg/100 g dry leaves)	
		1st season	2nd Season	1st Season	2nd season
Without	Zero	2.43	2.47	0.53	0.47
	100	2.54	2.57	0.68	0.62
	200	2.68	2.74	0.67	0.69
250	Zero	2.58	2.63	0.56	0.52
	100	2.67	2.71	0.69	0.71
	200	2.83	2.83	0.88	0.84
450	Zero	2.56	2.61	0.58	0.62
	100	2.69	2.76	0.73	0.69
	200	2.78	2.85	0.86	0.81
650	Zero	2.72	2.76	0.69	0.66
	100	2.84	2.87	0.78	0.74
	200	3.18	3.22	0.92	0.89
L.S.D at 0.05		**0.13**	**0.12**	**0.13**	**0.14**

Root fresh weight, diameter, and number of roots fed^{-1}

In both seasons, the RFW, diameter, and the number of roots fed^{-1} were significantly influenced by the different rates of zeolite applied. Supplying the soil with 650 kg fed^{-1} of zeolite resulted in the highest RFW, diameter, and number of roots/fed, in the two seasons (Table 5). This increase in these traits may be attributed to zeolite's ability to retain water, which improves the germination percentage. Similar findings were reported by Abdel Fatah and Khalil (2020), who demonstrated that adding zeolite to the soil produced higher root weight and diameter than beets grown in free zeolite soil.

Results in the same Table revealed that spraying sugar beet plants with boron appreciably increased root fresh weight and diameter compared to the control treatment. However, the number of roots was not influenced by the levels of boron applied during either season. Spraying beet tops with 200 ppm boron produced the thickest and heaviest roots compared to the other boron levels, in the 1st and 2nd seasons. These findings align with those stated by Enan *et al.* (2016), which indicated that applying boron at 100 ppm fed^{-1} level recorded higher values for root diameter and fresh weight per plant than untreated plants, in either season. Similarly, Nemeata Alla (2017) found that treating beet canopies with 100 or 150 ppm levels of boron enhanced root diameter and fresh weight/plant without significant variance in between.

Table 5: Influence of zeolite and boron levels on root weight, diameter and number of roots (fed^{-1}) of sugar beet in 2021/2022 and 2022/2023 seasons

Treatments	Root weight (kg)		Root diameter (cm)		Number of roots fed^{-1}	
	1st season	2nd Season	1st Season	2nd season	1st season	2nd Season
Zeolite levels (kg fed^{-1})						
Without	0.553	0.561	10.33	9.78	30663	30466
250	0.878	0.890	12.11	12.89	31444	31276
450	0.949	0.901	12.67	12.00	32375	32526
650	1.341	1.324	14.67	14.33	33222	33441
LSD at 5%	**0.27**	**0.35**	**1.55**	**1.97**	**461.67**	**31.78**
Boron spraying levels (ppm)						
Zero	0.815	0.760	11.42	11.58	31926	31931
100	0.901	0.940	12.50	12.09	31898	31926
200	1.075	1.057	13.42	13.08	31954	31924
LSD at 5%	**0.12**	**0.13**	**1.95**	**0.92**	**NS**	**NS**

Significant interaction effect

Results in Table 6 indicated that the differences in RFW between beet plants that were treated with 100 ppm and those unsprayed were insignificant when grown in soil mixed with 250, 450, and/or 650 kg zeolite/fed. However, these differences between the two boron levels reached a significant level in the absence of zeolite, in the 1st season. In the second one, a significant variance was found between the same mentioned levels, when beet plants fertilized with 250 kg zeolite. Meanwhile, these differences were insignificant in beet RFW whether fertilized with 450 or 650 kg of zeolite and/or those grown in the soil left without zeolite. Overall, fertilizing beet plants with 650 kg zeolite combined with spraying either 100 or 200 ppm (with no significant difference between them) resulted in heavier roots than those unsprayed with boron in soil fertilized with 650 kg zeolite.

Table 6: Significant interaction between zeolite and boron levels effect on root weight of sugar beet in 2021/2022 and 2022/2023 seasons

Zeolite levels (kg fed^{-1})	Boron levels (ppm)	Root fresh weight (kg)	
		1st season	2nd season
Without	Zero	0.426	0.406
	100	0.567	0.544
	200	0.667	0.733
250	Zero	0.767	0.714
	100	0.833	0.940
	200	1.033	1.016
450	Zero	0.800	0.733
	100	0.880	0.900
	200	1.167	1.070
650	Zero	1.267	1.185
	100	1.324	1.376
	200	1.433	1.410
LSD at 0.05		**0.140**	**0.193**

Results in Table 7 indicated that the potassium, sodium, and α-amino nitrogen contents of beet roots were insignificantly impacted by the presence or absence of zeolite, over two seasons. However, planting sugar beet in calcareous sandy soil treated with zeolite gave lower sodium and potassium contents, in the 1st and 2nd seasons.

Concerning the effect of boron levels, the data in Table 7 indicated that increasing the boron level from zero to 200 ppm caused markedly lower sodium and potassium content, compared to the check treatment. However, root α-amino N content increased. These findings highlight the important role of boron in this context.

Table 7: Influence of zeolite and boron levels on Na^+, K^+ and α-amino N contents (meq/100 g roots) of sugar beet in 2021/2022 and 2022/2023 seasons

Treatments	Na^+		K^+ content		α-amino N	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Zeolite levels (kg fed^{-1})						
without	2.81	2.99	6.31	5.64	1.98	2.10
250	2.32	2.56	6.38	5.85	2.04	2.35
450	2.36	2.83	5.78	5.25	2.14	2.10
650	2.26	3.32	5.34	5.06	2.26	2.24
LSD at 5%	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Boron spraying levels (ppm)						
Zero	2.55	3.32	6.31	5.68	1.70	2.01
100	2.41	2.86	5.93	5.45	2.19	2.24
200	2.36	2.60	5.63	5.23	2.42	2.35
LSD at 5%	**0.18**	**0.19**	**0.24**	**0.23**	**0.24**	**0.19**

The data in Table 8 showed an appreciable influence of zeolite addition on the root sucrose content and the quality index, in the first and second seasons. However, different levels of zeolite had an insignificant impact on SLM %, in the two seasons. Planting beets in mixed calcareous sandy soil with 650 kg zeolite/fed resulted in higher sucrose % and improved QI, in both seasons than applying 450 kg zeolite fed^{-1}. These results agree with those of Nemeata Alla and Helmy (2022).

Concerning the impact of boron rates, data in the same Table illustrated that the percentage of sucrose and quality index considerably improved when the amount of applied boron was increased from zero to 200 ppm fed^{-1}, in the examined seasons. However, treating beet tops with 100 and/or 200 ppm boron fed^{-1} without significant differences between them increased SLM %, in both seasons. The positive effect of boron on sucrose % and quality index traits was reported by (Enan, 2011), who explained that spraying beets with 200 ppm boron gave the highest sucrose content with is the correct enhancing the values of QI and boron in leaves.

Table 8: Influence of zeolite and boron levels on sucrose, sugar lost to molasses (SLM) %, and quality index of sugar beet in 2021/2022 and 2022/2023 seasons

Treatments	Sucrose %		SLM %		Quality index (QI)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Zeolite levels (kg fed^{-1})						
Without	14.54	14.43	2.27	2.23	84.60	85.03
250	15.07	14.92	2.18	2.16	85.43	85.71
450	14.93	15.09	2.23	2.27	85.67	85.31
650	15.98	16.05	2.13	2.23	86.67	86.09
LSD at 5%	**0.58**	**0.54**	**NS**	**NS**	**0.76**	**0.92**
Boron spraying levels (ppm)						
Zero	14.55	15.04	2.17	2.26	85.12	84.96
100	15.29	15.31	2.21	2.22	85.53	85.48
200	16.05	16.03	2.22	2.18	86.15	86.39
LSD at 5%	**0.36**	**0.34**	**0.06**	**0.07**	**0.66**	**0.87**

Significant interaction effect

Table 9 indicated that the sucrose percent was significantly affected by the interaction between the applied zeolite rates and the foliar application of boron. The differences between treating beet tops with 100 ppm boron fed^{-1} and those untreated with boron were insignificant when sown in the soil left without zeolite. However, the differences between the same two boron levels were significant, in the 1st season when the beets sown in soil mixed with 250, 450, and 650 kg zeolite/fed. The same result was also observed, in the second one. The highest root sucrose content was obtained, in both seasons when beets were sown in calcareous sandy soil treated with 650 kg zeolite/fed and sprayed with 200 ppm boron, throw this investigation easons. These results are consistent with those reported by (Enan, 2011).

Table 9: Significant interaction between zeolite and boron levels effect on sucrose of sugar beet in 2021/2022 and 2022/2023 seasons

Zeolite levels (kg fed^{-1})	Boron levels (ppm)	Sucrose %	
		1st season	2nd season
without	**Zero**	13.47	13.49
	100	14.73	14.57
	200	15.42	15.22
250	**Zero**	14.37	14.54
	100	14.82	14.93
	200	16.03	15.28
450	**Zero**	14.47	14.62
	100	14.86	14.96
	200	15.46	15.68
650	**Zero**	14.88	15.44
	100	15.76	15.77
	200	17.29	16.94
LSD at 0.05		**0.89**	**0.68**

Results in Table 10 stated that soil mixed with zeolite appreciably influenced root and sugar yields fed^{-1}, in the two seasons and ES%, in the 1st one. The addition of 650 kg zeolite increased root and sugar yields fed^{-1}, in the 1st and 2nd seasons and extracted sugar %, in the 1st season. When beets sown in soil received 650 kg/fed zeolite the enhancement of root yield amounted to (4.25 and 3.91 tons of roots), (0.86 and 0.85 tons of sugar) and (1.54 extracted sugar %) as compared to those grown in untreated soil. These improvements in productive traits may have resulted from relatively better conditions in the rhizosphere zone because of zeolite addition, which can preserve the moisture in the soil for a long time and improve the availability of nutrients to beet plants (Khodaei and Asilan, 2012).

Results in the same Table illustrated those higher values of extracted sugar %, root, and sugar yields fed^{-1} were recorded by increasing the sprayed boron level to 200 ppm, in the 1st and 2nd seasons. Supplying beet tops with 200 ppm boron gave increases in ES %, root, and sugar yields fed^{-1}, which amounted to (5.73% and 5.88%), (6.70% and 5.37%) and (13.01% and 11.64%) over that fertilized with 100 ppm boron, in the 1st and 2nd seasons, respectively. These results assured the major role of boron in maintaining the balance between sugar and starch; translocation of carbohydrates and sugars, normal cell division, nitrogen metabolism and protein formation, and cell wall configuration as reported by Enan, *et al.* (2016) and Nemeata Alla (2017).

Table 10: Influence of zeolite and boron levels on extracted sugar %, root and sugar yields fed^{-1} of sugar beet in 2021/2022 and 202220/23 seasons

Treatments	Extracted sugar %		Root yield/fed (ton)		Sugar yield/fed (ton)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Zeolite levels (kg fed^{-1})						
Without	12.31	12.16	18.44	19.12	2.28	2.33
250	12.80	12.68	19.49	19.91	2.49	2.53
450	12.75	12.93	22.11	22.16	2.82	2.87
650	13.85	13.82	22.69	23.03	3.14	3.18
LSD at 5%	**0.48**	**NS**	**0.96**	**0.87**	**0.61**	**0.79**
Boron spraying levels (ppm)						
Zero	12.38	12.78	19.49	19.94	2.41	2.55
100	13.08	13.08	20.59	21.05	2.69	2.75
200	13.83	13.85	21.97	22.18	3.04	3.07
LSD at 5%	**0.49**	**0.81**	**0.68**	**0.63**	**0.34**	**0.31**

Significant interaction effect

Extracted sugar %, yields of root and sugar were considerably impacted with the interaction between zeolite addition and boron application levels (Table 11). As for extracted sugar %, the differences between beets sprayed with 100 and 200 ppm boron were insignificant when beets were planted in soil mixed with 450 kg of zeolite, also in the absence of zeolite. However, these differences between the same two boron levels were significant in plants grown in soil mixed with 250 and 650 kg of zeolite, in 1st season. Nevertheless, in the second one, differences between beets sprayed with 100 or 200 ppm were insignificant when beets sown in the zeolite-free soil or those received 250 and 450 kg zeolite fed^{-1}, whilst the variance was appreciable in beets sown in soil treated with 650 kg zeolite.

Concerning root yield fed^{-1}, it was clear that the differences between beets foliar application with 100 and 200 ppm were insignificant in the absence of zeolite fertilizer or that grown in soil received 450 kg zeolite. However, these differences were significant when the other zeolite rates were applied, in the first season. A similar result was obtained, in 2nd season.

Regarding sugar yield fed^{-1}, in the 1st season, the differences between zero and 200 boron levels were insignificant when plants were sown in the soil without zeolite or treated with 250 and 450 kg fed^{-1}. Conversely, when beets were grown in soil fertilized with 650 kg zeolite, these differences reached a significant level. In the second one, similar findings were obtained.

Overall, sugar beet plants achieved their maximum ES%, root, and sugar yields fed^{-1} when grown in soil treated with 650 kg of zeolite and sprayed with 200 ppm boron fed^{-1}, in both seasons.

Table 11: Significant interaction effect between zeolite and boron levels on extracted sugar %, root and sugar yields fed^{-1} (ton) of sugar beet in 2021/2022 and 2022/2023 seasons

Zeolite levels (kg.fed^{-1})	Boron levels (ppm)	Extracted sugar %		Root yield fed^{-1} (ton)		Sugar yield fed^{-1} (ton)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season
Without	Zero	11.22	11.12	17.33	18.26	1.94	2.03
	100	12.50	12.34	18.54	19.43	2.32	2.40
	200	13.22	13.02	19.44	19.67	2.57	2.56
250	Zero	12.18	12.27	18.24	18.66	2.22	2.29
	100	12.55	12.68	19.36	19.72	2.43	2.50
	200	13.68	13.10	20.86	21.36	2.85	2.80
450	Zero	12.31	12.45	20.74	20.92	2.55	2.60
	100	12.69	12.79	22.18	22.18	2.81	2.84
	200	13.26	13.56	23.42	23.38	3.11	3.17
650	Zero	12.81	13.21	21.65	21.92	2.77	2.90
	100	13.58	13.53	22.28	22.86	3.03	3.09
	200	15.14	14.71	24.14	24.31	3.66	3.58
LSD at 0.05		1.12	1.17	1.33	1.25	0.69	0.62

Conclusion

To optimize root and sugar yields and enhance the quality index in the Borg El-Arab region it is recommended that beet plants be treated with 650 kg of zeolite and sprayed with 200 ppm of boron.

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تأثير الزيوليت والبورون علي محصول وجودة بنجر السكر في منطقة برج العرب

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الملخص العربي

أقيمت تجربتان حقليتان بمزرعة خاصة بمنطقة الغربانيات (دائرة عرض ٥٥ °٣٠ شمالاً وخط طول ٣٢ °٢٩ شرقاً) - برج العرب- محافظة الإسكندرية، مصر خلال موسمي ٢٠٢٢/٢٠٢١ و ٢٠٢٣/٢٠٢٢ لدراسة تأثير إضافة الزيوليت والرش الورقي بالبورون علي حاصل وجودة بنجر السكر المنزرع في تربة رملية كلسية. تكونت التجربة من إنتي عشرة معاملة تتألف من الزيوليت بأربعة مستويات (بدون و ٢٥٠ و ٤٥٠ و ٦٥٠ كجم للفدان)، وثلاثة مستويات البورون بورون بمعدل (بدون و ١٠٠ و ٢٠٠ جزء علي المليون) فى صورة حامض بوريك ١٧ %. وقد تم إستخدام تصميم القطاعات كاملة العشوائية في ترتيب القطع المنشقة مرة واحدة في ثلاث مكررات.

- أوضحت النتائج ما يلي: سجلت إضافة الزيوليت كمحسن للتربة بمعدل ٦٥٠ كجم للفدان أعلى القيم بفروق معنوية لصفات دليل مساحة الأوراق ومعدل النمو النسبي ووزن الجذور وقطرها وعدد الجذور للفدان، بالإضافة إلى النسبة المئوية للسكروز ومؤشرالجودة وحاصلي الجذور والسكرللفدان (طن) خلال موسمي الدراسة، فضلا عن النسبة المئوية للسكر المستخلص في الموسم الأول. بينما لم تتأثر النسبة المئوية للسكر المستخلص معنويا في الموسم الثاني.

- سجل الرش الورقي لنباتات بنجر السكر بمعدل ٢٠٠ جزء في المليون بورون زيادة معنوية في دليل مساحة الأسواق ومعدل النمو النسبي ، ووزن الجذوروقطرها والنسب المئوية للسكروز والسكر المستخلص، فضلا عن حاصل الجذور والسكر للفدان مع تَحسُن مؤشر الجودة في كلا الموسمين. بينما انخفض محتوي الجذور من البوتاسيوم و نسبة السكر المفقود في المولاس.

- يمكن التوصية بإضافة الزيوليت للتربة الرملية الكلسية بمعدل ٦٥٠ كجم للفدان مع رش نباتات البنجربـ ٢٠٠ جزء فى المليون بورون للفدان للحصول علي أعلي حاصل من الجذور والسكر(طن) للفدان.