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IMPACT OFHUMIC ACID AND FOLIAR APPLICATION OF IRON, MANGANESE AND BORON NANOPARTICLES ON SUGAR BEET YIELD AND QUALITY

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ABSTRACT: Two field experiments were carried out at the Research Farm of Sakha Agricultural Research Station (latitude of 31º 10 N and longitude 30º 93 E, at an elevation of 14 m above sea level), Kafr El-Sheikh Governorate, Egypt in 2021/2022 and 2022/2023 seasons to study the effect of humic acid as a soil amendment and foliar application of trace elements as a Nano fertilizer on growth, yield, and quality of sugar beet (*Beta vulgaris* var. saccharifera, L.), This work included twelve treatments representing the combinations of three soil application levels of humic acid (without, 2.5 and 5 kg/fed) and spraying canopies with four Nano elements (without, iron, manganese and boron), were separately sprayed at the rate of 100 mg/L after 50, 65 and 80 days from sowing. A complete block design in a split-plot arrangement with three replications was used. The results showed that applying humic acid at a rate of 5 kg/fed increased photosynthetic pigments, leaf area index, peroxidase enzyme activity and yields of root and sugar/fed however, alpha-amino N content decreased in both seasons. Additionally, catalase enzyme activity increased in the first season, compared to adding half humic/fed acid dose (2.5 kg). Fertilizing beet plants with 2.5 kg of humic acid/fed attained lower potassium and sodium content and improved quality index than adding 5 kg of humic acid/fed in both seasons. Moreover, supplying beets with either 2.5 or 5 kg humic acid/fed (without considerable differences) resulted in the highest root sucrose, extracted sugar percentages and reduced sugar lost to molasses %, compared to untreated beet plants in both seasons. Sprayed beet plants with Nano boron, resulted in the highest values of leaf area index, photosynthetic pigments, Peroxidase activity, root and sugar yields/fed in both seasons, with catalase activity in 1st season. Main while, the values of alpha-amino N content and sugar lost to molasses% were reduced in the second season compared to beets sprayed with the rest of the treatments. However, sprayed beets with Nano trace elements had insignificant effects on the quality index, sucrose and extracted sugar percentages in both seasons. The highest root and sugar yields/fed were obtained by fertilizing beets with 5 kg of humic acid along with spraying Nano boron compared to the other combinations in both seasons.

Key words: Humic acid rates, Nano trace elements, Sugar beet

INTRODUCTION

Sugar beet (*Beta vulgaris* var. sacchariferous L.) is a key winter crop in Egypt for sugar production, grown in various soil types including poor, alkaline, and calcareous soils. Egypt's sugar beet cultivation is around 637,000 fed, yielding approximately 1.5 million tons of sugar annually (Sugar Crops Council Annual Report, 2022). However, this production falls short of meeting the country's sugar consumption needs, highlighting the importance of expanding the cultivated area and increasing sugar production per unit area. Humic acid is an essential component of humic substances, which are significant organic compounds found in soil. Humic substances are molecules that result from the decomposition and microbial activity of dead biological material and plant tissues. Humic acid is produced as a result of the biodegradation of organic matter and consists of a complex mixture of various acids containing carboxyl and phenolate groups. Humic acids can form

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complexes and ions commonly found in the environment, creating humic colloids (Kaya *et al.*, 2018 and Ekin, 2019). Furthermore, humic compounds play a vital role in maintaining and enhancing soil fertility and positively impacting the physiological functions of soil biota and plants. In this concern, the positive effects of humic acid on the growth and yield of sugar beet have been reported by (Abd El-Aal and Abd El-Rahman, 2014) and (Rassam *et al.*, 2015).

Nanoparticles, ranging from 1 to 100 nm, can be utilized in agriculture to enhance plant growth and yield by gradually providing nutrients, improving absorption and solubility, and reducing the risk of environmental contamination. They may serve as an alternative to conventional fertilizers (Thavaseelan and Priyadarshana, 2021). Among the nanoparticles studied, iron is crucial for plants as it increases chlorophyll and carbohydrates, acts as an electron acceptor, and activates several electron transfer enzymes in photosynthesis as reported by (Irmak *et al.*, 2012). Also, Manganese serves as a co-factor for various enzymes involved in photosynthesis, and its deficiency can lead to decreased soluble sugars, impacting photosynthesis, nitrogen, and carbohydrate metabolism as noted by (Andresen *et al.*, 2018). Furthermore, Boron is particularly critical in sugar beet cultivation, as its deficiency can lead to smaller, stiffer, and thicker leaves, affecting the formation of new leaves and the translation of assimilation products from leaves and roots as mentioned by (Enan *et al*., 2016).

So, this work aimed to evaluate the effectiveness of soil application of humic acid and spraying Nano trace elements fertilizer to maximize beetroot yield and improve quality in the North Delta region.

MATERIALS AND METHODS

Two field experiments were carried out at the Research Farm of Sakha Agricultural Research Station (latitude of 31°10 N and longitude 30° 93 E, at an elevation of 14 m above sea level), Kafr El-Sheikh Governorate, Egypt in 2021/2022 and 2022/2023 seasons to study the effect of humic acid as a soil amendment and foliar application of Nano elements on growth, yield, and quality of sugar beet (*Beta vulgaris* var. saccharifera, L.), This work included twelve treatments representing the combinations of three soil application levels of humic acid (without, 2.5 and 5 kg/fed) and spraying canopies with four Nano elements (without, iron, manganese and boron), were separately sprayed at the rate of 100 mg/L after 50, 65 and 80 days from sowing. A complete block design in a split-plot arrangement with three replications was used, where levels of humic acid were distributed in the main plots, while spraying of Nano elements was allocated at random in the sub-plots. The sub-plot area was 20 m^2, including 8 ridges of 5 m in length and 50 cm in width, with 20 cm between hills. The Multi-germ sugar beet variety viz "Raspoly" sown on the 2nd week of September, while harvesting beets took place at the age of 210 days after planting in both seasons. Plants were thinned at the 4-leaf stage to ensure one plant per hill. Fertilizer application at 200 kg/fed of phosphorus was added in the form of calcium super phosphate (15 % P_2O_5) at seed bed preparation. Nitrogen fertilizer was applied in the form of urea (46.5% N) at the rate of 80 kg N/fed in two equal doses: the 1st after thinning and one month later. Potassium fertilizer was added in the form of potassium sulphate (48% K_2O) at the rate of 50 kg/fed in two equal doses: with 1st doses of nitrogen fertilizer and just before canopy closer (75 days). Fertilizer of Nano-material was procured from the Physiology Department (Nanotechnology project), Faculty of Agriculture at Cairo University. Humic acid was obtained from Setra Company in Tanta, Egypt. Its analysis was (humic acid content of 85%, fulvic acid content of 0.8%, K_2O content of 5%, N content of 0.7%, P_2O_5 content of 0.06%, Ca content of 0.99%, Mg content of 0.39%, Fe content of 0.89%, Mn content of 0.043%, Zn content of 0.013%, Cu content of 0.056%, B content of 0.048% and soluble matter content of 5%). It was added before sowing with the recommended field practices of the Sugar Crop Research Institute. Soil samples were collected from the experimental site at 0-30 cm depth to determine their physical and chemical properties using the method described by AOAC in 1990 as shown in Table, 1.

Studied traits

1. **Biochemical and physiological analysis:**

In the assessment of antioxidant enzyme activity in leaves, Catalase activity (CAT) was determined using the method outlined by Aebi (1984). Peroxidase activity was estimated following the procedure described by Polle et al. (1994). Enzyme activity levels were expressed as units of enzymatic activity per gram of protein content in the samples (U/g protein). Hydrogen peroxide (H_2O_2) content was expressed as m mol/ g fresh weight.

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

2. Leaf area index (LAI): Leaf area was measured and determined by the disk method using ten disks of 1.0 cm diameter according to Watson (1958), and then the following equation was used:

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

3. Photosynthetic pigments i.e., chlorophyll a, b, and carotenoids (mg/g leaf fresh weight) were determined according to the method described by Wettstein (1957).
4. Quality analysis was done on fresh samples of sugar beet roots at the Laboratory of Al-Hamoul Factory in Kafr El-Sheikh, Egypt. Sucrose percentage (Pol %), was determined in fresh macerated root according to the method of Le-Docte (1927).
5. Impurities: Sodium, potassium and α-amino-nitrogen contents in roots were estimated as meq/100 g beet, where sodium and potassium were determined in the digested solution using “Flame-photometer”. Alfa-amino N was determined using Hydrogenation according to the method described by Cooke and Scott (1993).
6. Sugar lost to molasses percentage (SLM%) was calculated according to the equation of Devillers (1988):

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

7. Extracted sugar percentage (ES %) was calculated by the following equation of Dexter *et al*. (1967):

ES% = sucrose % - SLM % - 0.6

8. Quality index (QI) was calculated using the equation of Cooke and Scott (1993) as follows:

QI = (extracted sugar% / sucrose %) x 100

Table 1: Physical and chemical properties of the experimental soil site

2021/2022 season									
Coarse sand %	Fine sand %	Silt %	Clay %		Texture	O.M %	$CaCO_3$ %		
3.5	13.8	35.8	46.9		Clay	1.77	4.66		
pH (1:2:5)	EC (ds/m)	Cations (meq/l)				Anions (meq/l)			
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO^{-}_3	Cl^{-}	SO^{--}_4	
7.8	2.15	6.00	6.10	8.50	0.90	2.00	10.80	8.70	
Available Macro& micronutrients (mg/kg)									
N	P	K	Fe	Mn		B			
46.4	8.1	250	3	1.2		0.25			
2022/2023 season									
Coarse sand %	Fine sand %	Silt %	Clay %		Texture	O.M %	$CaCO_3$ %		
4.2	14.9	34.4	46.5		Clay	1.86	4.74		
pH (1:2:5)	EC (ds/m)	Cations (meq/l)				Anions (meq/l)			
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO^{-}_3	Cl^{-}	SO^{--}_4	
7.9	2.29	6.40	7.20	8.60	0.70	3.00	10.50	9.40	
Available Macro&micronutrients (mg/kg)									
N	P	K	Fe	Mn		B			
49.3	8.9	240	2.5	1.6		0.23			

Yields

1. Root yield/fed (ton).
2. Sugar yield/fed (ton) was calculated according to the following equation:

Sugar yield/fed (ton) =
Root yield/fed (ton) x Extracted sugar%.

Statistical analysis

All obtained datawere statistically analyzed according to the technique (Co-STATE) computer software package, using 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 test the differences between treatment means at the 5% level of probability as described by Snedecor and Cochran (1980).

RESULTS AND DISCUSSION

Data in Table 2 showed higher values of leaf photosynthetic pigments were recorded by increasing the soil application of humic acid level to 5 kg/fed in both seasons. Fertilizingbeets with 5 kg humic acid/fed gave 38.8%, 42.9% and 57.6% increases in chlorophyll a, chlorophyll b and carotenoid in the 1st season. However, these increases were 27.2%, 51.7%, and 33.3% in the 2nd season, respectively, compared to half the applied humic acid dose (2.5 kg/fed). These results are in agreement with Tan (2003) emphasized the advantages and benefits of humic acid, citing its ability to improve soil properties and foster plant growth by improving aggregation, aeration, permeability, and water-holding capacity. Moreover, humic compounds can boost the absorption of macro and microelements and improve cell permeability, thereby stimulating respiration and photosynthesis.

Table 2: Photosynthetic pigments (mg/g fresh weight), of beets as affected by fertilization with humic acid levels and spraying Nano microelements in 2021/2022 and 2022/2023 seasons.

B: Nano fertilizer	Traits	A: Humic acid rates/fed (kg)							
		2021/2022				2022/2023			
		Zero	**2.5**	**5**	**Mean**	**Zero**	**2.5**	**5**	**Mean**
Without spraying	Chlo. A	1.32	1.69	2.46	**1.82**	1.28	2.05	2.66	**2.00**
Nano Fe		1.36	1.84	2.56	**1.92**	1.40	2.14	2.79	**2.11**
Nano Mn		1.50	2.00	2.72	**2.07**	1.51	2.31	2.92	**2.25**
Nano B		1.60	2.19	2.98	**2.25**	2.00	2.45	3.01	**2.49**
Mean		**1.44**	**1.93**	**2.68**		**1.55**	**2.24**	**2.85**	
LSD at 5% for factor A and B		**A: 0.78**		**B: 0.17**		**A: 0.73**		**B: 0.18**	
LSD at 5% for A x B		**NS**				**NS**			
Without spraying	Chlo. B	0.48	1.14	1.74	**1.12**	0.43	1.02	1.28	**0.91**
Nano iron		0.57	1.24	1.79	**1.20**	0.59	1.10	1.44	**1.04**
Nano Mn		0.68	1.46	1.85	**1.33**	0.80	1.19	1.66	**1.21**
Nano boron		0.71	1.55	2.36	**1.54**	0.81	1.23	2.53	**1.53**
Mean		**0.61**	**1.35**	**1.93**		**0.66**	**1.14**	**1.73**	
LSD at 5% for factor A and B		**A: 0.74**		**B: 0.14**		**A: 0.42**		**B: 0.22**	
LSD at 5% for A x B		**NS**				**NS**			
Without spraying	Carotenoid	0.17	0.38	0.61	**0.38**	0.31	0.42	0.58	**0.44**
Nano Fe		0.27	0.56	0.76	**0.53**	0.46	0.66	0.80	**0.64**
Nano Mn		0.41	0.59	0.88	**0.62**	0.54	0.75	0.95	**0.75**
Nano B		0.46	0.54	1.03	**0.68**	0.57	0.70	1.03	**0.77**
Mean		**0.33**	**0.52**	**0.82**		**0.46**	**0.63**	**0.84**	
LSD at 5% for factor A and B		**A: 0.20**		**B: 0.68**		**A: 0.23**		**B: 0.18**	
LSD at 5% for A x B		**NS**				**NS**			

Relating to the spraying Nano microelements effect, it was noted that the content of leaf photosynthetic pigments in terms of chlorophyll a and b, significantly increased when beets were sprayed with Nano boron followed by Nano manganese, compared to beets sprayed with the rest of the other treatments in both seasons. However, there was an insignificant difference between spraying Nano boron and Nano manganese in their effect on carotenoid content in both seasons. These results were confirmed by Enan*et al.* (2016) who explain the role of boron in cell elongation. They noted that boron deficiency, results in smaller, stiffer, thicker leaves and its function in the formation of new leaves and the translation of assimilation products from leaves and roots. Furthermore, Liu and Lal (2015) found that the spraying of nanoparticles to sugar beet plants can lead to faster plant growth.

According to the data in Table 3, there was a significant increase in the leaf area index and peroxidase enzyme activity in both seasons, as well as an increase in catalase enzyme activity in the 1stseason, when humic acid fertilization levels were increased from zero to 5 kg/fed. Providing beet plants with 5 kg humic resulted in notable increases in leaf area index and peroxidase enzyme activity in beet plants. These increases were about 27.4% and 96.7% in the 1stseason, and 16.0% and 52.7% in the 2ndseason, respectively. Meanwhile, the increase in catalase enzyme activity was only 63.1% in the first season when compared to applying 2.5 kg/humic acid/fed. These results suggest that higher levels of humic acid fertilization may lead to an expansion in leaf surface per unit area, an increase in the photosynthetic process, and better defense mechanisms in beets. These mechanisms are positively associated with increased antioxidant enzyme activity. These results align with Wang *et al.* (2013), who reported that plants under certain stresses produce reactive oxygen species that can disrupt their normal defensive system. Therefore, the elevated activity of antioxidant enzymes such as ascorbate peroxidase (APX), catalase (CAT) and peroxidase (POD) is necessary to counter the intense flux of reactive oxygen species and maintain the normal defensive system of the plant.

Spraying iron, manganese and boron as a Nano fertilizer on beet tops significantly affected the leaf area index and the activity of peroxidase enzyme in both seasons, with catalase enzyme activity in 1st season, according to Table 3. Foliar application of Nano boron resulted in higher values of leaf area index and activity of peroxidase and catalase enzymes compared to other treatments.This study suggests that the use of nanotechnology can help reduce the damage caused by nutrient deficiencies in beet crops and optimize their physiological processes, nutritional efficiency, and growth without posing any environmental risks, as evidenced by Alejandro *et al.* (2020). Moreover, some previous studies indicate that boron and manganese play important roles in enhancing respiration, chlorophyll content, photosynthetic activity, enzymatic activity, plant growth, development, and productivity (wang*et al.*, 2013).

Interaction effect

Data in Table 3 shows that supplying soil application of humic acid with Nano trace elements spraying led to significant increases in the activity of catalase enzyme in 2nd season and peroxidase enzyme in both seasons. The activation of antioxidants was observed in terms of peroxidase enzyme and catalase enzyme in beets grown in soil fertilized with 2.5 kg or when doubled to 5 kg humic acid/fed (without significant difference between them), along with sprayed with Nano boron or manganese (without significant variance in between). These results may explain the importance of activation antioxidants for plant metabolism, defense, and signal perception and the significant role humic acid plays in activating antioxidant enzymes and sprays beet canopies with boron and/or manganese as nanostructure agents can further enhance this activity.

Table 3: Leaf area index (LAI), activity of catalase (CAT) and peroxidase enzymes (POX) (mM H_2O_2 g^{-1} FW min^{-1}) of beets as affected by fertilization with humic acid levels and spraying Nano microelements in 2021/2022 and 2022/2023 seasons

B: Nano fertilizer	Traits	A: Humic acid rates/fed (kg)							
		2021/2022				2022/2023			
		Zero	**2.5**	**5**	**Mean**	**Zero**	**2.5**	**5**	**Mean**
Without spraying	LAI	3.68	4.74	5.67	**4.70**	2.83	3.92	4.00	**3.58**
Nano-Fe		4.07	4.93	6.46	**5.15**	2.77	4.99	5.13	**4.30**
Mano-Mn		4.39	5.20	6.59	**5.39**	4.13	3.52	5.86	**4.50**
Nano-B		4.54	5.51	7.28	**5.78**	4.68	5.82	6.16	**5.55**
Mean		**4.17**	**5.10**	**6.50**		**3.60**	**4.56**	**5.29**	
LSD at 5% for factor A and B		**A: 0.67**		**B: 0.38**		**A: 0.64**		**B: 1.00**	
LSD at 5% for A x B		**NS**				**NS**			
Without spraying	CAT	1.22	3.13	5.38	**3.24**	5.48	5.03	3.04	**4.50**
Nano-Fe		1.90	3.31	5.69	**3.64**	5.46	3.82	4.59	**4.62**
Nano-Mn		1.97	3.43	5.96	**3.79**	3.90	4.87	5.44	**4.74**
Nano-B		2.87	4.57	6.52	**4.65**	3.14	5.12	6.30	**4.85**
Mean		**1.99**	**3.61**	**5.89**		**4.48**	**4.71**	**4.84**	
LSD at 5% for factor A and B		**A:1.30**		**B:0.50**		**A: NS**		**B: NS**	
LSD at 5% for A x B		**NS**				**1.85**			
Without spraying	POX	0.15	0.17	0.48	**0.26**	0.15	0.12	0.48	**0.25**
Nano-Fe		0.16	0.27	0.61	**0.34**	0.22	0.17	0.59	**0.33**
Nano-Mn		0.22	0.21	0.58	**0.33**	0.20	0.57	0.50	**0.43**
Nano-B		0.10	0.60	0.77	**0.49**	0.51	0.56	0.61	**0.56**
Mean		**0.15**	**0.31**	**0.61**		**0.27**	**0.36**	**0.55**	
LSD at 5% for factor A and B		**A:0.19**		**B:0.12**		**A:0.14**		**B: 0.13**	
LSD at 5% for A x B		**0.20**				**0.22**			

Data in Table 4 manifest the fertilizing beets varying rates of humic acid had a significant impact on the root sucrose, extracted sugar and sugar lost to molasses percentages in both seasons. It was observed that supplying beets with 2.5 or 5 kg of humic acid/fed (without significant differences between them) resulted in the highest root sucrose and extracted sugar percentages compared to the untreated beet plants in both seasons. Soil application of 2.5 or 5 kg humic acid/fed significantly reduced sugar lost to molasses %, compared to soil plants untreated with humic acid (control) in the first season. However, in 2nd season, fertilizing beets with 2.5 kg humic acid/fed was found to be more effective in reducing the percentage of sugar lost to molasses compared to using 5 kg of humic acid/fed.

As for, the impact of Nano trace elements studied on beet plants, data indicated that neither sucrose% nor extracted sugar % showed a significant effect when beet plants were sprayed with Nano trace elements in both seasons. However, foliar application of beet plants with Nano boron led to lower values of sugar lost to molasses% compared to spraying other Nano micronutrients in the second season only, according to Table 4.

Table 4: Sucrose(S), extracted (EX) sugar and sugar lose to molasses (SLM) percentages of beets as affected by fertilization with humic acid levels and spraying Nano microelements in 2021/2022 and 2022/2023 seasons

B: Nano fertilizer	Traits	A: Humic acid rates/fed (kg)							
		2021/2022				2022/2023			
		Zero	2.5	5	Mean	Zero	2.5	5	Mean
Without spraying	S%	13.77	16.69	16.42	**15.62**	12.94	16.44	16.58	**15.32**
Nano -Fe		14.62	14.93	17.46	**15.67**	15.12	15.35	17.96	**16.14**
Nano –Mn		15.55	16.87	14.83	**15.75**	16.05	17.29	15.33	**16.22**
Nano -B		14.02	17.77	15.87	**15.89**	14.52	18.19	16.37	**16.36**
Mean		**14.49**	**16.56**	**16.14**		**14.66**	**16.82**	**16.56**	
LSD at 5% for factor A and B		**A: 0.51**		**B: NS**		**A: 0.45**		**B: NS**	
LSD at 5% for A x B		**1.97**				**1.90**			
Without spraying	EX%	11.14	14.15	13.78	**13.03**	10.17	14.05	14.29	**12.84**
Nano-Fe		11.88	12.45	14.99	**13.11**	12.51	13.11	15.39	**13.67**
Nano-Mn		13.00	14.48	12.44	**13.31**	13.36	15.07	12.68	**13.70**
Nano-B		11.40	15.35	13.50	**13.42**	11.87	15.96	14.16	**14.00**
Mean		**11.85**	**14.11**	**13.68**		**11.98**	**14.54**	**14.13**	
LSD at 5% for factor A and B		**A:0.60**		**B: NS**		**A:0.41**		**B: NS**	
LSD at 5% for A x B		**2.00**				**1.94**			
Without spraying	SLM	2.03	1.94	2.03	**2.00**	2.16	1.79	1.69	**1.88**
Nano-Fe		2.14	1.88	1.87	**1.69**	2.01	1.64	1.98	**1.87**
Nano-Mn		1.94	1.79	1.79	**1.84**	2.09	1.62	2.04	**1.92**
Nano-B		2.02	1.82	1.77	**1.87**	2.05	1.64	1.60	**1.76**
Mean		**2.03**	**1.86**	**1.87**		**2.08**	**1.67**	**1.83**	
LSD at 5% for factor A and B		**A:0.10**		**B: NS**		**A:0.11**		**B: 0.12**	
LSD at 5% for A x B		**NS**				**0.16**			

Interaction effect

The interaction effect in Table 4 cleared that fertilizing beet plants with 5 kg and/or 2.5 kg humic acid/fed (without significant differences between them), along with spraying beet tops with Nano boron gave the highest root sucrose and extracted sugar percentages, compared with other nanostructures elements combinations in both seasons. These results assured the vital role of humic acid and boron in the metabolic translocation process, as reported by (Abd El-Aal and Abd El-Rahman, 2014) and Enan*et al.* (2016). Moreover, the difference in sugar lost to molasses% in beets root fertilized with 5 kg and 2.5 kg humic/fed was insignificant in the state of spraying beets with Nano boron. However, the difference between those two levels of humic acid reached the level of significance when unsprayed beets with nanostructured elements. The lowest values of sugar lost to molasses were obtained in the case of fertilizing beet plants with 2.5 or 5 humic acid, with spraying Nano boron in the second season.

Data in Table 5 revealed significant differences between humic acid levels in potassium and sodium contents in 2nd season, with a notable impact in their effect on alpha amino-N in both seasons. Supplying beet plants with 2.5 kg humic/fed resulted in lower potassium and sodium content compared to using 5 kg humic acid/fed in the second season. Furthermore, increasing humic acid levels up to 5 kg/fed significantly decreased the values of alpha-amino N content, compared to adding 2.5 kg humic/fed in both seasons. These results may be attributed to the higher available potassium at the experimental site exceeding the critical level, along with the important role of humic acid as a key component of soil organic structure. Additionally, humic acids have a beneficial effect on enzyme activity, plant nutrients, and nutrient levels in plants.

Concerning the effect of spraying beet tops with nanoparticles, the results in Table 5 showed an insignificant effect on juice impurities, in terms of (potassium and sodium contents) of sugar beet roots in both seasons. On the other hand, spraying Nano boron led to significantly lower values of alpha amino-N, compared to spraying beet plants with anothernanomaterial in both seasons.

Table 5: Potassium (K), sodium (Na) and alpha amino-N contents in root beets as affected by fertilization with humic acid levels and spraying Nano microelements in 2021/2022 and 2022/2023 seasons

B: Nano fertilizer	**Traits**	**A: Humic acid rates/fed (kg)**							
		2021/2022				**2021/2022**			
		Zero	**2.5**	**5**	**Mean**	**Zero**	**2.5**	**5**	**Mean**
Without spraying	**K**	5.92	5.45	6.70	**6.02**	7.07	4.98	4.12	**5.39**
Nano-Fe		6.75	5.39	6.07	**6.07**	5.79	4.03	6.64	**5.49**
Nano-Mn		5.73	5.10	5.12	**5.32**	6.53	4.26	7.38	**6.06**
Nano-B		5.99	5.63	5.32	**5.65**	6.52	4.64	4.79	**5.32**
Mean		**6.10**	**5.39**	**5.80**		**6.48**	**4.48**	**5.73**	
LSD at 5% for factor A and B		**A: NS**		**B: NS**		**A: 0.67**		**B: NS**	
LSD at 5% for factor A x B		**NS**				**1.06**			
Without spraying	**Na**	1.88	1.81	1.77	**1.82**	1.50	1.59	1.90	**1.66**
Nano-Fe		1.98	1.68	1.43	**1.69**	1.85	1.56	1.79	**1.73**
Nano-Mn		1.71	1.61	2.02	**1.78**	1.87	1.50	1.73	**1.70**
Nano-B		2.06	1.48	1.85	**1.80**	1.70	1.41	1.39	**1.50**
Mean		**1.91**	**1.65**	**1.77**		**1.73**	**1.51**	**1.70**	
LSD at 5% for factor A and B		**A: NS**		**B: NS**		**A: 0.16**		**B: NS**	
LSD at 5% for factor A x B		**NS**				**NS**			
Without spraying	**A- amino N**	1.75	1.68	1.39	**1.61**	1.85	1.50	1.40	**1.58**
Nano-Fe		1.68	1.55	1.29	**1.51**	1.75	1.43	1.19	**1.46**
Nano-Mn		1.61	1.39	1.17	**1.39**	1.66	1.25	1.07	**1.33**
Nano-B		1.56	1.31	1.05	**1.31**	1.59	1.16	0.95	**1.23**
Mean		**1.65**	**1.48**	**1.22**		**1.71**	**1.34**	**1.15**	
LSD at 5% for factor A and B		**A: 0.24**		**B: 0.05**		**A: 0.11**		**B: 0.07**	
LSD at 5% for A x B		**NS**				**NS**			

Interaction effect

An insignificant difference was detected in root potassium content between fertilizing beet plants with 2.5 and 5 kg humic acid/fed in the state of spraying beet plants with Nano boron and in the state of absence of humic acid in 2nd season. However, the differences in root potassium content between the same two applied levels of humic acid were significantly affected when spraying beets with Nano manganese and/or Nano iron. The combination of adding 5 kg humic acid/fed+ spraying beets with Nano manganese resulted in the highest root potassium content values, while the lowest values were recorded in adding 2.5 kg humic along with spraying Nano iron (Table, 5).

Table 6 results demonstrate that the application of humic acid to beet plants significantly increased their root, sugar yields/fed and quality index in both seasons. Using 5 kg of humic acid/fed gave 14.15% and 15.94% tons increase in root yield/fed and increased sugar yield by about 10.37% and 11.70 tons in both seasons, compared to using 2.5 kg humic/fed. However, adding 2.5 kg produced the highest quality index values and exceeded 5 kg humic/fed by about 0.60% and 1.4 % in both seasons respectively. These findings highlight the importance of humic acid as a soil amendment for enhancing the qualitative and quantitative yield of sugar beet, as it improves soil fertility and water use efficiency. Furthermore, humic acid application can enhance microbial and enzymatic processes, promote beet growth and facilitate metabolic translocation. These results are consistent with previous studies by Feckova *et al.* (2013) who demonstrated that applying humic acid increased root yield of sugar beet by up to 20% compared to control, attributed to the ability of humate chelates complexes with microelements to more easily reach plant cells more than the common ions.

Results in the same Table reported that foliar application of Nano fertilizer increased yields of root and sugar/fed in both seasons. However, the response of beet quality index to foliar application of Nano fertilizer had an insignificant effect in both seasons. Spraying beet canopies treated with Nano boron produced the heaviest yield of root/fed in both seasons compared to the other Nano elements and the highest sugar yield/fed (without significant differences between it and Nano manganese), in 1st season, compared to plants that received Nano iron and those that untreated with Nano fertilizer. These results are in agreement with those reported by Enan *et al.* (2016) who explained the enhanced role of boron in the translocation of photosynthesis from leaves to roots, which was reflected in root and sugar yields/fed.

Interactions effect

Data revealed that the difference in root yield/fed was insignificant between spraying Nano boron and Nano manganese when beets fertilized with 5 kg humic/fed in the first season. Meanwhile, the difference between spraying the same two elements under the higher dose of humic (5 kg/fed) reached the level of significance and increased in 2nd season. The maximum root yield was obtained when fertilizing beets with 5 kg humic/fed along with spraying by Nano boron compared to the other combinations in both seasons as shown in (Table, 6).

The interaction between the studied factors showed that the difference in sugar yield/fed of beets fertilized with 2.5 and 5 kg humic/fed when spraying beets with Nano iron had a significant effect while the difference between the same two doses of humic acid did not reach the level of significance when beet spraying with the rest other elements in the two growing seasons. Fertilized beets with the combination of adding 2.5 kg or 5 kg humic acid/fed (without significant difference between them) + spraying with Nano boron resulted in the highest values of this trait compared to the other combinations in 1st season. Furthermore, in the 2021/2022 season, the quality index of beets in Table 6 was significantly affected by the interaction between the studied factors. The results showed that insignificant difference in beet quality index that was fertilized with 5 kg of humic acid/fed and those that were untreated with humic acid, when sprayed with Nano manganese. However, the differences between the two treatments reached a significant level when beets were sprayed with other Nano elements. The highest values of this trait were attained when using 2.5 kg of humic acid /fed in beets fertilization, and spraying with Nano boron or Nano manganese (without significant difference in between), compared to the other combinations in the second season. These results suggest that humic acid and Nano fertilizers potentially have a synergistic effect compared to conventional fertilizers, resulting in better nutrient absorption by plant cells for optimal growth.

Table 6: Root, sugar yields/fed and quality index, of beets as affected by fertilization with humic acid levels and spraying Nano microelements in 2021/2022 and 2022/2023 seasons

B: Nano fertilizer	Traits	A: Humic acid rates/fed (kg)							
		2021/2022				2021/2022			
		Zero	2.5	5	Mean	Zero	2.5	5	Mean
Without spraying	Root yield/fed (ton)	14.40	17.94	18.60	**16.98**	15.09	16.18	18.77	**16.68**
Nano Fe		20.63	26.21	29.45	**25.43**	16.16	23.03	24.54	**21.24**
Nano Mn		21.04	26.92	31.71	**26.56**	17.00	23.44	26.10	**22.18**
Nano B		22.17	27.26	32.50	**27.31**	22.36	23.91	30.97	**25.75**
Mean		**19.56**	**24.58**	**28.06**		**17.65**	**21.64**	**25.09**	
LSD at 5% for factor A and B		**A: 0.96 B: 0.69**				**A: 2.68 B: 1.43**			
LSD at 5% for A x B		**1.19**				**2.48**			
Without spraying	Sugar yield/fed (ton)	1.60	2.54	2.57	**2.24**	1.53	2.27	2.68	**2.16**
Nano Fe		2.45	3.27	4.43	**3.38**	2.02	3.02	3.78	**2.94**
Nano Mn		2.74	3.90	3.93	**3.52**	2.27	3.53	3.29	**3.03**
Nano B		2.52	4.18	4.39	**3.70**	2.65	3.81	4.36	**3.61**
Mean		**2.33**	**3.47**	**3.83**		**2.12**	**3.16**	**3.53**	
LSD at 5% for factor A and B		**A: 0.16 B: 0.35**				**A: 0.41 B: 0.25**			
LSD at 5% for A x B		**0.56**				**0.42**			
Without spraying	Quality index	80.90	84.80	83.75	**83.15**	78.62	85.44	86.07	**83.38**
Nano Fe		81.17	83.42	85.81	**83.46**	82.63	85.37	85.64	**84.55**
Nano Mn		83.63	85.84	83.68	**84.39**	83.23	87.15	85.59	**84.33**
Nano B		81.32	86.32	85.07	**84.24**	81.68	87.67	86.52	**85.29**
Mean		**81.76**	**85.09**	**84.58**		**81.54**	**86.41**	**85.21**	
LSD at 5% for factor A and B		**A: 1.03 B: NS**				**A: 0.88 B: NS**			
LSD at 5% for A x B		**NS**				**2.3**			

Conclusion

Under the conditions of this work can be recommended to add 5 kg humic acid/fed to sugar beet soil and spraying boron as nanostructure can significantly increase yields and improve quality traits.

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تاثير حمض الهيوميك و الرش بعناصر الحديد و المنجنيز و البورون النانونية علي انتاجية وجودة بنجر السكر

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الملخص العربي

أقيمت تجربتان حقليتان بمزرعة محطة بحوث سخا الزراعية - محافظة كفر الشيخ، مصر خلال موسمي ٢٠٢٢/٢٠٢١ و ٢٠٢٣/٢٠٢٢ لدراسة تأثير حامض الهيوميك كمحسن للتربة والرش الورقي بالعناصر الصغري كسماد نانوي علي نمو وحاصل ونوعية بنجر السكر ، وقد تضمن هذا العمل اثني عشر معاملة مثلت توليفات من ثلاثة مستويات من حامض الهيوميك (بدون إضافة ، إضافة ٢.٥ و ٥ كجم/فدان) والرش بأربعة عناصر صغري في صورة نانوية (بدون رش، رش الحديد، المنجنيز، البورون) للرش الورقي بمعدل ثابت (١٠٠مجم/ لتر)، والذين تم رشهم عند ٥٠ و ٦٥ و ٨٠ يوما من الزراعة. استُخدِم تصميم القطاعات كاملة العشوائية فى ترتيب القطع المنشقة مرة واحدة فى ثلاث مكررات.

- سجلت إضافة حامض الهيوميك بمعدل ٥ كجم/فدان أعلي القيم بفروق معنوية لأصباغ التمثيل الضوئي، دليل المساحة الورقية، نشاط إنزيم البيروكسيديز وحاصل الجذور والسكر/فدان، مع انخفاض محتوى ألفا-أمينونيتروجين في كلا الموسمين، كما زاد نشاط إنزيم الكتالاز في الموسم الأول فقط مقارنة بالمتحصل علية من إضافة نصف جرعة حمض الهيومك/فدان (٢.٥ كجم). كما أدى تسميد نباتات البنجر بـ ٢.٥ كجم حامض الهيوميك/فدان إلى انخفاض محتوى البوتاسيوم والصوديوم، بالإضافة إلى تحسين مؤشر الجودة مقارنة باضافة ٥ كجم حامض الهيوميك/فدان في كلا الموسمين. في حين أدي تزويد البنجر بـ ٢.٥ أو ٥ كجم من حامض الهيوميك / فدان (بدون فروق معنوية بينهم) إلى أعلى نسبة من السكروز والسكر المستخلص مع انخفاض في نسبة السكر المفقود في المولاس مقارنة بالمتحصل عليه من التربة الغير معاملة بحمض الهيومك في كلا الموسمين.
- سجل الرش الورقي لنباتات البنجر بالبورون في صورته النانوية أعلى القيم لمؤشر دليل المساحة الورقية وأصباغ التمثيل الضوئي، ونشاط انزيم البيروكسيديز، وحاصل الجذور والسكر/فدان في كلا الموسمين، مع نشاط انزيم الكتالاز في الموسم الأول فقط. بينما إنخفض محتوى الجذور من الألفا أمينونيتروجين والنسبة المئوية للسكر المفقود للمولاس في الموسم الثاني فقط، مقارنة مع الرش بباقي العناصر النانوية . كما لم يكن لرش البنجر بالعناصر النانوية تأثير معنوي على مؤشر الجودة والنسب المئوية للسكروز والسكر المستخلص في كلا الموسمين.
- تحت ظروف هذا البحث يمكن التوصية بتسميد البنجر بـ ٥ كجم هيومك/فدان مع الرش بالنانو بورون للحصول على أعلى إنتاجية للجذور والسكر/فدان مقارنةً بالتوليفات الأخرى.