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Effect of irrigation with magnetized water and spraying boron-sugar alcohol complex on yield and quality of sugar beet under west-west El-Minya conditions

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ABSTRACT

Two field experiments were carried out at the research farm of west-west El-Minya, (latitude of 28.24° N and longitude of 29.59° E with 134 meters elevation above sea level), El- Minya Governorate, Egypt, in the 2019/2020 and 2020/2021 seasons to find out the effect of magnetizing irrigation water and foliar application of boron-sugar alcohol complex on growth, yield, and quality of sugar beet (*Beta vulgaris var.* saccharifera, L.), under drip irrigation system in sandy soil. This work included ten treatments representing the combinations of two types of irrigation water [irrigation with well water (the conventional practice) and watering with magnetized well water] and five levels of boron-sugar alcohol complex (zero, 50,100,150, and 200 ppm/fed), equivalent to (zero, 2.36, 4.72, 7.08 and 9.44 cm^3) of the compound containing 15% boron, which was sprayed twice at 65 and 85 days from sowing. A split-plot randomized complete block design in arrangement with four replications was used. Results revealed that sugar beet plants irrigated with magnetized well water had better performance and productivity than those received well water without magnetization. Leaf area index, photosynthetic pigments, root criteria, percentages of sucrose, extracted sugar and quality index, as well as root, top, and sugar yields/fed increased compared to that received non-magnetized well water. However, impurities contents and sugar lost to molasses% were insignificantly affected in both seasons. Spraying beets with 150 and/or 200 ppm boron-sugar alcohol complex gave the highest values of sucrose, extracted sugar percentages, quality index, root, and top yields/fed in both seasons, as well as sugar yield/fed, in 1^{st} season while sodium and alpha-amino N contents decreased, in both seasons. On the other hand, spraying with 200 ppm boron-sugar alcohol complex increased leaf area index, photosynthetic pigments, root criteria, and root potassium content in both seasons as well as sugar yield/fed in the second one compared with those sprayed with 150 ppm. The combination of irrigation with magnetized well water + spraying with 150 and/or 200 ppm boron-sugar alcohol complex recorded the highest values of the root, top, and sugar yields/fed in both seasons.

Keywords: Boron-sugar alcohol complex, Magnetized water, Sugar beet.

INTRODUCTION

The total area of the sugar beet crop in 2021 amounted to 643,925 acres compared to 516,265 acres in the previous season, with an increase of 24.7%. Sugar beet has contributed to the production of 1,835,851 tons of beet sugar which represents 67.7% of the total sugar production in Egypt (Sugar Crops Council Annual Report, 2021). De facto, there is still a great need for increasing the area under sugar beet cultivation, especially in the newly reclaimed soil that is irrigated with well water and suffers from a deficiency in many nutrients, which requires more research concerning the use of irrigation technologies and fertilization under changing climatic conditions. Among these technologies, magnetized water is a promising one for improving water quality and preventing harmful metals such as lead and nickel from reaching the roots as well as dissolving and facilitating many nutrients like phosphorus, potassium, and zinc into the root zone to become more available, thus stimulating plant growth and development (Tai *et al.* 2008). In this context, Hilal *et al.* (2002) noted that magnetized water saves more irrigation water and has three main effects: first, increasing the leaching of excess soluble salts, second, lowering soil alkalinity, and third dissolving slightly soluble salts such as carbonates, phosphates, and sulfates. At the same time, the degree of effectiveness of magnetized water on soil salinity and ionic balance of soil solution depended on the traveling distance of magnetized water along the drip irrigation lines. Vasilevski (2003) indicated that irrigating sugar beet with magnetized water increased the root mass, leaf surface area, and beet yield by about 94.0%, 52.0%, and 12.88%, respectively. Maheshwari and Grewal (2009) found that there have been changes in water's physical and chemical properties depending on the magnetizing force of the water. These properties have changed including hydrogen bonds, surface tension, electrical conductivity, salts and power of hydrogen (pH). These changes increased the absorption of nutrients and vegetative growth of plants. Behrouz *et al.* (2010) reported that irrigation with magnetic water significantly increased soil moisture by up to 7.5% compared to using non-magnetic water. They added that the usage of magnetized water for irrigation saved irrigation water. Hozayn *et al.* (2013) showed that irrigation of beet plants with magnetized water could be used as the most important modern technology, which helps in saving irrigation water and increased sucrose% by about 4.07% compared to irrigation with non-magnetized water under sandy soil conditions. Ali *et al.* (2014) noted that magnetically treated water increases the efficiency of added fertilizers and helps nutrient mobility in soil, and enhances the uptake of N, P, K, Fe and Zn by plants. Faiyad and Hozayn (2020) indicated that irrigation of sugar beet plants with magnetic water significantly increased photosynthetic pigments, root diameter, fresh weight/plant, sucrose%, root, top, and sugar yields/fed. Meanwhile, the quality index was significantly decreased. Ibrahim *et al.* (2020) found that irrigation of beets with magnetized water significantly increased root criteria, sucrose, extracted sugar percentages and quality index with decreased impurities contents. These increments in root, top, and corrected sugar yields/fed were by about (4.15 and 3.73 tons), (1.87 and 1.73 tons) and (1.42 and 1.28 tons) in the 1st and 2nd seasons, successively, compared to irrigation with non-magnetized water.

Foliar application of micronutrients is one of the fastest ways to meet the deficiency requirements of boron and other elements in sandy soil, which contains relatively large particles, thereby fast filtration, which leads to loss of water and fertilizers which leads to decreased fertility. That's why studies have recently tended to use a spray of some complex nutrients with sugar alcohols. Brown and Hu (1996) indicated that sugar alcohols are the primary products of photosynthesis and exist in stable liquid form and the migration of mineral nutrients is better in an alkaline environment after forming complexes with sugar alcohols. Also, it had a low molecular weight and linear structure, which helped to improve foliar absorption as it moves freely, easily and efficiently within the plant, thus facilitating the transfer of boron inside the phloem. In this context, El Sayed *et al.* (2011) found that increasing boron levels caused significant increases in chlorophyll "a", "b" and carotenoids of sugar beet leaf. They added that these results could be attributed to the fact that boron is an essential element for photosynthetic pigments. Enan (2011) obtained the highest values of root diameter, fresh weight, root, sucrose%, top and sugar yields/fed as well as root and leaves contents of boron by spraying boron at 200 ppm/fed due to the function of boron in increasing plant metabolism, development and growth. Armin and Asgharipour (2012) indicated that the highest root yield/fad and sucrose, extracted sugar percentages were obtained by spraying 12% boric acid, while potassium, sodium, alpha amino-N contents and sugar lost to molasses decreased compared with the control treatment. Abbas *et al.* (2014) showed that the application of boron resulted in a significant increase in most growth traits, as the applied boron fertilizer increased up to 0.20 g/l and gave the highest sucrose, sugar recovery, purity percentages, root and recoverable sugar yields/fed compared to check treatment. Awuchl (2017) illustrated that applying small molecular compounds, such as sugar alcohols during agricultural production has been reported to increase the absorption of nutrients by plants. The translocation and movement of boron to the roots are affected by plant boron status and the synthesis of photosynthetic assimilates and contain sugar alcohols. Moreover, foliar-supplied boron can be translocated into the roots through the phloem, at least by forming the boron-sucrose complex (Du *et al.* 2020).

So, this work aimed to study the effect of irrigating sugar beet with magnetized water and fertilizing it with boron-bonded sugar alcohol for its applicability as sustainable agricultural practice under sandy soil conditions using a drip irrigation system.

MATERIALS AND METHODS

Two field experiments were carried out at the research farm of west-west El-Minya, (latitude of 28.24^{o} N and longitude of 29.59^{o} E with 134 meters elevation above sea level), El- Minya Governorate, Egypt, in the 2019/2020 and 2020/2021 seasons to find out the effect of magnetizing irrigation water and foliar application of boron-sugar alcohol complex on growth, yield, and quality of sugar beet (*Beta vulgaris var*. saccharifera, L.), under drip irrigation system in sandy soil. This work included ten treatments represented the combinations of two types of irrigation water [irrigation with well water (the conventional practice) and watering with magnetized well water] and five levels of sugar alcohol-boron complex (zero, 50,100,150, and 200 ppm/fed), equivalent to (zero, 2.36, 4.72, 7.08, and 9.44 cm^3) of liquid organic fertilizer containing (15% boron, 100% water solubility and pH 5–7, Agrostar Co. Malaysia), which was sprayed twice at 65 and 85 days from sowing. A split-plot randomized complete block design in arrangement with four replications was used, where the two irrigation water types were allocated at random in the main plots, while foliar doses of boron-sugar alcohol complex were distributed in the sub-plots. The sub-plot area was 28.8 m^2, including 8 ridges of 6 m in length and 60 cm in width, with 20 cm between hills. The Multi-germ sugar beet variety *viz* "Magribel" was sown after maize on 1st week of October in the 1st and 2nd seasons, while harvesting beets took place at the age of 180 days after planting in both seasons. Plants were thinned at the 4-leaf stage to ensure one plant per hill. Phosphorus fertilizer was applied in the form of calcium super phosphate (15 % P_2O_5) at the rate of 200 kg/fed at seedbed preparation. Nitrogen fertilizer was applied at 120 kg N/fed, which split as follows: the 1st dose was applied after thinning (4-true leaf stage), as a soil application at the rate of 20 kg N/fed as urea (46 % N), followed by four doses of nitrate (33.5% N) at the rate of 25 kg N/fed, given at two-week intervals after the first one. Potassium fertilizer was added in the form of potassium sulphate (48% K_2O) at the rate of 24 kg/fed in two equal doses: with 1st and 3rd doses of nitrogen fertilizer. The control treatment was irrigated with well water, while magnetized water was obtained, bypassing the well water through a 14500-gauss magnetron unit of 1.0-inch diameter purchased from Delta Water Company, Alexandria, Egypt, by Soil Water and Environment Research Institute. The device was installed in the foreword of the irrigation lines in the main plots that will be irrigated, with magnetically treated water. Drippers with a discharge of 4 liters/hour were used to reach the largest wet area as quickly as possible so that the roots of plants could absorb the water before it percolates beyond the root zone. Soil samples (at 0-30 cm depth) were collected from the experimental site to determine their physical and chemical properties using the method described by (AOAC, 1990), as shown in Table 1. The layout of the experiment design and the location of the magnetized water device under the drip irrigation system, was shown in (Fig. 1). An analysis of the well water used for irrigation, before and after magnetization, was performed by the standard methods used by Richards (1954), as manifested in Table 2.

Table 1. Particle size distribution and chemical soil properties of the experimental site in 2019/2020 and 2020/2021 seasons

Soil properties	**2019/2020 season**	**2020/2021 season**
Particle size distribution:		
Sand %	89.85	88.55
Silt %	8.85	9.95
Clay %	1.30	1.50
Soil Texture	sandy	sandy
Available nutrients		
Organic Matter %	0.69	0.74
Available Nitrogen mg/kg soil	28.75	29.42
Available P_2O_5 mg/kg soil	5.90	6.35
Available K_2O mg/kg soil	218	228
Available boron mg/kg soil	0.11	0.13
pH at (1:2.5) soil : water suspension	7.60	7.58
EC dS/m^{-1}	5.80	5.29
Soluble cations (meq/l^{-1})		
K^+	0.59	0.51
Na^+	9.99	9.56
Mg^{++}	10.62	9.25
Ca^{++}	31.52	32.59
Soluble anions (meq/l^{-1})		
$So_4^=$	27.72	28.21
Cl^-	16.10	16.80
HCO_3^-	8.90	6.90
$CO_3^=$	-	-
$CaCo_{3\%}$	8.95	7.65
*** Sodium Adsorption Ration (SAR)**	2.18	2.09
*** Exchangeable sodium percentage (ESP%)**	4.20	4.10

* SAR=Na/SQRT(Ca^{+2} + Mg^{+2})/2 according to **(Richards**, **1954)**.

* ESP = 1.95 + 1.03 SAR

Fig. 1: Layout of the experiment design and location of the magnetized water device under the drip irrigation system

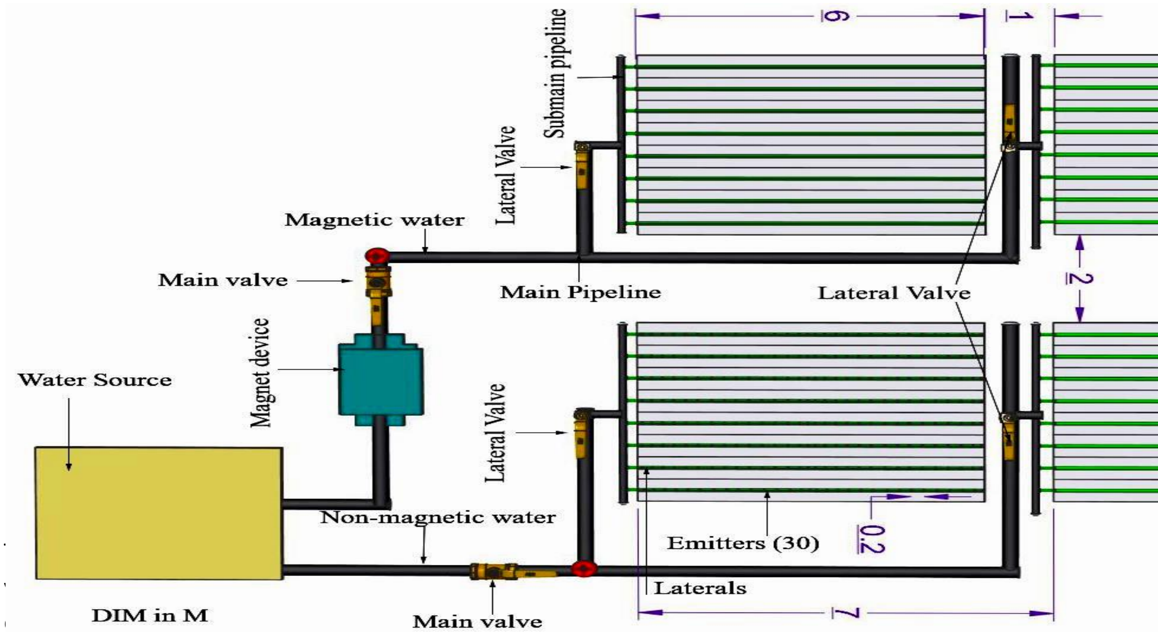

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Table 2. Chemical properties of the used irrigation well water before and after magnetizing water in 2019/2020 and 2020/2021 seasons

Parameters	1st season		2nd season	
	Well water	Magnetized well water	Well water	Magnetized well water
pH	8.10	7.90	7.85	7.70
EC dSm^{-1}	3.25	3.16	3.00	2.95
Soluble cations (meql^{-1})				
Ca^{2+}	10.8	10.4	9.80	9.74
Mg^{2+}	7.3	7.5	6.5	6.8
Na^{+}	13.7	13.4	11.6	11.1
K^{+}	0.85	0.86	0.96	0.96
Soluble anions (meql^{-1})				
Co_3^{-2}	0.01	0.01	0.01	0.01
HCO_3^{-}	0.56	0.59	0.39	0.47
Cl^{-}	18.62	18.00	15.27	14.85
$SO4^{-2}$	13.46	13.56	13.19	13.27

Studied traits:

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

1. 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) was measured at 120 days from sowing using the leaf area meter, model: 3000 A.

2. Photosynthetic pigments *i.e.*, chlorophyll a, b, and carotenoids (mg/g leaf fresh weight) were determined according to the method described by Wettstein (1957).

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

1. Root diameter/plant (cm).
2. Root and foliage fresh weights/plant (g).

3. Quality analysis was done on fresh samples of sugar beet roots at the Laboratory of El-Mina Sugar Factory, Egypt. Sucrose percentage (Pol %), was determined in fresh macerated root according to the method of Le-Docte (1927).
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).
Sugar lost to molasses percentage (SLM%) was calculated according to the equation of Devillers (1988):

$$SLM = 0.14\ (Na + K) + 0.25\ (\alpha\text{–amino N}) + 0.5$$

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

$$ES\% = \text{sucrose }\% - SLM\ \% - 0.6$$

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

$$QI = (\text{extracted sugar}\% / \text{sucrose }\%) \times 100$$

Yields:

1. Root and top yields/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:

The obtained data were statistically analyzed according to the technique (Co-STATC) 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

1. Leaf area index and photosynthetic pigments:

The magnetic field can change the properties of water, as it becomes more able to flow and more energetic and increases the absorption of some nutrients such as phosphorus and potassium. Results in **Table (3)** indicated that the application of magnetized water significantly increased the leaf area index and leaf content of photosynthetic pigments compared with used non-magnetized water irrigation in both seasons. These increments in leaf expansion and their contents of chlorophyll "a", b" and carotenoids induced by using magnetically treated water amounted to 27.22%, 14.55%, 11.70%, and 13.92% in the 1st season, as opposed to 23.22%, 16.14%, 12.12%, and 13.10%, in the second season. Relating to the sugar alcohol complexed boron levels effect, it was noted that leaf photosynthetic pigments increased gradually due to being sprayed with sugar alcohol complexed boron levels in both seasons. The highest leaf area index and chlorophyll a, b, and carotenoid contents were recorded when beet plants were sprayed, with 200 ppm complexed boron compared to that received 150 ppm and those unsprayed ones, which gave the lowest value of photosynthetic pigments Table (3).

Table 3. Effect of irrigation water type and sugar alcohol complexed boron levels on leaf area index and photosynthetic pigments of sugar beet in 2019/2020 and 2020/2021 seasons

Treatments	Leaf area index		Photosynthetic pigments (mg/g f.w.)					
			Chlorophyll a		Chlorophyll b		Carotenoids	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd season	1st Season	2nd Season
(A) Irrigation water type								
Well water	2.02	2.11	3.30	3.47	1.88	1.98	0.79	0.84
Magnetized well water	2.57	2.60	3.78	4.03	2.10	2.22	0.90	0.95
LSD at 0.5%	**0.41**	**0.12**	**0.35**	**0.22**	**0.21**	**0.13**	**0.11**	**0.09**
(B) Sugar alcohol complexed boron levels (ppm)								
0	1.27	1.62	3.00	3.27	1.33	1.46	0.64	0.68
50	1.72	1.94	3.11	3.34	1.47	1.57	0.72	0.74
100	2.26	2.26	3.31	3.44	1.67	1.77	0.80	0.85
150	2.91	2.53	3.92	4.20	2.54	2.64	0.97	1.03
200	3.31	3.44	4.36	4.49	2.94	3.07	1.08	1.17
LSD at 0.5%	**0.28**	**0.20**	**0.25**	**0.19**	**0.17**	**0.15**	**0.10**	**0.11**
A x B	**	**	NS	NS	NS	NS	NS	NS

The interaction effect:

In this work, the leaf area index was appreciably affected by the interaction between irrigation water type and foliar application of sugar alcohol complexed boron levels in both seasons (Table 4). Data elucidated that the difference in leaf area index of beets sprayed with 100 ppm and those received 150 ppm of boron was insignificant when beets were irrigated traditionally, while the variance between those two levels of complexed boron reached the level of significance in case of irrigating with magnetized water in both seasons. Sugar beet plants reached their maximum leaf expansion to intercept more light per unit area of soil when using magnetically treated water + sprayed 200 ppm complexed boron /fed.

Table 4. Significant interaction between irrigation water type and sugar alcohol complexed boron levels on leaf area index for sugar beet in 2019/2020 and 2020/2021 seasons

Irrigation water type	Sugar alcohol complexed boron levels (ppm)									
	1st season					2nd season				
	zero	50	100	150	200	zero	50	100	150	200
Well water	1.05	1.59	2.30	2.38	2.79	1.56	1.62	2.10	2.31	2.98
Magnetized well water	1.48	1.85	2.23	3.45	3.82	1.67	2.25	2.43	2.75	3.90
LSD	**0.39**					**0.29**				

2. Root diameter, root and foliage fresh weights/plant:

Results in Table 5 showed that root diameter, root and foliage fresh weights/plant of sugar beet significantly increased due to the irrigation with magnetized water in both seasons. Irrigating sugar beet with magnetized water produced thicker, heavier roots and leaves per plant than that irrigated with non-magnetically treated water (the control). Concerning the effect of boron-bonded sugar alcohol levels, data indicated that root diameter, root and foliage fresh weights/plant responded to the increase of foliar application of sugar alcohol complexed boron levels in the two growing seasons. Raising boron-bonded sugar alcohol levels from zero to 200 ppm resulted in a significant increase in root diameter, fresh and foliage weights/fed amounted to (0.67, 0.99 cm), (91.12, 91.77 g fresh root), and 104.57, 100.41 g fresh foliage) compared to those that received 150 ppm complexed boron in 1st and 2nd seasons, successively.

Table 5. Effect of irrigation water type and sugar alcohol complexed boron levels on root diameter, root and foliage fresh weights/plant of sugar beet in 2019/2020 and 2020/2021 seasons

Treatments	Root diameter (cm)		Root fresh weight/plant (g)		Foliage fresh weight/plant (g)	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd season
(A) Irrigation water type						
Well water	9.22	9.27	545.58	561.51	227.73	226.07
Magnetized well water	11.12	11.18	585.15	599.65	261.16	261.16
LSD 0.5%	1.03	0.94	18.31	20.19	18.35	17.23
(B) Sugar alcohol complexed boron levels (ppm)						
0	8.63	8.82	461.52	477.04	171.28	171.28
50	9.26	9.59	472.97	484.75	186.60	186.60
100	10.24	10.20	564.14	578.89	216.31	216.31
150	11.03	10.76	618.54	635.22	271.73	271.73
200	11.70	11.75	709.66	726.99	376.30	372.14
LSD 0.5%	**0.34**	**0.31**	**18.85**	**16.13**	**17.81**	**17.70**
A x B	**	**	**	**	**	**

The interactions effect:

Data in Tables 6 and 7 illustrated that both root diameter and fresh weight/plant were significantly affected by the interaction between types of irrigation water and boron-bonded sugar alcohol in both seasons. it was obvious that the differences in root diameter and fresh weight/plant of sugar beet plants sprayed with 100 and 150 ppm complexed boron levels were insignificant when beets had been irrigated with well water (conventional irrigation) in both seasons. However, these variances in root diameter and fresh weight/plant between those two levels of complexed boron were significant in case of beets watered using magnetized water in both seasons. Irrigating sugar beet plants with magnetized water along with spraying them with 200 ppm boron-bonded sugar alcohol produced thicker roots by a higher number of cambium rings as well, the heaviest roots in both seasons.

Table 6. Significant interaction between irrigation water type and sugar alcohol complexed boron levels on root diameter of sugar beet in 2019/2020 and 2020/2021 seasons

Irrigation water type	Sugar alcohol complexed boron levels (ppm)									
	1st season					2nd season				
	Zero	50	100	150	200	Zero	50	100	150	200
Well water	7.78	8.53	9.35	9.77	10.69	7.71	8.94	9.40	9.74	10.55
Magnetized well water	9.47	9.99	11.13	12.30	12.72	9.93	10.23	11.00	11.77	12.95
LSD 0.5%	**0.48**					**0.45**				

Table 7. Significant interaction between irrigation water type and sugar alcohol complexed boron levels on root fresh weight/plant of sugar beet in 2019/2020 and 2020/2021 seasons

Irrigation water type	Sugar alcohol complexed boron levels (ppm)									
	1st season					2nd season				
	0	50	100	150	200	0	50	100	150	200
Well water	449.77	467.02	554.64	574.07	682.38	465.83	480.27	574.08	591.94	695.43
Magnetized well water	473.27	478.92	573.64	663.00	736.94	488.24	489.24	583.71	678.50	758.55
LSD 0.5%	**26.66**					**22.81**				

Foliage fresh weight/plant was significantly affected by the interaction between irrigation water type and boron-bonded sugar alcohol in both seasons (Table 8). It was observed that the difference in foliage fresh weight/plant between beets sprayed with 50 ppm and those untreated with complexed boron was insignificant in a state of irrigated beets with well water without magnetization. Nevertheless, the difference in this trait between the same two levels of complexed boron was significant if using magnetized water in both seasons. Spraying beet plants with 200 ppm complexed boron/fed was accompanied by significantly increased foliage weight/plant, amounting to 5.01% and 10.06% in sugar beets irrigated with magnetized water than those had been watered traditionally (well water) in the 1st and 2nd seasons, respectively.

Table 8. Interaction effect between irrigation water type and sugar alcohol complexed boron levels on foliage fresh weight/plant of sugar beet in 2019/2020 and 2020/2021 seasons

Irrigation water type	Sugar alcohol complexed boron levels (ppm)									
	1st season					2nd season				
	0	50	100	150	200	0	50	100	150	200
Well water	158.56	167.95	181.37	259.41	363.04	172.24	184.13	192.50	270.91	355.11
Magnetized well water	184.01	205.25	251.26	284.05	381.23	193.38	217.17	265.56	288.93	390.85
LSD 0.5%	**25.09**					**17.27**				

3. Sucrose% and impurities contents.

Sucrose % was markedly influenced by the two types of irrigation applied (Table 9). Meanwhile, neither irrigating sugar beet traditionally with normal nor magnetized water led to a significant influence, on the values of potassium, sodium, and alpha-amino N contents, in both seasons. Irrigating beet plants with magnetized water led to a significant increase in sucrose%, which ranged from 5.89% to 7.30 % compared with that irrigation using traditional well water in the 1st and 2nd seasons sequentially. Regarding the boron-bonded alcoholic sugar levels effect in the same Table, data detected that sucrose% and impurities contents were significantly affected by spraying boron complex in both seasons. It turned out that the increase in the level of complexed boron was accompanied by an ascending increase in both root sucrose% and potassium content but with a descending decrease in sodium and alpha amino-N contents in both seasons. Fertilizing sugar beet with 150 and/or 200 ppm complexed boron (without significant difference between them) gave the highest values of sucrose% and lowest values of sodium and alpha-amino N contents, compared with those plants that were inadequately supplied, with bonded-boron. Meanwhile, the highest dose of boron-bonded sugar alcohol (200 ppm) led to higher values of root potassium content compared to other studied levels in both seasons.

Table 9. Effect of irrigation water type and sugar alcohol complexed boron levels on sucrose%, potassium, sodium and alpha-amino N contents of sugar beet in 2019/2020 and 2020/2021 seasons

Treatments	Sucrose %		Impurities (meq/100 g beet)					
			Potassium		Sodium		Alpha-amino N	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd season	1st Season	2nd Season
(A) Irrigation water type								
Well water	16.63	17.27	3.53	3.82	1.60	2.04	1.27	1.47
Magnetized well water	17.61	18.53	3.73	3.98	1.54	1.70	1.15	1.13
LSD 0.5%	**0.41**	**0.48**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
(B) Sugar alcohol complexed boron levels (ppm)								
0	16.69	17.42	3.45	3.71	1.82	2.01	1.41	1.53
50	17.00	17.53	3.47	3.75	1.62	1.92	1.25	1.39
100	17.05	17.86	3.54	3.80	1.54	1.86	1.18	1.33
150	17.31	18.21	3.60	3.81	1.48	1.80	1.14	1.21
200	17.54	18.47	4.10	4.42	1.40	1.77	1.08	1.06
LSD 0.5%	**0.50**	**0.28**	**0.35**	**0.37**	**0.11**	**0.12**	**0.20**	**0.18**
A x B	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

4. Sugar lost to molasses, extracted sugar percentages and quality index.

Data in Table 10 showed that magnetized well water irrigation positively increased extracted sugar% and improved the quality index compared to irrigation with non-magnetically treated well water in both seasons. These increases in extracted sugar% and quality index amounted to (6.83%, 0.88 %) and (9.14%, 1.74%) compared with those irrigated traditionally with well water in the first and second seasons, respectively. On the other hand, the response of sugar loss to molasses% to irrigation water types was an insignificant effect in both seasons. As far as the sugar alcohol complexed boron effect, the results indicated that extracted sugar% and quality index significantly increased by raising the foliar-applied complexed boron levels from zero up to 200 ppm/fed in both seasons. However, the sugar lost to molasses% trait was not significantly affected by increasing the boron-bonded sugar alcohol fertilization level, although it tends to decrease in both seasons. Spraying beets with 150 and/or 200 ppm complexed boron (without significant differences between them) attained the highest values of these traits compared with the other boron-bonded sugar alcohol levels.

Table 10. Effect of irrigation water type and sugar alcohol complexed boron levels on sugar lost to molasses, extracted sugar percentages and quality index of sugar beet in 2019/2020 and 2020/2021 seasons

Treatments	Sugar lost to molasses %		Extracted sugar %		Quality index	
	1st Season	2nd Season	1st Season	1st Season	2nd Season	1st Season
(A) Irrigation water type						
Well water	1.54	1.69	14.49	14.98	87.14	86.73
Magnetized well water	1.52	1.58	15.48	16.35	87.91	88.24
LSD 0.5%	**NS**	**NS**	**0.39**	**0.52**	**0.15**	**0.68**
(B) Sugar alcohol complexed boron levels (ppm)						
0	1.59	1.68	14.50	15.13	86.86	86.87
50	1.52	1.64	14.88	15.92	87.49	87.19
100	1.51	1.62	14.49	15.64	87.64	87.51
150	1.49	1.59	15.22	16.02	87.86	87.96
200	1.54	1.63	15.40	16.24	87.77	87.89
LSD 0.5%	**NS**	**NS**	**0.49**	**0.26**	**0.51**	**0.33**
A x B	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

4. Root, top and sugar yields/fed (ton).

Data in Table 11 showed that irrigating beet plants with magnetized well water significantly increased root, top, and sugar yields/fed, compared with non-magnetically treated well water, in both seasons. These increments were substantial in the root, top and sugar yields per fed, amounting to (2.13, 1.27, and 0.54 tons/fed), in 1st season and (2.38, 1.25, and 0.68 tons/fed) in the second one, sequentially, compared with those gained by irrigated with non-magnetized water. As for, the effect of sugar alcohol complexed boron levels in the same Table. Results revealed that increasing complexed boron levels from zero up to 200 ppm/fed resulted in a significant increase in root, top and sugar yields/fed in both seasons. Fertilizing beet plants with 150 and/or 200 ppm of complexed boron (without significant variation between them) gave higher values of root and top yields/fed in both seasons, as well as sugar yield/fed in the first season, compared to spraying other levels of boron-bonded sugar alcohol (Table 11).

Table 11. Effect of irrigation water type and sugar alcohol complexed boron levels on root, top and sugar yields/fed of sugar beet in 2019/2020 and 2020/2021 seasons

Treatments	Root yield/fed (ton)		Top yield/fed (ton)		Sugar yield/fed (ton)	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
(A) Irrigation water type						
Well water	20.56	20.72	5.32	5.18	2.98	3.10
Magnetized well water	22.69	23.10	6.59	6.43	3.52	3.78
LSD 0.5%	**0.53**	**0.50**	**0.70**	**1.07**	**0.08**	**0.17**
(B) Sugar alcohol complexed boron levels (ppm)						
0	19.84	20.06	4.41	4.24	2.88	3.04
50	20.85	21.39	5.87	5.21	3.11	3.27
100	22.11	22.27	6.11	5.98	3.31	3.49
150	22.55	22.73	6.58	6.73	3.43	3.62
200	22.77	23.09	6.81	6.90	3.52	3.76
LSD 0.5%	**0.26**	**0.37**	**0.31**	**0.25**	**0.10**	**0.09**
A x B	**	**	**	**	**	**

Interactions effect:

The interaction between the studied factors had a significant effect on root and top yields/fed in both seasons, as depicted in Tables (12 and 13). It was clear that the difference in root and top yields per fed between the two levels of boron-bonded sugar alcohol sprayed at 100 and 150 ppm was insignificant if beets, were irrigated using traditional well water. Nevertheless, the variance between the same two levels of complexed boron reached the level of significance in case of irrigation sugar beet plants with magnetically treated water in both seasons. The highest values of root and top yields/fed were obtained by beet irrigation with magnetically treated water + spraying with 150 and/or 200 ppm of complexed boron (with insignificant differences between them) in both seasons.

Table 12. Significant interaction between irrigation type water and sugar alcohol complexed boron levels on root yield/fed of sugar beet in 2019/2020 and 2020/2021 seasons

Irrigation water type	Sugar alcohol complexed boron levels (ppm)									
	1st season					2nd season				
	Zero	50	100	150	200	Zero	50	100	150	200
Well water	18.98	19.97	21.04	21.10	21.68	18.77	20.84	21.16	21.27	21.56
Magnetized well water	20.70	21.73	23.18	23.86	24.00	21.35	21.93	23.38	24.20	24.62
LSD at 0.5%	**0.37**					**0.52**				

Table 13. Interaction effect between irrigation water type and sugar alcohol complexed boron on top yield/fed of sugar beet in 2019/2020 and 2020/2021seasons

Irrigation water type	Sugar alcohol complexed boron levels (ppm)									
	1st season					2nd season				
	Zero	50	100	150	200	Zero	50	100	150	200
Well water	4.37	5.09	5.43	5.66	6.04	3.53	5.25	5.57	5.63	5.93
Magnetized well water	4.44	5.65	6.78	7.50	7.58	4.95	5.17	6.39	7.83	7.87
LSD at 0.5%	**0.44**					**0.35**				

Data in Table 14 illustrated that sugar yield/fed was affected significantly by the interaction between two water irrigation types and sugar alcohol complexed boron levels during the two growing seasons. Decreasing boron-bonded sugar alcohol rates from 200 ppm to zero significantly decreased sugar yield/fed under the studied water irrigation types in both seasons. Fertilizing beet plants with 200 ppm complexed boron/fed, gave a significant increase in sugar yield, amounting to 0.50 and 0.63 tons-sugar/fed when beet plants were irrigated, with non-magnetized water in both seasons. While, these increases reached 0.79 and 0.80 tons-sugar/fed when plants were watered with magnetized water in 1st and 2nd seasons, successively. The highest values of sugar yield were recorded by watering beet plants with magnetized water and spraying 150 and/or 200 ppm complexed boron (without significant difference between them) in 1st season and by adding 200 ppm complexed boron in the second season compared to other interactions.

Table 14. Significant interaction between irrigation water type and sugar alcohol complexed boron on sugar yield/fed of sugar beet in 2019/2020 and 2020/2021seasons

Irrigation water type	Sugar alcohol complexed boron levels (ppm)									
	1st season					2nd season				
	Zero	50	100	150	200	Zero	50	100	150	200
Well water	2.69	2.89	3.05	3.09	3.19	2.72	3.06	3.14	3.22	3.35
Magnetized well water	3.07	3.33	3.56	3.77	3.86	3.37	3.49	3.84	4.01	4.17
LSD at 0.5%	**0.15**					**0.12**				

DISCUSSION

These experiment results referred that increases in leaf expansion and their contents of chlorophyll "a", b" and carotenoids in Table 3, induced by irrigation with magnetically treated water, may be due to the implementation of magnetic treatment technology for irrigation water which, can dissolve soil salts and lessen salts in the root zone through some changes in physical and chemical properties of water including hydrogen bonding, polarity, surface tension, conductivity, and pH. These changes in water characteristics are capable of affecting the growth of plants Table (2). This result was consistent with what was indicated by **Maheshwari and Grewal (2009)**. In addition to what was mentioned by **Faiyad and Hozayn (2020)**, who reported that magnetized water facilitates the entry of water, increases the transport of nutritious elements through plant cell membranes, and improves its activity and division hence, having a positive enhancement effect on sugar beet plants. Relating the positive role of boron-bonded sugar alcohol in increasing leaf area index and photosynthetic pigments. It is worth noting that it contributes to transporting slow-moving elements such as boron through the xylem, which moves freely and easily, within the plant on a complex structure with sugar alcohols as borate ester, as explained by **(Silke, 2011)**. The easy movement of boron from the source to the sink may be involved in cell wall synthesis and structural integration as well as some physiological and chemical processes such as activating meristem tissue, increasing cell division, elongation, and increased growth traits hence increasing the photosynthesis rate **(El Sayed *et al.* 2011)**.

The positive effect of interaction between irrigation water type and foliar application of sugar alcohol complexed boron levels has appeared on leaf area index in both seasons (Table 4). The results demonstrate the beneficial effect of magnetically treated water and spraying complexed boron in improving many physiological and chemical processes by activating meristematic tissues and cell division, which led to leaf expansion and increased its ability to intercept light **(Awuchl, 2017)**. As well as, the role of sugar alcohols in facilitating the action of boron and nutrient transport from leaves to the roots, which are reflected in growth traits. These findings agree with those mentioned by Wang *et al.* (2015) who explained that boron deficiency inhibits plant growth, hinders leaf expansion, causes leaf chlorosis or shoot tip dieback deforms the leaf, decreases yield and quality, as well limits root elongation.

Data in Table (5) regarding root diameter, fresh and foliage weights/plant traits were significantly affected by magnetized water and its role in increased irrigation efficiency, soil water retention, and the beneficial effect of the low frequency of magnetic water on the overall growth of sugar beet plants. These increases in root diameter root and foliage fresh weights/plant were consistent with what was indicated by both Vasilevski (2003) and Faiyad and Hozayn (2020). Concerning the sugar alcohol-boron complex, these results may point to its role as a preliminary product of photosynthesis with good properties including easy penetration of boron bound to it, wetting and reduction of surface tension. Boron also had a positive role in activating and increasing the growth regulators, especially auxins and cytokines, as well as in the formation of proteins in the plant through the transcription of RNA (Brown and Hu 1996). In addition to the stimulation effect of magnetized water and sugar alcohol-boron complex on the leaf area index and its chlorophyll contents, as mentioned previously in Table (3).

The results of the interaction between the two studied factors on root diameter and fresh weight/plant Tables 6 and 7, may be due to the favorable role of magnetized water, as was revealed by Hilal *et al.* (2002). In addition, the role of alcoholic sugar in transporting slow-moving elements such as boron through the xylem freely and easily within the plant. Hence, performs their functions effectively during the building of cell walls and accelerate photosynthetic activity and enhancement of carbohydrate compared to the deficiency of boron, as is the case in the experimental site, which suffers from low boron content where, which was less than the critical level, as shown in (Table 1). Also, the relative advantage of spraying beet plants with boron was confirmed by mentioned by Enan (2011).

Foliage fresh weight/plant, which was affected significantly by the interaction between two irrigation types and spraying boron-bonded sugar alcohol levels in both seasons, are listed in Table (8). Data showed partial agreement with those obtained by Takachenko (1997), who reported that irrigating with magnetized water can remove the effect of salts accumulated soil (50 % to 80 %) compared to a removal of 30 % by non-magnetized irrigation water, hence the improvement of germination. As for the complexed boron effect, these findings may explain the relative advantage of boron-bonded sugar alcohol distinguished by its low molecular weight, covering the entire leaves surface completely as natural humectants, in addition to its linear structure that enables it to move freely in the plant and increasing the efficiency of boron absorption thereby, helping healthy growth of sugar beet.

Irrigating beet plants with magnetized water led to a significant increase in sucrose% in Table (9), as a result of the effect of magnetized water on the root diameter and the correlation between increasing root diameter and the number of cambium rings, as well as the distance between rings that are responsible for storing sugar in roots. The stimulating effect of magnetically treated water was indicated by Hozayn *et al.* (2013), who stated that irrigation of sugar beet using magnetized water is considered the most important modern technology, which helps in saving irrigation water and increasing the content of sucrose by about 4.07% over that watered with normal water, under the sandy soil condition. Also, the favorable effect of boron was reported by Enan (2011), who explained that the increase in sucrose concentration due to spraying 200 ppm boron could be due to the increased root thickness and expansion distance between rings which is responsible for the storage capacity in roots.

A significant increase in extracted sugar and quality index in Table 10, is mainly due to the role of magnetization water and complexed boron levels in increasing sucrose % and neutralizing the effect of impurities Table (9). This view is consistent with the results obtained by Tai *et al.* (2008) and Armin and Asgharipour (2012). At the same time, the response of sugar loss to molasses% to irrigation water types and complexed boron levels was insignificant despite its trend to decrease in both seasons which, in turn, affected the juice purity and thus extracted sugar%.

The increases in root, top, and sugar yields/fed in Table (11), may be attributed to the positive effect of irrigation with well water after magnetizing along with spraying boron-bonded sugar alcohol and their effect on root criteria and assimilations of photosynthetic pigments, which reflected on the above-mentioned, yields. Irrigation of beet plants using magnetized water led to improvement in root traits as well as increases in the efficiency of added fertilizers and helping nutrient mobility in soil and enhancing the uptake of N, P, K, Fe, and Zn, as reported by Ali *et al.* (2014) and Ibrahim *et al.* (2020).

Concerning, the effect of boron-bonded sugar alcohol levels. These results could be due to its effect on the easy translocation of components for photosynthesis from leaves to roots and regulating nitrogen uptake, which in turn is reflected in root yield and sugar accumulation. In addition to its effect on root and foliage fresh weights/plant, root thickness, and sucrose% Tables (5 and 9). Hence yields of the root, top, and sugar/fed increased. These findings are broadly in agreement with both Abbas *et al.* (2014) and Awuchl (2017). As well as, the experimental soil used was sandy textured and suffered boron deficiency, which was less than the critical limit due to leaching and fewer nutrients retention, as shown in Table (1).

The interaction between the studied factors cleared a significant effect on root and top yields/fed in both seasons, as depicted in Tables (12 and 13). These results indicate the complementary effect between the role of magnetized water and boron-bonded sugar alcohol in increasing photosynthesis consequently, leaf expansion and foliage fresh weight/plant, which in turn reflected on root yield/fed Tables (3 and 5). Similar results were mentioned by Hilal *et al.* (2002) and Wang *et al.* (2015).

The interaction between the two studied factors positively increased sugar yield/fed in both seasons Table (14). Such an increase in this trait may be accredited to the role of magnetized water and boron-bonded sugar alcohol levels which were earlier obtained on sucrose and extracted sugar percentages and hence were reflected on sugar yield/fed. These results are in agreement with those concluded by Ibrahim *et al.* (2020) and Du *et al.* (2020).

CONCLUSIONS

Under west-west El-Minya conditions, irrigation of beet plants with magnetized well water and spraying them with 150 ppm boron-bonded sugar alcohol can be, recommended to get the highest root and sugar yields/fed and improves the quality index. Also, there is a need to conduct more research to study the effect of magnetically treated water under different irrigation systems and locations and the expansion of the application of spraying different, nutrition elements-bonded sugar alcohols.

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الملخص العربي

تأثير الري بالماء الممغنط والرش بمعقد البورون-السكرالكحولي علي حاصل وجودة بنجر السكر تحت ظروف غرب-غرب المنيا

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أقيمت تجربتان حقليتان بمزرعة بحوث غرب غرب المنيا - محافظه المنيا ، مصر خلال موسمي 2019/ 2020 و2021/2020 لدراسه تأثيرنوعية مياه الري [الري بمياه البئر (الممارسة التقليدية - كمقارنة) ، والري بمياه البئر بعد المغنطة] ، وخمسة مستويات للرش الورقي بالبورون المعقد مع السكر الكحولي (بدون إضافه ، 50، 100، 150، و200 جزء في المليون)) ، بما يعادل (صفر ، 2.36 ، 4.72 ، 7.08 ، 9.44 سم [3]) من المركب المحتوي على 15٪ بورون ، والذي تم رشه مرتين عند 65 و 85 يومًا من الزراعة علي حاصل وجودة بنجر السكر، تحت نظام الري بالتنقيط في التربة الرملية . استُخدم تصميم القطاعات الكاملة العشوائية في ترتيب القطع المنشقة مرة واحدة في أربع مكررات.

أوضحت النتائج أن نباتات بنجر السكر المروية بمياه البئرالمُمغنطة كان لها أداء وإنتاجية أفضل من تلك المروية بمياه البئر بدون مغنطة ، حيث زاد دليل مساحة الأوراق ، الصباغات الضوئية ، مقاييس الجذر ، النسبه المئويه للسكروز و السكر المُستخلص وحاصلي الجذور ، العرش و السكر/ فدان ، كما تحسن مؤشر الجودة مقارنةً بالمُتحصل عليه من الري بماء البئر العادي . مع ذلك ، لم يتأثر محتوى الشوائب بالجذر والنسبه المئوية للسكر المفقود في المولاس معنوياً في كلا الموسمين.

- سجل الرش الورقي لنباتات بنجر السكر بمعدل 150 أو 200 جزء في المليون بمعقد البورون مع السكر الكحولي أعلى القيم للنسبة المئوية للسكروز ، السكر المُستخلص ، مؤشر الجودة وحاصلي الجذور ، العرش و كذا حاصل السكر/ فدان في الموسم الأول ، بينما إنخفض محتوى الصوديوم والألفا أمينو نيتروجين في كلا الموسمين.
- أدي الرش بـ 200 جزء في المليون من معقد البورون مع السكر الكحولي إلي زيادة دليل مساحة الأوراق ، وصباغات التمثيل الضوئي ، ومقاييس الجذر ، ومحتوى الجذور من البوتاسيوم في كلا الموسمين وكذلك حاصل السكر/ فدان في الموسم الثاني مقارنةً بالرش بمعدل 150 جزء في المليون من معقد البورون مع السكر الكحولي.
- سجلت توليفه (الري بالماء المغنط + الرش بـ 150 أو 200 جزء في المليون من معقد البورون مع السكر الكحولي) أعلي القيم لحاصل الجذورو العرش والسكر/فدان في كلا الموسمين.

تحت ظروف هذا البحث يمكن التوصية بري نباتات بنجر السكر بالمياه بعد المغنطة مع الرش بـ 150 جزء في المليون من البورون المعقد مع السكريات الكحولية للحصول علي أعلي حاصل من الجذور والسكر فدان./

الكلمات المفتاحية: معقد السكر الكحولي والبورون ، الماء الممغنط ، بنجر السكر