J. of Plant Production, Mansoura Univ.,Vol 11 (5):485 - 493, 2020

Journal of Plant Production

Journal homepage: www.jpp.mans.edu.eg
Available online at: www. jpp.journals.ekb.eg

Effect of Phosphorus, Boron and Magnesium Fertilization on Yield and Quality of Sugar Beet Grown in a Sandy Soil

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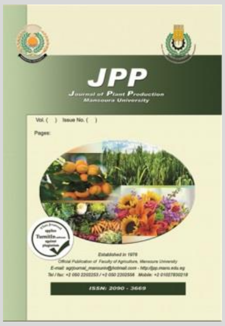

ABSTRACT

Two field experiments were conducted in a sandy soil at Um Saber village, Kom Hamada, (latitude of 30.52° N and longitude of 30.79° E), El-Beheira Governorate, Egypt, during 2017/2018 and 2018/2019 seasons to find out the optimal levels of phosphorus, boron and magnesium to get the highest yield and quality of sugar beet. Sugar beet variety "Hamza" was sown. RCBD in a split-plot arrangement was used to lay out 27 treatments, represented the combinations of three phosphorus (P) levels (15, 30 and 45 kg P_2O_5/fed), three foliar levels of boron "B" (zero, 75 and 150 ppm) and three magnesium "Mg" levels (zero, 5 and 10 g $MgSO_4.7H_2O$/l). Raising P-level to 30 kg P_2O_5/fed considerably increased sucrose%, extracted sugar% (ES%), quality index (QI), sugar yield/fed in the 2^{nd} season, as well as root diameter, root fresh weight/plant (RFW) and root yield/fed, while, sugar lost to molasses (SLM%) was markedly decreased. Increasing B-level to 150ppm appreciably increased RFW, sucrose%, ES%, QI, root and sugar yields/fed. Raising Mg-fertilizer level to 10 g/l sharply increased RFW, sucrose%, ES%, QI, root and sugar yields/fed in both seasons, while SLM% substantially reduced in the 2^{nd} one. Effects of the significant interactions among phosphorus, boron and magnesium levels on the studied traits were discussed. Under the environmental conditions of this study, adding 30 kg P_2O_5/fed to the soil + spraying 150 ppm boron + spraying 10 g $MgSO_4.7H_2O$/l could be recommended to attain economical root and sugar yields/fed, as well as the best quality of sugar beet.

Keywords: Boron, magnesium, phosphorus, quality, sandy soil, sugar beet, yield.

INTRODUCTION

Sugar beet (*Beta vulgaris* var. saccharifera L.) has acquired more importance in Egypt and become the first source for sugar production preceding sugar cane. Egypt attained 72.8 % self-sufficiency in sugar commodity in 2019 (SCC, 2019). Although, sandy soils are mostly characterized with poor nutrient contents and weak texture, sugar beet can be successfully grown in this type of soils under modern irrigation systems and foliar application of nutrients to fill the domestic negative gape in sugar.

Phosphorus is a major element in plant nutrition that is the most important component of nucleic acids and lipids, and is important in the production and transportation of sugars in the beet plant. Phosphorus is effective in early development of the sugar beet root (Kharchenko, 1983). Ibrahim (1998) found that 15 kg P_2O_5/fed attained substantially the maximum root length, fresh weight/plant, root and sugar yields, while sucrose% and purity% appreciably reduced. El-Mansoub and Mohamed (2014) stated that feeding sugar beet with 30 kg P_2O_5/fed significantly increased root length and fresh weight and juice quality traits, and gave the highest top and root yields. Hussain *et al.* (2014) noted that the increase in P-fertilizer level from 60 to 120 kg P_2O_5/ha increased the root yield appreciably. Sun *et al.* (2015) exhibited that P fertilization positively influenced the leaf, plant total dry mass and leaf area. Singh *et al.* (2017) showed that, under P deficiency, photosynthetic pigments declined, except carotenoids, which were relatively stable indicating its role in photoprotection. Kumar and Halikatti (2018) concluded that the 90 kg P_2O_5/ha application reported a appreciably higher percentage of sucrose, as well as the top and root yields/ha. Whereas, the same amount gave the lowest content of Na and α-amino N compared to 30 kg of P_2O_5/ha. Mohamed *et al.* (2018) found that increasing phosphorus levels from 10 to 30 kg P_2O_5/fed resulted in a significant increase in yields of root and sugar/fed, as well as in percentages of sucrose, sugar extraction, extractability and purity. Ghaly *et al.* (2019) revealed that the 48 kg P_2O_5/fed application was the best treatment among other phosphorus treatments (0, 12 , 24 and 36 kg P_2O_5/fed), which caused a marked increase in root diameter, top fresh weight, sucrose percentage and root yield.

Balanced and efficient use of micronutrients fertilizers can improve agricultural production and quality (Mousavi *et al.*, 2013). Foliar application of micronutrients can compensate their deficiencies, especially in sandy soils to improve crop yield and its components. Boron is by far the most important trace elements that sugar beets need because the productivity and quality of the roots are markedly depressed without adequate supply, where boron plays an important role in the physiological and bio-chemical processes of plants. Abido (2012) mentioned that 80 ppm boron foliar spraying increased total chlorophyll, leaf area/plant, root dimensions and its fresh weight, percentages of total soluble solids, sucrose and apparent purity, as well as yields of root, top and sugar/ha compared to control treatment. Soliman *et al*. (2014) showed that

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DOI: 10.21608/jpp.2020.103564

sugar beet growth criteria responded significantly and positively to the rise in foliar application of boron from 0.0 to 0.4 g/1. Boron application has demonstrated a marked improvement in percentages of sugar, purity and crude protein. Mekdad (2015) confirmed that the spraying of 120 and 150 ppm boron substantially improved root yield and its components, gross and white sugar percentages. On the contrary, there was a decline in Na, K, α-amino N, sugar loss percent, harvest index and sugar loss yield. Mohamed and Afifi (2017) revealed that using combination with foliar spray of boron at 200 mg/l recorded the highest root dimensions and root yield/fed, while spraying boron at 100 mg/l gave a marginal increase in sucrose, sugar extraction, purity and extractability percentages and the lowest impurities and sugar lost to molasses%. Ghaly *et al*. (2019) showed that increased levels of borax / fed from 750 g to 1125 g led to an increase in root yield. The interaction of Gloria variety + phosphorus fertilizer at a rate of 48 kg P_2O_5/fed + 1125 g borax/fed scored the best studied trait values.

Plants require some nutrients for optimum growth, among which elements like B, Fe, Mn, Mg and Mo are needed (Fajrya, 1998); but, their deficiencies in soil can affect the macronutrients performance (Xue *et al*., 2014). Magnesium is believed by some workers to be intimately associated with movement of phosphates within the plant (Meyer and Anderson, 1939). The abundance of Mg would increase the efficiency of P utilization within plant. Magnesium's main roles in plants are in chlorophyll and enzyme activator formation. Photosynthesis, protein formation and energy transfer are all partially dependent on a sufficient supply of Mg. It is taken up as the ion Mg^{2+} by plants, and is mobile once in the plant, so it can pass from older to younger tissues. Therefore, the deficiency appears to be seen first in older leaves when the dry matter concentration drops below 0.2% Mg. For fertilizers, Mg usually exists for or in mixtures of sulphate, carbonate, oxide or, occasionally, nitrate forms. Magnesium sulphate is a readily soluble and quick acting. Kristek *et al*. (2000) exhibited that foliar application of $MgSO_4.7H_2O$ as 5% w/v solution resulted in a substantial improvement sucrose, yields of root and sugar, as well as a decrease in amino-N, K and Na contents. In this regard, Barłóg and Grzebisz (2001) clarified that foliar application of Epsom salt-$MgSO_4.7H_2O$, 1% w/v solution , increased root yield by 9.9%, corresponding to 9.5% for white sugar yield, compared to the control, as well as α-amino N content in root was increased. Hermans *et al*. (2004) concluded that there was inadequate supply of Mg to the roots; recycling of Mg is needed to support the growth of newly developed organs. Moustafa and Omran (2006) demonstrated that spraying beets with Mg-fertilizer substantially increased juice quality, root dimensions and its fresh weight, as well as, yields of root, top and sugar. Al-Labbody (2007) mentioned that, increasing Mg foliar application level to 1.0 kg $MgSO_4$/fed significantly increased root diameter, fresh weights of root and foliage/plant, impurities contents, sucrose%, extractability%, sugar lost to molasses%, as well as top, root and sugar yields/fed. Orlovius and McHoul (2015) mentioned that sugar concentrations in sugar beet were influenced only slightly by the Mg-fertilizer. Nemeat Alla (2016) found that spraying beet foliage three times with Mg at 6 g/l significantly increased root dimensions, as well as root and sugar yields/fed, compared to the check treatment (without addition). D'Egidio *et al*. (2019) observed that in both the leaves and storage organs, sucrose was found to be the most abundant and influenced by supply of Mg. It obtained the highest chlorophyll content, combining light reduction and a high Mg rate. Mg nutrient potential for ensuring good yield and beet crop quality.

This work was conducted to find out the optimal phosphorus, boron and magnesium levels to attain the maximum yields of root and sugar with the best quality traits of sugar beet crop grown in a sandy soil at El-Beheira Governorate.

MATERIALS AND METHODS

Two field experiments were conducted in a sandy soil at Um Saber village, Kom Hamada, (latitude of 30.52° N and longitude of 30.79° E), El-Beheira Governorate, Egypt, in 2017/2018 and 2018/2019 seasons to find out the optimal levels of phosphorus, boron and magnesium fertilizers to get the highest yield and quality traits of sugar beet grown under conditions of drip irrigation. A randomized complete block design in a split-plot arrangement was used with three replications to lay out twenty seven treatments, which represented the combinations of three phosphorus fertilizer levels (15, 30 and 45 kg P_2O_5/fed "fed = 0.42 ha^{-1}") as mono-super phosphate "15% P_2O_5" during seed bed preparation, which occupied the main plots, whereas nine combinations among three concentrations of boron (zero, 75 and 150 ppm) as boric acid "17% B" and three concentrations of magnesium sulphate heptahydrate "$MgSO_4.7H_2O$" containing 16.2% MgO (zero, 5 g/l "0.5% w/v" and 10 g/l "1.0% w/v"), which were distributed randomly in the sub plots. Each combination of "B" and "Mg" was sprayed on sugar beets foliage twice at 60 and 90 days from sowing, in a solution of 300 liters of water/fed. Starch was used as a spreader at the rate of 2 g/l to help in preventing droplets from rolling off the leaves. Experimental unit (sub-plot) was 24 m^2, including 4 ridges of 60-cm apart and 10-m long, with 20 cm between hills. Nitrogen fertilizer was applied at 100 kg N/fed as ammonium nitrate "33.5% N" in 4 equal doses; the 1st dose was added after thinning (4-6 true leaf stage) and the other three ones were applied later on, at two-week interval. Potassium fertilizer was added at 48 kg K_2O/fed as potassium sulfate "48% K_2O" in 3-equal dose; the 1st one was applied with the 2nd N-dose and the other two ones were added with the other N doses. The multi-germ sugar beet variety "Hamza" was sown during the 1st week of November in the 1st season and the 4th week of October, in the 2nd one, while harvesting was done at age of 210 days, in both seasons. The preceding summer crop was sorghum, in both seasons. Other field practices were done as recommended by Sugar Crops Research Institute.

Some physical properties of soil of the experimental site were analyzed using the procedure described by Black *et al.* (1981). Soil chemical analysis was determined according to the method of Jackson (1973). Physical and chemical analyses of the experimental soil (at 30-cm depth) are presented in Table 1.

Table 1. Soil physical and chemical properties of the experimental sites

2017/2018 season									
Particle size distribution %			**Texture class**	**Available nutrients (mg/kg soil)**					
Sand	**Silt**	**Clay**		**N**	**P_2O_5**	**K_2O**	**B**	**Mg**	
91.1	4.7	4.2	Sandy	19.76	4.79	65.19	0.11	10.67	
EC dS/cm	pH	Soluble cations and anions (meq/l)							
		Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{-2}	Cl^{-}	
0.48	8.1	1.62	0.79	2.08	0.34	2.11	0.80	1.92	
2018/2019 season									
Particle size distribution %			Texture class	Available nutrients (mg/kg soil)					
Sand	Silt	Clay		N	P_2O_5	K_2O	B	Mg	
92.2	4.1	3.7	Sandy	21.48	6.13	70.55	0.14	11.01	
EC dS/cm	pH	Soluble cations and anions (meq/l)							
		Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{-2}	Cl^{-}	
0.51	8.3	1.67	0.82	2.23	0.39	2.13	0.96	2.02	

The recorded data:

After 110 days from sowing, a representative sample of ten plants was randomly taken from the guarded ridges of each sub-plot to determine the following traits:

1. Leaf area index (LAI), which was determined as described by Watson (1958) using the following equation:

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

Where;

Plant leaf area was determined using the "disk method" in 50 leaf disks of 1.0 cm diameter.

2. Photosynthetic pigments (mg/g) were determined in the fresh leaves as mentioned by Wettestien (1957).

Chlorophyll a = 9.784 (A 662) – 0.99 (A 644)

Chlorophyll b = 21.426 (A 644) – 4.65 (A 662)

Carotenoids = 4.695 (A 440) – 0.268 (chlorophyll a +chlorophyll b)

Where;

A = optical density at the wave length indicate.

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

1. Root diameter (cm).
2. Root and foliage fresh weights/plant (g).
3. Root/top ratio, which was calculated on fresh weight basis.
4. Potassium "K", sodium "Na" and alpha amino nitrogen concentrations (meq/100 g beet) in roots were estimated as shown by Cooke and Scott (1993).
5. Sugar lost to molasses% (SLM) was calculated according to the equation of Deviller (1988) as follows:

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

6. Sucrose% was estimated using "Saccharometer" according to the method described in A.O.A.C. (2005).
7. Extracted sugar% (ES%) was calculated using the following equation of Dexter *et al.* (1967):

ES% = sucrose% – SLM% – 0.6

8. Quality index (QI) was calculated according to Cooke and Scott (1993) equation:

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

9. Top and root yields/fed (ton), which were determined on sub-plot weight (kg) and converted to tons/fed.
10. 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 collected data were statistically analyzed according to the technique of analysis of variance (ANOVA) for the split-plot design published by Gomez and Gomez (1984) by using "MSTAT-C" computer software package. Least significant of difference (LSD) method was used to test differences between means at 5% level of probability as described by Snedecor and Cochran (1980).

RESULTS AND DISCUSSION

Photosynthetic pigment contents and leaf area index:

Leaf area index (LAI) is the main characteristic that has a direct relation with the processes of light interception and competition in plant communities. Chlorophyll "a" and "b" are the main pigments needed for light energy absorption, and both pigment synthesis requires Mg. A normal response to the Mg deficiency is a reduction in chlorophyll concentrations (Mengutay *et al.* 2013; Faust and Schubert 2016 and Tränkner *et al.*, 2016).

Data in Table 2 confirmed that phosphorus levels appreciably affected chlorophyll "a", carotenoids and LAI, in the 1st season only, whereas, chlorophyll "b" was insignificantly affected in both growing seasons. The results cleared that feeding beets with 45 kg P_2O_5/fed led to a significant increment in chlorophyll "a" and carotenoids amounted to 0.50 and 0.28 mg/g leaf fresh weight (lfw), respectively, this corresponds to 0.82 for LAI, in the 1st season, compared to that fertilized with 15 kg P_2O_5/fed.

It could be observed that the variance between 30 and 45 kg P_2O_5/fed in their effect on the above-mentioned traits did not reach the significance level, except for carotenoids in the 1st season. In this concern, Figas *et al.* (2016) mentioned that the additional amount of phosphorus had a statistically essential effect in increasing of chlorophyll a + b. These results are in agreement with those obtained by Sun *et al*. (2015).

Concerning boron influence, the obtained results proved that there was a statistical influence on chlorophyll "a", carotenoids contents and LAI, in both seasons as well as chlorophyll "b" in the 2nd one. Raising the concentration level of sprayed boron on beet canopy to 150 ppm resulted in a marked increase of 0.53 and 0.38 mg/g lfw in chlorophyll "a", corresponding to 0.29 and 0.28 mg/g lfw for carotenoids, as well as, 0.47 and 0.60 in LAI, in the 1st and 2nd season, successively, compared with the check treatment. These observations may be back to role of boron element in cell elongation and the new leaves formation, where the leaves are smaller, stiff and thicker in case of a boron deficiency (Mousavi *et al*., 2013). Additionally, the benefit of boron application can be attributed to boron's distinctive role in increasing plant metabolism, development and growth. These results are consistent with those stated by Abido (2012).

Table 2. Effect of phosphorus, boron and magnesium fertilization levels on photosynthetic pigment contents and leaf area index in 2017/2018 and 2018/2019 seasons

Treatments	Photosynthetic pigments (mg/g lfw)						Leaf area index	
	Chlorophyll "a"		Chlorophyll "b"		Carotenoids			
	1st season	2nd Season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Phosphorus levels "kg P_2O_5/fed" (A)								
15	4.01	3.68	2.26	2.02	0.96	1.01	2.90	3.08
30	4.17	3.71	2.28	2.11	1.03	1.08	3.63	3.46
45	4.51	4.11	2.34	2.35	1.24	1.18	3.72	3.48
LSD at 0.05	0.37	NS	NS	NS	0.04	NS	0.42	NS
Boron levels "ppm" (B)								
Zero	4.02	3.66	2.20	1.90	0.89	0.93	3.17	3.04
75	4.12	3.81	2.30	2.18	1.15	1.13	3.44	3.35
150	4.55	4.04	2.38	2.40	1.18	1.21	3.64	3.64
LSD at 0.05	0.15	0.18	NS	0.24	0.05	0.11	0.10	0.21
Mg sulphate heptahydrate levels "g/l" (C)								
Zero	4.07	3.51	2.01	2.00	0.92	1.02	2.99	3.12
5	4.23	3.89	2.24	2.12	1.10	1.07	3.51	3.29
10	4.40	4.11	2.63	2.36	1.20	1.18	3.75	3.61
LSD at 0.05	0.15	0.18	0.24	0.24	0.05	0.11	0.10	0.21
Interactions								
A x B	NS	NS	NS	NS	NS	NS	NS	*
A x C	*	*	NS	*	*	NS	NS	NS
B x C	NS	NS	NS	NS	NS	NS	NS	NS
A x B x C	NS	NS	NS	NS	NS	NS	NS	NS

***: significant, NS: insignificant difference and lfw: leaf fresh weight.**

Data in the same Table indicated that increasing concentrations of Mg-fertilizer up to 10 g $MgSO_4.7H_2O$/l attained a significant increase in the values of photosynthetic pigments and LAI, in both growing seasons. Similar tendency was observed by D'Egidio *et al.* (2019). These findings may be related to the main role of magnesium in plant chlorophyll formation and enzyme activators, in addition to its action as an important element in the process of photosynthesis for solar energy harvesting and photochemical driving (Pakrasi *et al.*, 2001).

Root diameter, root and foliage fresh weights/plant and root/top ratio:

The statistical analysis indicated that root diameter and its fresh weight per plant substantially responded to the increase in the levels of the applied phosphorus fertilizer from 15 up to 45 kg P_2O_5/fed. Meanwhile, foliage fresh weight/plant and root/top ratio were insignificantly influenced. This finding was true in both growing seasons (Table 3).

Table 3. Effect of phosphorus, boron and magnesium fertilization levels on root diameter, root and foliage fresh weights/plant and root/top ratio in 2017/2018 and 2018/2019 seasons

Treatments	Root diameter (cm)		Root fresh weight/plant (g)		Foliage fresh weight/plant (g)		Root/top ratio	
	1st season	2ndseason	1st season	2ndseason	1st season	2ndseason	1st season	2ndseason
Phosphorus levels "kg P_2O_5/fed" (A)								
15	10.24	9.83	845	802	394	349	2.14	2.30
30	12.11	11.72	1129	1063	436	384	2.59	2.77
45	12.53	12.27	1208	1074	442	394	2.73	2.73
LSD at 0.05	1.77	1.80	224	197	NS	NS	NS	NS
Boron levels "ppm" (B)								
Zero	10.68	10.45	993	919	406	369	2.45	2.49
75	11.53	11.41	1057	979	426	367	2.48	2.67
150	12.66	11.96	1133	1042	439	392	2.58	2.66
LSD at 0.05	0.48	0.60	31	34	17	12	0.09	0.11
Mg-sulphate heptahydrate levels "g/l" (C)								
Zero	11.39	10.73	1037	950	419	370	2.47	2.57
5	11.62	11.43	1059	976	421	373	2.52	2.62
10	11.85	11.67	1087	1013	432	385	2.52	2.64
LSD at 0.05	NS	0.60	31	34	NS	12	NS	NS
Interactions								
A x B	*	*	NS	*	NS	NS	NS	NS
A x C	NS	NS	NS	NS	NS	NS	NS	NS
B x C	NS	NS	NS	NS	NS	NS	NS	NS
A x B x C	NS	NS	NS	NS	NS	NS	NS	NS

***: significant and NS: insignificant difference.**

Data elucidated that, in the first season, the mean values of root fresh weight per plant significantly increased with increasing P-level to 30 and 45 kg P_2O_5/fed by 284 and 363 g, corresponding to 261 and 272 g in the second season, respectively, as compared to that gained by adding 15 kg P_2O_5/fed. These results are in accord with those obtained by Ghaly *et al.* (2019). It was found that the differences between 30 and 45 kg P_2O_5/fed in their influence on the above-mentioned growth traits were insignificant, in the two growing seasons. In this respect, Ismail and Abo El-Ghait (2004) and Abdou *et al.* (2014) remarked that increasing the amount of P-fertilizer up to 30 kg of P_2O_5/fed markedly increased root weight/plant.

Data in the same Table exhibited a gradual and/or statistical increase in root diameter, fresh weights of root and foliage/plant and root/top ratio, as a result of raising the concentrations of boron solution sprayed on sugar beet foliage from zero up to 150 ppm, in both seasons. It was found that fertilizing beets with 150 ppm boron attained heavier foliage, root and higher rate of translocation of dry matter from leaves to roots. Spraying beet canopy with 150 ppm boron led to a significant increment amounted to 1.98 and 1.51 cm in root diameter, 140 and 123 g in root fresh weight/plant, corresponding to 33 and 23 for foliage fresh weight per plant, as well as 0.13 and 0.17 in root/top ratio, in the 1st and 2nd season, successively, as compared to the control treatment (without addition). These observations may be referred to the important role of boron in cell elongation of root and dry matter translocation, which in turn was reflected on growth and the final root and foliage fresh weights (Abido, 2012). These results are in line with those detected by Mohamed and Afifi (2017).

The results in Table 3 revealed that increasing the rate of Mg-sulphate heptahydrate sprayed on beets from zero to 10 g/l had a significant and positive effect on root fresh weight per plant (in both seasons), as well as root diameter and foliage fresh weight per plant (in the 2nd one). However, root/top ratio was insignificantly affected, in both seasons. Spraying beets with 10 g $MgSO_4.7H_2O$/l caused a substantial increase of 50 and 63 g in root fresh weight/plant in the 1st and 2nd season, respectively, corresponding to 0.94 cm for root diameter and 15 g in foliage fresh weight/plant in the 2nd one, as compared to the check treatment. It could be noted that the difference between 5 and 10 g Mg-sulphate heptahydrate/l was considerable in their influence on root and foliage fresh weights/plant in the 2nd season only. In this concern, Mg is necessary for cell division process, where the Mg-pectate participate with the Ca-pectate in adhering to cellulose fibers when building the cell wall. These results are in agreement with those obtained by Moustafa and Omran (2006), Al-Labbody (2007) and Nemeat Alla (2016).

Impurities of juice, sugar lost to molasses%, sucrose% and quality index:

Data in Table 4 illustrated that phosphorus levels significantly affected root potassium content and sugar lost to molasses% (SLM), in both seasons, sodium and α-amino N contents, in the 1st season, as well as sucrose% and quality index in the 2nd one. Adding 30 kg P_2O_5/fed to beet plants resulted in a significant decrease in impurities content and SLM, but it caused a substantial increase in sucrose% and quality index, as compared to that gained by 15 kg P_2O_5/fed. The results are in line with these obtained by Mohamed *et al.* (2018). These findings may be due to the fact that phosphorous reduces the absorption of inorganic nitrogen, which positively reflected on quality index. Furthermore, the impact of phosphorus can be ascribed to its share of in-plant bio-activities and increases the creating of carbohydrates as starch and sugar.

Raising phosphorus levels from 30 to 45 kg P_2O_5/fed caused an appreciable decrease in root potassium content, whereas, it increased sucrose% and quality index slightly and insignificantly. These results are in harmony with those reported by Kumar and Halikatti (2018) and Ghaly *et al.* (2019).

Table 4. Effect of phosphorus, boron and magnesium fertilization levels on impurities of juice, sugar lost to molasses%, sucrose% and quality index in 2017/2018 and 2018/2019 seasons

Treatments	Impurities of juice (meq/100 g beet): K		Na		α-amino N		Sugar lost to molasses %		Sucrose %		Quality index	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Phosphorus levels "kg P_2O_5/fed" (A)												
15	4.14	4.40	2.07	1.94	1.68	1.35	1.79	1.73	18.09	16.94	86.79	86.27
30	3.69	3.50	1.31	1.74	1.27	1.09	1.52	1.51	18.21	18.41	88.37	88.56
45	3.27	3.10	1.11	1.63	1.23	1.06	1.42	1.43	18.40	18.42	89.02	88.99
LSD at 0.05	0.34	0.36	0.68	NS	0.36	NS	0.12	0.15	NS	0.73	NS	0.92
Boron levels "ppm" (B)												
Zero	3.86	4.05	1.90	1.99	1.59	1.43	1.70	1.70	17.69	17.30	86.98	86.69
75	3.70	3.62	1.47	1.81	1.38	1.10	1.57	1.54	18.40	18.02	88.21	88.15
150	3.55	3.33	1.12	1.51	1.21	0.96	1.46	1.42	18.61	18.45	88.95	89.06
LSD at 0.05	0.15	0.17	0.30	0.23	0.15	0.13	0.06	0.05	0.16	0.23	0.33	0.36
Mg-sulphate heptahydrate levels "g/l" (C)												
Zero	3.99	3.86	1.76	1.94	1.04	1.03	1.56	1.57	17.96	17.54	87.95	87.63
5	3.73	3.69	1.56	1.83	1.49	1.20	1.61	1.57	18.24	17.86	87.87	87.83
10	3.37	3.45	1.16	1.54	1.66	1.26	1.55	1.51	18.51	18.37	88.39	88.49
LSD at 0.05	0.15	0.17	0.30	0.23	0.15	0.13	NS	0.05	0.16	0.23	0.33	0.36
Interactions												
A x B	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	*
A x C	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A x B x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS

***: significant and NS: insignificant difference.**

Regarding boron fertilizer, the results cleared that increasing boron concentration up to 150 ppm led to a gradual and statistical increment in sucrose% and quality index. Meantime, a significant reduction in impurities content and SLM% was recorded. This finding was true in both seasons. These results are in agreement with those declared by Abido (2012) and Mohamed and Afifi (2017). In addition to the important role of boron element in the metabolic translocation process, these results may be attributed to the low content of N and K in the soil analysis (Table, 1), which reduced the content of impurities.

Data in the same Table pointed to an appreciable effect of Mg fertilizer levels on juice impurities, sucrose% and quality index, in both seasons, as well as, SLM% in the 2nd one. Spraying sugar beet foliage with 10 g Mg-sulphate heptahydrate/l decreased potassium, sodium contents and SLM%, whereas, α-amino N increased, as compared to the control treatment. Barłóg and Grzebisz (2001) obtained similar tendency concerning α-amino N. These results were similar to those found by Kristek *et al.* (2000) and Moustafa and Omran (2006). Raising levels to 10 g $MgSO_4.7H_2O$/l resulted in a sharp increment of 0.55 and 0.83 in sucrose%, corresponding to 0.44 and 0.86 in quality index, in the 1st and 2nd season, successively, as compared to the check treatment. These observations may be due to the fact that Mg is an essential component of the formation of the chlorophyll molecule, and hence photosynthesis. It also works as a stimulant for many important enzymes in metabolic metabolism changes in carbohydrates. It seems to be in this concern that adequate nutrition of Mg is required for the maintenance of high-quality.

Extracted sugar%, top, root and sugar yields:

The results in Table 5 clarified that the extracted sugar%, top and sugar yields/fed (in the 2nd season), as well as root yield/fed in both seasons were substantially affected by the applied phosphorus levels. Raising P-level from 15 to 30 kg P_2O_5/fed attained a considerable increment in root yield/fed amounted to 4.82% (1.21 tons) in the 1st season, and 7.00% (1.70 tons) in the 2nd one, corresponding to 1.69 in extracted sugar% and 0.69 ton for sugar yield/fed, in the 2nd season. These findings may be referred to the positive role of phosphorous on root fresh weight/plant (Table 3). These results are in line with those confirmed by El-Mansoub and Mohamed (2014) and Mohamed *et al.* (2018). The differences between 30 and 45 kg P_2O_5/fed in their influence on the previously-mentioned traits failed to reach the significance level in both seasons, which indicates that applying 30 kg P_2O_5/fed was enough to achieve the economical values.

Table 5. Effect of phosphorus, boron and magnesium fertilization levels on extracted sugar%, top, root and sugar yields in 2017/2018 and 2018/2019 seasons

Treatments	Top yield/fed (ton)		Extracted sugar %		Root yield/fed (ton)		Sugar yield/fed (ton)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Phosphorus levels "kg P_2O_5/fed" (A)								
15	10.63	10.47	15.70	14.61	25.10	24.28	3.94	3.55
30	12.47	11.94	16.09	16.30	26.31	25.98	4.23	4.24
45	12.73	11.86	16.38	16.39	26.93	26.36	4.41	4.32
LSD at 0.05	NS	1.22	NS	0.80	1.09	0.62	NS	0.27
Boron levels "ppm" (B)								
Zero	11.55	10.83	15.39	15.00	25.47	24.47	3.92	3.67
75	11.86	11.40	16.23	15.88	25.87	25.53	4.20	4.06
150	12.42	12.04	16.55	16.43	26.99	26.62	4.47	4.37
LSD at 0.05	0.29	0.30	0.16	0.23	0.50	0.21	0.09	0.06
Mg-sulphate heptahydrate levels "g/l" (C)								
Zero	11.37	10.99	15.80	15.37	25.37	24.90	4.01	3.83
5	11.95	11.47	16.03	15.69	26.23	25.71	4.20	4.03
10	12.52	11.82	16.36	16.26	26.74	25.98	4.37	4.23
LSD at 0.05	0.29	0.30	0.16	0.23	0.50	0.21	0.09	0.06
Interactions								
A x B	NS	NS	NS	*	NS	*	NS	*
A x C	NS	NS	NS	NS	*	NS	NS	NS
B x C	NS	NS	NS	NS	NS	NS	NS	NS
A x B x C	*	NS	*	NS	NS	NS	NS	NS

***: significant and NS: insignificant difference.**

In the same table, the results showed that spraying sugar beet foliage with boron concentrations markedly affected the extracted sugar%, top, root and sugar yields/fed, in both seasons. Increasing boron levels from 75 to 150 ppm increased root yield substantially by 1.12 ton/fed (4.33%) and 1.09 ton/fed (4.27%), corresponding to 0.27 ton/fed (6.43%) and 0.31 ton/fed (7.64%) for sugar yield, in the 1st and 2nd season, respectively. The lowest values in the above-mentioned traits was recorded by the check treatment. The increase in root yield/fed could be ascribed to the role of B-element in increasing the fresh weight and thickness of roots (Table 3). On the other hand, the distinguished effect of B-element on sugar yield/fed is probably attributed to its role in raising values of both root yield/fed and extracted sugar % (Table 5) as well as decreasing values of impurities and sugar lost to molasses (Table 4). The results are in harmony with these obtained by Mekdad (2015) and Mohamed and Afifi (2017).

Concerning Mg effects, increasing Mg-sulphate heptahydrate level up to 10 g/l caused a substantial increment in extracted sugar%, top, root and sugar yields/fed, in both seasons. In this respect, the efficiency of the sugar extraction process is adversely affected by increasing the concentration of solute substances other than sucrose (*i.e.* potassium, sodium and α-amino nitrogen) and the inter-relationships among accumulation of sucrose and these so-called impurities (Table 4). Raising Mg-sulphate heptahydrate level to 10 g/l scored a statistical increase reached 5.40% (1.37 tons) and 4.34% (1.08 tons) in root yield/fed, corresponding to 8.98% (0.36 ton) and 10.44% (0.40 ton) for sugar yield/fed, in the 1st and 2nd season, successively, as compared to the check treatment. These results are in agreement with those obtained by Kristek *et al.* (2000), Moustafa and Omran (2006) and D'Egidio *et al.* (2019).

Significant interaction effect between phosphorus and boron levels:

The interaction between phosphorus and boron levels had significant impacts on root fresh weight/plant, LAI, sucrose%, quality index, extracted sugar% as well as yields of root and sugar/fed, in the 2nd season. Likewise, root diameter was markedly affected by the interaction of P x B, in both seasons (Table 6).

In the case of spraying beets with 75 and/or 150 ppm boron, the results pointed to insignificant variances in root diameter, LAI and sucrose%, when 30 and/or 45 kg P_2O_5/fed was added to the soil. However, when phosphorus level decreased to 15 kg P_2O_5/fed, the difference between these two levels of boron in their influence on these traits reached the level of significance. Significant difference was detected in root fresh weight per plant and extracted sugar%, when beet foliage was sprayed with 75 and/or 150 ppm boron under 45 kg P_2O_5/fed. These results are in harmony with those obtained by Ghaly *et al.* (2019).

Table 6. Significant interaction effect between phosphorus and boron levels on some traits of sugar beet in 2017/2018 and 2018/2019 seasons

Phosphorus levels	Boron levels "ppm"	Root diameter (cm) 1st season	Root diameter (cm) 2nd season	Root fresh weight (g/plant) 2nd season	LAI 2nd season	Sucrose % 2nd season	Quality index 2nd season	ES% 2nd season	Root yield /fed (ton) 2nd season	Sugar yield /fed (ton) 2nd season
15 kg P_2O_5fed	Zero	9.03	8.81	770	2.52	15.87	84.29	13.38	23.20	3.10
	75	9.77	9.59	802	3.15	17.09	86.81	14.84	23.98	3.56
	150	11.92	11.08	833	3.58	17.84	87.56	15.62	25.62	4.00
30 kg P_2O_5/fed	Zero	11.48	11.45	1005	3.41	18.13	87.93	15.94	24.84	3.96
	75	12.05	11.79	1067	3.43	18.48	88.31	16.32	26.03	4.25
	150	12.79	11.93	1118	3.54	18.63	89.43	16.66	27.08	4.51
45 kg P_2O_5/fed	Zero	11.54	11.10	980	3.18	17.90	87.56	15.67	25.37	3.98
	75	12.78	12.86	1068	3.46	18.49	89.22	16.50	26.56	4.38
	150	13.28	12.86	1174	3.80	18.87	90.13	17.01	27.06	4.62
LSD at 0.05		0.82	1.04	59	0.37	0.39	0.63	0.39	0.37	0.11

LAI: leaf area index and ES%: extracted sugar%.

Data in the same Table disclosed that insignificant differences in the extracted sugar% were obtained between 75 and 150 ppm boron, along with 30 kg P_2O_5/fed. On the other hand, a marked variance was observed in quality index as well as root and sugar yields/fed, when beets were sprayed with 75 and 150 ppm boron under the different phosphorus levels. The highest root diameter and its fresh weight/plant, LAI, sucrose% and extracted sugar% as well as root and sugar yields/fed were recorded with adding 30 or 45 kg P_2O_5/fed to soil + spraying 150 ppm boron, but without significant between them.

Using 30 kg of P_2O_5/fed + 150 ppm boron resulted in a statistical increase in root yield/fed of 5.70% (1.46 tons) and 12.75% (0.51 tons) for sugar yield/fed in the second season, as compared to that fertilized with 15 kg of P_2O_5/fed + 150 ppm boron. This may be attributed to the role of phosphorus in the carbohydrates transformation processes within the plant, such as the conversion of starch into sugar, In addition to the role of boron in the sugars translocation to storage in root, which positively returned in the final sugar yield/fed.

Significant interaction effect between phosphorus and magnesium levels:

Data in Table 7 clarified that carotenoids and root yield/fed in the 1st season, and chlorophyll "b" and potassium content in the 2nd one, as well as, chlorophyll "a" in both seasons, were markedly influenced by the interaction between the tested phosphorous levels and foliar spraying with Mg fertilizer.

Table 7. Significant interaction effect between phosphorus and magnesium levels on some traits of sugar beet in 2017/2018 and 2018/2019 seasons

Phosphorus levels	Mg-sulphate heptahydrate levels "g/l"	Chlorophyll "a" (mg/g lfw) 1st season	Chlorophyll "a" (mg/g lfw) 2nd Season	Chlorophyll "b" (mg/g lfw) 2nd Season	Carotenoids (mg/g lfw) 1st Season	K (meq/100 g beet) 2nd season	Root yield/fed (ton) 1st season
	zero	3.83	3.17	1.94	0.84	4.57	24.01
15 kg P_2O_5/fed	5	4.01	3.70	1.96	1.01	4.29	25.39
	10	4.18	4.18	2.16	1.03	4.33	25.89
	zero	4.20	3.56	1.78	0.85	3.63	25.27
30 kg P_2O_5/fed	5	4.03	3.76	2.12	1.04	3.72	26.43
	10	4.28	3.83	2.43	1.21	3.14	27.10
	zero	4.17	3.79	2.07	1.09	3.38	26.83
45 kg P_2O_5/fed	5	4.64	4.21	2.31	1.27	3.07	26.86
	10	4.73	4.32	2.68	1.36	2.86	27.23
LSD at 0.05		0.25	0.32	0.42	0.08	0.29	0.86

There was a statistical variance between 5 and 10 g $MgSO_4.7H_2O$/l in their influence on chlorophyll "a" and carotenoids in the 1st season, as well as, potassium content in the 2nd one, when 30 kg P_2O_5/fed was added to the soil. Meanwhile, the difference between the two levels of Mg-sulphate heptahydrate fertilizer on these traits failed to reach the level of significance with adding 15 kg P_2O_5/fed. Significant difference in carotenoids was detected between spraying plants with 5 and 10 g Mg-fertilizer/l, when beets were fertilized with 45 kg P_2O_5/fed. Meantime, raising Mg fertilizer levels from 5 to 10 g $MgSO_4.7H_2O$/l showed a significant effect on chlorophyll "a" as a result of decreasing the fertilization level to 15 kg P_2O_5/fed, in the 2nd season. Feeding beet plants with the combination of 30 kg P_2O_5/fed

+ spraying beet foliage with 10 g Mg-fertilizer/l resulted in a statistical increment in root yield/fed reached 4.67% (1.21 tons), in the 1st season, as compared to that fertilized with 15 kg P_2O_5/fed + 10 g Mg-sulphate heptahydrate/l.

Data cleared that the difference between 30 and/or 45 kg P_2O_5/fed with 10 g $MgSO_4.7H_2O$/l in their effect on root yield/fed, was insignificant. This finding may be back to that Mg element helped in the movement of phosphorus and carbohydrates inside the plant, which raised the efficiency of phosphorus use at a rate of 30 kg P_2O_5/fed.

Significant interaction effect among levels of phosphorus x boron x magnesium:

As for the 2nd order interaction effect, the collected data demonstrated that the interaction among phosphorous, boron and Mg fertilizer levels had a marked influence in extracted sugar% and top yield/fed in the 1st season, as well as, sucrose% in the 2nd one. (Table, 8).

The results confirmed that the considerable increases in extracted sugar and sucrose percentages, were found as a result of raising the concentrations of Mg-sulphate level from zero to 10 g $MgSO_4.7H_2O$/l under 30 kg P_2O_5/fed + 150 ppm boron. Extracted sugar% and top yield/fed were appreciably increased, when concentration of Mg-fertilizer was raised from zero to 10 g/l with 75 ppm boron + 45 kg P_2O_5/fed. Increasing boron levels from 75 to 150 ppm had a significant increment in extracted sugar percentage, when sugar beet plants were fertilized with 30 kg P_2O_5/fed + 10 g Mg-sulphate heptahydrate/l. Meanwhile, the difference between the two boron levels in this trait did not reach the significance level under 15 and/or 45 kg P_2O_5/fed + 10 g $MgSO_4.7H_2O$/l.

Table 8. Significant interaction effect among phosphorus, boron and magnesium levels on sucrose and extracted sugar percentages and top yield/fed in 2017/2018 and 2018/2019 seasons

Phosphorus levels	Boron levels "ppm"	Sucrose % (2nd season)			Extracted sugar % (1st season)			Top yield/fed (ton) (1st season)		
		Mg-sulphate heptahydrate levels "g/l"								
		zero	**5**	**10**	**zero**	**5**	**10**	**zero**	**5**	**10**
15 kg P_2O_5/fed	zero	14.88	16.08	16.66	14.20	14.93	15.77	10.12	10.48	10.65
	75	16.70	16.81	17.77	15.71	15.96	16.30	10.18	10.60	11.12
	150	17.71	17.67	18.13	15.87	16.29	16.31	10.21	10.88	11.43
30 kg P_2O_5/fed	zero	18.35	17.78	18.24	15.40	15.39	15.64	10.91	12.03	12.91
	75	18.06	18.46	18.92	16.01	16.30	16.33	11.78	12.62	13.14
	150	18.15	18.65	19.10	16.11	16.47	17.18	12.75	12.81	13.25
45 kg P_2O_5/fed	zero	17.56	17.74	18.41	15.56	15.72	15.85	10.93	11.90	12.76
	75	17.96	18.69	18.80	16.09	16.49	16.94	12.18	12.67	13.70
	150	18.50	18.86	19.25	16.66	16.66	16.91	13.23	13.54	13.70
LSD at 0.05			0.68			0.49			0.88	

The combination among 30 kg P_2O_5/fed, 150 ppm boron and 10 g Mg-fertilizer/l caused a significant increment amounted to 0.87 in extracted sugar% and 1.82 ton in top yield/fed (in the 1st season), corresponding to 0.97 in sucrose% (in the 2nd one), as compared to the same levels of boron and Mg with soil fertilized by 15 kg P_2O_5/fed. However, there were insignificant differences between 30 and 45 kg P_2O_5/fed under 150 ppm boron and 10 g $MgSO_4.7H_2O$/l in their impact on the above-mentioned traits.

CONCLUSION

Under conditions of the present study, supplying sugar beets with a combination of (30 kg P_2O_5/fed + 150 ppm boron + 10 g Mg-sulphate heptahydrate/l) can be recommended to get the economical top, root and sugar yields, as well as the best quality traits of sugar beet crop grown in a sandy soil at El-Beheira Governorate, Egypt.

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تأثير التسميد بالفوسفور والبورون والمغنيسيوم علي حاصل وجودة بنجر السُكَّر المُنزرع في أرضٍ رملية

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أجريت تجربتان حقليتان في قرية أُم صابر- كوم حمادة - محافظة البحيرة (دائرة عرض 30.52° شمالاً وخط طول 30.79° شرقاً) خلال موسمي 2018/2017 و 2019/2018 لتحديد المستويات المثلى للفوسفور والبورون والمغنيسيوم للحصول على أعلى حاصل وجودة من بنجر السكر المنزرع في تربة رملية. تم زراعة الصنف "حمزة". إشتملت الدراسة على ثلاثة مستويات من السماد الفوسفاتي كإضافة أرضية (15 ، 30 و 45 كجم فو2أ5/فدان) وثلاثة تركيزات للرش الورقي بالبورون (صفر ، 75 و 150 جزء في المليون) والمغنيسيوم بثلاثة تركيزات من كبريتات المغنيسيوم "7 جزيئات ماء" (صفر ، 5 و 10 جم/لتر). استُخدِم تصميم القطع المنشقة مرة واحدة. أدت زيادة مستويات السماد الفوسفاتي إلى 30 كجم فو2أ5/فدان إلي زيادة معنوية في النسبة المئوية للسكروز والسُكَّر المُستخلَص والجودة وحاصل السُكَّر/فدان في الموسم الثاني ، وقطر الجذر والوزن الغض للجذر/النبات وحاصل الجذور/فدان في كلا الموسمين ، في حين إنخفضت معنوياً نسبة السُكَّر المفقود في المولاس. حققت زيادة تركيزات الرش بالبورون إلي 150 جزء في المليون زيادة معنوية في وزن الجذر الغض/النبات والنسبة المئوية للسكروز والسُكَّر المُستخلص والجودة وحاصل الجذور والسكر/فدان. أدت زيادة معدلات الرش بكبريتات المغنيسيوم إلي 10 جم/لتر إلي زيادة معنوية في الوزن الغض للجذر/النبات والنسبة المئوية للسكروز والسُكَّر المُستخلَص والجودة وحاصل الجذور والسُكَّر/فدان. تم مناقشة تأثير التفاعلات المعنوية بين مستويات الفوسفور والبورون والمغنيسيوم علي الصفات المدروسة. تحت ظروف هذه الدراسة ، يمكن التوصية بتسميد بنجر السُكَّر بإضافة 30 كجم فو2أ5/فدان للتربة + الرش الورقي بالبورون بتركيز 150 جزء في المليون + الرش الورقي بمعدل 10 جم كبريتات المغنيسيوم "7 جزيئات ماء"/لتر للحصول علي الحاصل الاقتصادي للجذور والسُكَّر/فدان وأفضل صفات جودة.