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RESPONSE OF SUGAR BEET TO SANDY SOIL AMENDED BY ZEOLITE AND POTASSIUM SULFATE FERTILIZATION

H.E.A. NEMEATA ALLA[1*] and S.A.M. HELMY[2]

[1]Department of Agronomy and Agricultural Practices, Sugar Crops Research Institute, ARC, Giza, Egypt
[2]Department of Physiology and Biochemistry, Sugar Crops Research Institute, ARC, Giza, Egypt
*Corresponding author's email: nemeatalla@yahoo.com
Email addresses of co-author: allabbodyashraf@yahoo.com, samer20222@yahoo.com

SUMMARY

Two field experiments were carried out on a private farm at Wadi El-Natrun (latitude of 30.48° N and longitude of 30.50° E), Beheira Governorate, Egypt, in the 2019–2020 and 2020–2021 seasons, to find out the effect of adding zeolite as a soil conditioner and potassium fertilizer on growth, yield, and quality of sugar beet crop (*Beta vulgaris* L. var. saccharifera) grown in sandy soil conditions. The present work included 12 treatments, which were the combinations of four zeolite levels (Zero, 476, 952, and 1,428 kg ha^{-1}), and three levels of potassium in the form of potassium sulfate (119, 178.5, and 238 kg K_2SO_4 ha^{-1}), which were added as a soil application. The treatments were arranged in a complete block design in a split plot with four replications. The results showed that higher values of the photosynthetic pigments, root diameter, fresh and foliage weights $plant^{-1}$, as well as, sucrose and extracted sugar percentages, quality index, yields of the root, top, and sugar ha^{-1}, were obtained by adding 1,428 kg zeolite, compared with the other levels of zeolite, in both seasons. However, sodium, alpha-amino N contents in the root, and sugar lost to molasses% were insignificantly affected by zeolite rates in both seasons. Application of 238 kg K_2SO_4 ha^{-1} significantly resulted in the highest values of photosynthetic pigments, root dimensions, sucrose%, and root potassium content. In addition, extracted sugar %, quality index, root, top, and sugar yields ha^{-1} were increased compared with the other lower K-sulphate levels in both seasons. On the contrary, sugar lost to molasses% was insignificantly affected by applied potassium sulfate in both seasons. The maximum values of root diameter, fresh weight, yields of root and top ha^{-1} in both seasons, and also sugar yield in the second season were produced from the interaction between applying 1,428 kg zeolite and 238 kg potassium sulfate ha^1.

Keywords: potassium sulphate, sandy soil, sugar beet, zeolite

Key findings: Improving sandy soil which has low fertility and water scarcity, is one of the main factors for increasing the yield of beet plants. Therefore, the zeolite is incorporated into the soil, improving its structure and increasing the soil's capacity to capture and store water, in addition to the role of potassium sulfate in protein synthesis, energy transfer, and cation-anion balance. Hence, increased root yield and quality of sugar beet.

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INTRODUCTION

Sandy soils are described with poor fertility and holding water capacity. Wadi El-Natrun is considered one of the promising reclamation areas in developing the cultivation and production of sugar beet as a drought-resistant crop. Global climate change, next to the limited water components, is the most important factor in the field (Bastaubayeva *et al*., 2022). Zeolite is a natural mineral with physical and physicochemical properties that can be utilized in agriculture. It is an inert and non-toxic spongy mineral substance with a crystalline structure. Various researchers reported that zeolite increases soil cation exchange capacity and water retention in the root zone and decreases mineral component leaching (Ramesh and Reddy, 2011). In this context, Gruener *et al.* (2003) and Rehakova *et al.* (2004) described zeolite as a carrier that is hydrated aluminosilicates consisting of a stable three-dimensional framework, of silica and tetrahedral aluminum, which have a molecular sieve action due to their open channel network. Savvas *et al.* (2004) indicated that 500 kg ha^{-1} zeolite significantly increased root attributes and yield in most crops.

Additionally, Khodaei and Asilan (2012) explained that zeolite could improve the efficiency of water and nutrient use of plants and decrease runoff and sediment amounts by increasing the soil water holding capacity, acting as slow and controlled light sandy soils, in particular, which result in higher yield and better quality. Likewise, Cairo *et al*. (2017) observed that the use of zeolite improved the effectiveness of nitrogen application in the soil by about 16%–22% and also should great potential to adsorb K^+ from chemical fertilizers and reduce leaching, as well as, has been used as a slow-release K-fertilizer. Nakhli *et al.* (2017) indicated that the unique chemical and physical properties of natural zeolites, in particular their high cation exchange capacity and strong affinity for NH_4^+ and K^+, can be used to increase nitrogen and potassium use efficiency, consequently, increasing soil water content. Jakkula and Wani (2018) found that the positive effects of zeolite on plants include extra nutrients supplied by the mineral, increases in soil cation exchange capacity, water retention in the root zone, and decreasing mineral components leaching. Mihok *et al*. (2020) and Jarosz *et al.* (2022) confirmed that zeolite-based fertilizers caused the slower release of nutrients compared with other conventional and slow-release fertilizers. At the same time, they found that a direct application of zeolites to the soil has a beneficial effect on the soil sorption capacity, and increases the efficiency of nutrient use. Generally, the better utilization of nutrients from fertilizers gives higher yields which reduce nutrient dispersion in the soil.

Potassium (K) is the third most important nutrient for plant growth and development, and its significance in agriculture is comprehensively documented. Applying K-sulfate is beneficial for sugar beet, under the conditions of sandy soils, as it contains sulfur (S), which is one of the major nutrients required for the synthesis of amino acids needed to produce functional and structural proteins (Yu, 1992; Wang *et al.*, 2015). In Egyptian soils, which are characterized by their high pH, sulfur can also improve growth by reducing soil pH and increasing the activity of soil microorganisms by the oxidation of S to sulfate through various species of soil microorganisms. Draycott (2006) pointed out that K plays essential roles in enzyme activation, protein synthesis, osmoregulation, energy transfer, cation-anion balance, and stress resistance, and increases the salt tolerance of sugar beet by enhancing the biosynthesis of organic metabolites and improving nutritional status.

In addition, Mehran and Samad (2013) showed that increasing K rates significantly increased root and foliage fresh weight, root and sugar yields fed^{-1} of sugar beet. Hussain *et al.* (2014) explained that potassium sulfate increased top and sugar yields fed^{-1} by mitigating of the adverse effect of Na and, thus would be an effective source of K for crop production. Enan (2016) explained that fertilizing sugar beet with 75 and/or 100 kg K_2SO_4 fed^{-1} produced significantly higher values of leaves chlorophyll b and carotenoids, root fresh weight $plant^{-1}$, sucrose% and foliage contents of potassium in both seasons. Applying 75 kg K_2SO_4 fed^{-1} significantly decreased the amount of Na, K, and alpha-amino N contents in roots, sugar lost to molasses%, and quality index increased, as well extractable sugar in both seasons. Mekdad *et al.* (2021) illustrated that applying 180 kg K_2O ha^{-1}, increased responses of morpho-physiological trait, root dimensions, and weight; top fresh weight; quality index; and root, top, and sugar yields ha^{-1}. Moreover, increasing top and biological yields are associated with increasing photosynthetic pigments. This study aimed to investigate the effect of using different levels of zeolite and potassium sulfate to assess their importance for the yield and quality of sugar beet under sandy soil conditions.

MATERIALS AND METHODS

Experimental design and procedure

Two field experiments were carried out on a private farm at Wadi El-Natrun (latitude of 30.48° N and longitude of 30.50° E), Beheira Governorate, Egypt, in the 2019–2020 and 2020–2021 seasons, to find out the effect of adding zeolite as a soil conditioner and potassium fertilizer on growth, yield, and quality of sugar beet crop *(Beta vulgaris* L. var. saccharifera) grown in sandy soil conditions. The present work included 12 treatments, which were the combination of four zeolite levels: Zero, 476, 952, and 1,428 kg ha^{-1}, in combination with three levels of potassium in the form of potassium sulfate, *i.e.*, 119, 178.5, and 238 kg K_2SO_4 ha^{-1}, which were added as a soil application.

A complete block design in a split-plot arrangement was used with four replications. The four rates of zeolite were allocated in the main plots and the three levels of K-sulfate fertilizer were randomly distributed in the sub-plots. The sub-plot area was 21.6 m^2 including six ridges of 6 m in length and 60 cm in width, with 20 cm between hills. The overall dose of 476 kg ha^{-1} of calcium superphosphate (15% P_2O_5) was applied during seedbed preparation. Natural zeolite levels were mixed with experimental soil at seedbed preparation. Nitrogen fertilizer was applied at 285.6 kg N ha^{-1} in the form of ammonium nitrate (33.5% N) in four equal doses; the first was applied after thinning (four true-leaf stages) and the other three were given at two-week intervals. Potassium in the form of potassium sulfate (48% K_2O) was added with the first and second dose of nitrogen fertilizer. Zeolite was purchased from El-Ahram Company for Mining and Natural Fertilizers, Giza, Egypt, and its zeolite chemical properties are shown in Table 1.

Sowing of the commercial sugar beet multi-germ variety "Oscar poly" took place during the first week of September and irrigation, while harvesting was done seven months later in both seasons. Other field practices were done as recommended by the Sugar Crop Research Institute. The physical properties of the soil 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). The soil (upper 30 cm) physical and chemical analyses of the experimental site are shown in Table 2.

Data recorded

At harvest, a random sample of 10 guarded plants was taken from the middle ridges of each plot to determine the following traits: Photosynthetic pigments, i.e., chlorophyll a, b and carotenoids (mg g^{-1} leaf fresh weight)

Table 1. Chemical composition of the zeolite as a soil conditioner

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3
65%	12.4%	1.6%	1.45%	0.98 %	2.67%	1.90 %	0.31%

Table 2. Physical and chemical properties of the experimental site in the 2019–2020 and 2020–2021 seasons

2019/2020 season										
Particle size				Soil texture	EC ($dS\ m^{-1}$)		Soil pH (1:2.5)	Organic matter %		
Sand%	Silt %	Clay %		Sandy loam						
81.2	14.20	4.6			1.28		7.89	0.51		
Cations (meq l^{-1})				Anions (meq l^{-1})				Available macro-nutrients (mg kg^{-1})		
Ca^{++}	Mg^{++}	Na^+	K^+	CO_3^{--}	HCO_3^-	Cl^-	$SO4^{--}$	N	P_2O_5	K_2O
3.2	2.5	4.8	1.02	-	0.4	7.5	3.62	39.40	4.52	95.2
2020/2021 season										
Particle size				Soil texture	EC ($dS\ m^{-1}$)		Soil pH (1:2.5)	Organic matter %		
Sand%	Silt %	Clay %		Sandy loam						
83.0	10.28	6.72			1.21		8.01	0.54		
Cations (meq l^{-1})				Anions (meq l^{-1})				Available macro-nutrients (mg kg^{-1})		
Ca^{++}	Mg^{++}	Na^+	K^+	CO_3^{--}	HCO_3^-	Cl^-	$SO4^{--}$	N	P_2O_5	K_2O
2.50	3.0	4.0	1.39	-	0.6	8.0	2.29	41.00	5.00	109.0

were determined according to the method described by Wettstein (1957); Root diameter (cm) and root fresh and foliage weights plant^{-1} (g) were also measured.

Quality analysis was done on fresh samples of sugar beet roots at the Laboratory of El-Nubaria Sugar Factory, Egypt. Sucrose percentage (Pol %) was determined in fresh macerated root according to the method of A.O.A.C. (2005). Impurities in terms of potassium, sodium, and α-amino-nitrogen concentrations were estimated as meq 100^{-1} g beet, where sodium and potassium were determined in the digested solution using a "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 following equation by Devillers (1988).

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

Extractable sugar percentage (ES %) was calculated using the following equation (Dexter *et al.*, 1967).

$$Ex\% = sucrose\ \% - SLM\ \% - 0.6$$

The quality index (QI) was calculated using the following equation (Cooke and Scott, 1993).

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

Root yield and top yield ton ha^{-1} were measured on plot weight (kg), from the four middle ridges of each plot and then converted to ton ha^{-1}.

$$\text{Sugar yield ha}^{-1}\ (\text{ton}) = \text{root yield ha}^{-1}\ (\text{ton}) \times \text{extractable sugar}\%$$

Statistical analysis

All obtained data were statistically analyzed according to the technique (MSTAT-C) computer software package. Analysis of variance (ANOVA) for the split-plot design as published by Gomez and Gomez (1984) was used. The least significant of differences (LSD) method was used to test the differences between treatment means at a 5% level of probability as described by Snedecor and Cochran (1980).

RESULTS

Chlorophyll a, b, and carotenoids

Chlorophyll a, chlorophyll b, and carotenoid content in leaves were significantly affected by the soil application of zeolite. Adding 1,428 kg ha^{-1} zeolite attained the highest values in the aforementioned traits. The lower values of photosynthetic pigments were associated with the non-addition of zeolite, and the other two lower zeolite levels in both seasons. Concerning the potassium sulfate effect, it was noted that applying potassium fertilizer at different levels significantly increases photosynthetic pigments compared with the check treatment in both seasons. Fertilizing K-sulfate at 178.5 and/or 238 kg ha^{-1} was more effective and significantly increased leaves chlorophyll a, b, and carotenoid contents compared with an addition of only 119 kg ha^{-1}, without significant differences between these higher levels in K-sulfate, in both seasons (Table 3).

Root diameter, fresh and foliage weight per plant

Adding zeolite as a soil conditioner significantly increased diameter, fresh and foliage weights plant^{-1} compared with untreated ones, in both seasons. These increases were 3.26, 3.32 cm (in root diameter), 311.6, 288.80 g (in root fresh weight), and 208.02, 204.38 g (in foliage weight) in the first and second seasons, successively. As for the effect of potassium sulfate, raising potassium levels from 119 up to 238 K_2SO_4 ha^{-1} resulted in a significant increase in root diameter, and fresh and foliage weight plant^{-1} in both seasons. This increment was about 9.81%, 8.32% (in root diameter), 27.02%, 14.56% (in root fresh weight), and 14.88%, 14.59% (in foliage fresh weight) in first and second seasons, respectively, over those plants which were fertilized with only 119 K_2SO_4 ha^{-1} (Table 4).

The interaction effects

In this work, root diameter was affected by an interaction between different rates of zeolite and potassium fertilization levels. Zeolite usage at 1,428 kg ha^{-1} led to an increase in root diameter, but it was thicker when beet was fertilized with 238 kg K_2SO_4 ha^{-1}. Moreover, an increase in root diameter amounted to 7.18% and 5.91%, in the first and second seasons, respectively, compared with adding 1,428 kg ha^{-1} zeolite and fertilizing beet plants with only

Table 3. Photosynthetic pigments as affected by zeolite and potassium fertilizer levels in the 2019–2020 and 2020–2021 seasons

Treatments	Photosynthetic pigments ($mg\ g^{-1}$ f.w.)					
	Chlorophyll a		Chlorophyll b		Carotenoids	
	1st season	2nd Season	1st season	2nd season	1st season	2nd season
Zeolite rates ($kg\ ha^{-1}$)						
Zero	1.41	1.47	0.40	0.84	0.30	0.44
476	1.79	1.92	0.62	0.72	0.45	0.64
952	2.31	2.51	0.98	1.47	0.58	0.77
1428	2.59	2.64	1.26	1.50	0.89	0.93
$LSD_{0.05}$	0.47	0.50	0.39	0.41	0.23	0.31
Potassium sulfate levels ($kg\ ha^{-1}$)						
119	1.87	1.96	0.64	0.88	0.47	0.61
178.5	2.03	2.16	0.86	1.07	0.57	0.70
238	2.18	2.29	0.94	1.18	0.63	0.77
$LSD_{0.05}$	0.23	0.20	0.24	0.19	0.11	0.12
A x B	NS	NS	NS	NS	NS	NS

Table 4. Root diameter, fresh, and foliage weight per plant as affected by zeolite and potassium fertilizer levels in the 2019–2020 and 2020–2021 seasons

Treatments	Root diameter (cm)		Root fresh weight $plant^{-1}$ (g)		Foliage fresh weight $plant^{-1}$ (g)	
	1st season	2nd Season	1st season	2nd season	1st season	2nd season
Zeolite rates ($kg\ ha^{-1}$)						
Zero	7.99	8.15	394.57	459.57	178.92	196.64
476	8.95	9.10	504.96	586.48	251.68	257.78
952	10.38	10.49	587.36	666.47	320.14	331.41
1428	11.25	11.47	706.21	748.33	386.94	402.96
$LSD_{0.05}$	0.52	0.53	32.63	61.70	29.26	44.20
Potassium sulfate levels ($kg\ ha^{-1}$)						
119	9.17	9.38	487.98	573.27	265.10	279.67
178.5	9.69	9.87	536.98	615.43	283.63	291.55
238	10.07	10.16	619.86	656.93	304.54	320.38
$LSD_{0.05}$	0.12	0.11	14.45	23.85	26.79	20.72
A x B	**	**	**	**	NS	NS

119 kg K_2SO_4 ha^{-1} in sandy soil (Table 5). Likewise, a gradual increase in root fresh weight as affected by the interaction between the same zeolite and K_2SO_4 ha^{-1} rates was recorded in both seasons (Table 6). This increase amounted to 6.89% and 7.95%, in the first and second seasons, respectively, resulting from beets fertilized with 238 kg K_2SO_4 ha^{-1} + 1,428 kg zeolite ha^{-1}, as compared with applying 119 kg K_2SO_4 ha^{-1} and a decrease rate of zeolite to 952 kg ha^{-1}.

Sucrose (%), potassium, sodium, and alpha-amino N contents

Sucrose% and root potassium content were significantly affected by different zeolite rates while increasing zeolite levels from zero up to 1,428 kg ha^{-1} failed to reach the level of significance in their effect on root sodium and alpha-amino N contents in beet root, during the two growing seasons. Application of 1,428 kg zeolite ha^{-1} gave the highest values of sucrose% and root potassium content in both seasons. As for the potassium sulfate effect, it was found that fertilizing beet plants with 238 kg K_2SO_4 ha^{-1} (48% K_2O), significantly increased sucrose% and potassium content in the beet root. On the contrary, significantly reduced sodium and alpha amino-N contents were recorded compared to adding the lower application of potassium sulphate in both seasons (Table 7). The interaction between zeolite rates and potassium fertilization had an insignificant effect on sucrose%, potassium, sodium, and alpha-amino N contents (Table 7).

Table 5. Effect of interaction between zeolite and potassium fertilizer levels on root diameter in 2019–2020 and 2020–2021 seasons

Zeolite rates (kg ha^{-1})	Root diameter (cm)					
	Potassium sulfate levels (kg ha^{-1})					
	1st season			2nd season		
	119	178.5	238	119	178.5	238
Zero	7.25	8.24	8.48	7.50	8.39	8.57
476	8.62	8.95	9.29	8.86	9.14	9.31
952	9.96	10.30	10.88	10.02	10.50	10.94
1428	10.85	11.27	11.63	11.15	11.44	11.81
$LSD_{0.05}$		0.24			0.23	

Table 6. Effect of interaction between zeolite and potassium fertilizer levels on root fresh weight per plant in 2019–2020 and 2020–2021 seasons

Zeolite rates (kg ha^{-1})	Root fresh weight $plant^{-1}$ (g)					
	Potassium sulfate levels (kg ha^{-1})					
	1st season			2nd season		
	119	178.5	238	119	178.5	238
Zero	341.1	362.8	479.9	360.4	472.7	545.7
476	438.8	486.2	589.9	565.4	584.7	609.4
952	513.1	609.1	639.8	655.0	667.7	676.7
1428	658.9	689.9	769.9	712.3	676.7	796.0
$LSD_{0.05}$		28.90			47.71	

Table 7. Sucrose%, potassium, sodium, and alpha-amino N contents as affected by zeolite and potassium fertilizer levels in the 2019–2020 and 2020–2021 seasons

Treatments	Sucrose %		Impurities contents (meq 100^{-1} g beet)					
			Potassium		Sodium		Alpha-amino N	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Zeolite rates (kg ha^{-1})								
Zero	16.44	16.51	3.56	3.61	1.79	1.89	1.68	1.65
476	17.40	17.80	3.78	4.04	1.66	1.79	1.49	1.61
952	18.18	18.58	4.49	4.61	1.64	1.74	1.37	1.52
1428	19.39	19.98	4.75	4.94	1.54	1.67	1.22	1.47
$LSD_{0.05}$	0.93	0.26	0.33	0.18	NS	NS	NS	NS
Potassium sulfate levels (kg ha^{-1})								
119	17.42	18.09	4.03	4.10	1.77	1.88	1.56	1.67
178.5	17.90	18.22	4.14	4.36	1.66	1.78	1.41	1.55
238	18.24	18.35	4.26	4.45	1.55	1.66	1.36	1.46
$LSD_{0.05}$	0.31	0.11	0.14	0.17	0.13	0.11	0.13	0.11
A x B	NS	NS	NS	NS	NS	NS	NS	NS

Sugar lost to molasses, extractable sugar percentages, and quality index

There were significant differences in extractable sugar% and quality index in response to the addition of zeolite to sandy soil. On the contrary, the difference among zeolite levels does not reach the level of significance in their effect on sugar losses in molasses% in both seasons. Improvement in sandy soil by adding 1,428 kg zeolite ha^{-1} caused a significant increment in extractable sugar% and quality index, in the amount of 7.68%, 8.51% extractable sugar % and 0.98%, 0.89% in quality index, in the first and second seasons respectively, over the soil that received only 952 kg zeolite ha^{-1}(Table 8). On the effect of potassium sulfate, increasing

Table 8. Sugar loss to molasses, extractable sugar percentages, and quality index as affected by zeolite and potassium fertilizer levels in the 2019–2020 and 2020–2021 seasons.

Treatments	Sugar lost to molasses %		Extractable sugar %		Quality index	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Zeolite rates (kg ha^{-1})						
Zero	1.67	1.68	14.17	14.23	86.15	86.17
476	1.64	1.72	15.17	15.48	87.14	86.97
952	1.70	1.77	15.88	16.21	87.34	87.24
1428	1.69	1.79	17.10	17.59	88.20	88.01
$LSD_{0.05}$	NS	NS	0.88	0.25	0.80	0.35
Potassium sulfate levels (kg ha^{-1})						
119	1.70	1.76	15.12	15.73	86.74	86.93
178.5	1.67	1.75	15.63	15.87	87.28	87.07
238	1.65	1.72	15.99	16.03	87.60	87.30
$LSD_{0.05}$	NS	NS	0.32	0.11	0.36	0.17
A x B	NS	NS	NS	NS	NS	NS

the recommended dose of K_2SO_4 ha^{-1} (119 kg ha^{-1}) doubled causing a significant and an ascending increase in extractable sugar% and quality index in both seasons. The response to adding 238 kg ha^{-1} K_2SO_4 was significantly more efficient than 178.5 and/or 119 kg ha^{-1}, which may be attributable to the experimental site suffering from low potassium content (Table 2).

On the other hand, results showed that, sugar lost to molasses % was not affected by K-sulfate levels, which in turn affects the juice purity, thus having an effect on the sugar extracted in both seasons (Table 2). The interaction between zeolite rates and potassium fertilization did not reach the level of significance in their effect on sugar lost to molasses, extractable sugar percentages, and quality index (Table 8).

Root, top, and sugar yields

Soil application of zeolite appreciably affected root, top, and sugar yields ha^{-1}, in both seasons, as compared with the untreated soil. Application of 1,428 kg zeolite ha^{-1} has positively increased root, top, and sugar yields ha^{-1} as compared with the given untreated zeolite, in both seasons. The increases in these traits were substantial and excelled the check treatment, about 6.43, 6.81 ton-roots, 6.37, 5.37 ton-foliage, and 2.50, 2.86 ton-sugar in the first and second seasons, respectively. Concerning the effect of potassium sulfate results, it was clear that the highest values of the root, top, and sugar yields ha^{-1} were obtained in beets fertilized with 238 kg ha^{-1}, whereas the lowest value was recorded in beets fertilized with 119 kg ha^{-1}, in both seasons. The increases in the root, top, and sugar yields ha^{-1} amounted to 2.76, 2.00 ton-root, 1.78, 1.64 ton-foliage, and 0.84, 0.43-ton sugar, over that which was fertilized with 119 kg K_2SO_4 ha^{-1}, in both seasons, respectively (Table 9).

The interaction effects

Fertilizing beet plants with 238 kg K_2SO_4 ha^{-1}, along with 1,428 kg zeolite ha^{-1} led to an increase in root yield ha^{-1} about by (6.90 and 5.14 tons ha^{-1}) compared with those plants that grew in sandy soil which treated with 238 kg K_2SO_4 ha^{-1}+ 952 kg zeolite ha^{-1} in both seasons, respectively (Table 10). The differences in top yield ha^{-1} between beets fertilized with 178 kg and 238 kg K_2SO_4 ha^{-1} were insignificant in the case of the soil left without zeolite and when it was treated with 476 and/or 952 kg of zeolite ha^{-1}. However, the differences in top yield ha^{-1} between those two levels of K-sulfate became significant when added with 1,428 kg zeolite ha^{-1} for both seasons. The most important input to have an increase was the maximum dose of 1,428 kg zeolite and 238 kg potassium sulfate ha^{-1} compared with the other treatments (Table 11)***.***

The results in Table 12 point to an insignificant variance in sugar yield ha^{-1}, was found between beets fertilized with 178 or 238 kg ha^{-1} K_2SO_4, in combination with no zeolite, as well as, with 476 and 952 kg ha^{-1} of it. However, significant variances were found between the two abovementioned levels of potassium and the addition of zeolite by 1,428 kg ha^{-1}. At the same time, rising potassium levels from 178 to 238 kg ha^{-1} K_2SO_4 increased sugar yield amounted to 0.34 t ha^{-1} with the addition of zeolite rate of 1,428 kg ha^{-1} in the first season only.

Table 9. Yields of the root, top, and sugar/ha as affected by zeolite and potassium fertilizer levels in the 2019–2020 and 2020–2021 seasons

Treatments	Root yield ha^{-1} (ton)		Top yield ha^{-1} (ton)		Sugar yield ha^{-1} (ton)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Zeolite rates (kg ha^{-1})						
Zero	48.79	49.50	14.88	17.48	6.94	7.05
476	49.62	50.69	16.90	20.01	7.53	7.85
952	51.12	52.12	18.78	21.18	8.12	8.45
1428	55.22	56.31	21.25	22.85	9.44	9.91
LSD at 5%	3.62	1.48	1.24	1.02	0.62	0.36
Potassium sulfate levels (kg ha^{-1})						
119	49.74	51.15	17.16	19.52	7.57	8.10
178.5	51.31	52.21	17.75	20.46	8.04	8.32
238	52.50	53.15	18.94	21.16	8.41	8.53
$LSD_{0.05}$	0.98	0.76	0.29	0.38	0.14	0.14
A x B	**	**	**	**	**	NS

Table 10. Effect of interaction between zeolite and potassium fertilizer levels on root yield in the 2019–2020 and 2020–2021 seasons

Zeolite rates (kg ha^{-1})	Root yield ha^{-1} (ton)					
	Potassium sulfate levels (kg ha^{-1})					
	1st season			2nd season		
	119	178.5	238	119	178.5	238
Zero	45.65	50.19	50.55	47.10	49.69	51.73
476	49.05	49.58	50.22	50.27	50.69	51.15
952	50.55	51.05	51.79	51.57	51.98	52.81
1428	53.74	54.45	57.45	55.63	56.46	56.87
$LSD_{0.05}$		1.95			1.50	

Table 11. Effect of interaction between zeolite and potassium fertilizer levels on top yield in the 2019–2020 and 2020–2021 seasons

Zeolite rates (kg ha^{-1})	Top yield ha^{-1} (ton)					
	Potassium sulfate levels (kg ha^{-1})					
	1st season			2nd season		
	119	178.5	238	119	178.5	238
Zero	14.52	14.78	15.30	15.94	17.45	19.05
476	16.16	16.90	17.66	19.47	20.15	20.40
952	18.14	18.61	19.59	20.59	21.30	21.67
1428	19.83	20.68	23.25	22.09	22.93	23.52
$LSD_{0.05}$		1.05			0.79	

Table 12. Effect of interaction between zeolite and potassium fertilizer levels on sugar yield in the 2019–2020 season

Zeolite rates (kg ha^{-1})	Sugar yield ha^{-1} (ton)		
	Potassium sulfate levels (kg ha^{-1})		
	1st season		
	119	178.5	238
Zero	6.26	7.14	7.42
476	7.30	7.55	7.75
952	7.96	8.10	8.29
1428	8.76	9.37	10.19
$LSD_{0.05}$		0.26	

DISCUSSION

In this work's results, zeolite increased the photosynthesis pigments, which was probably due to the availability of different elements and water for plants to use zeolite. It is worth noting that zeolite did not directly contribute to the synthesis of chlorophyll. But, it indirectly increased the soil water retention capacity, which provided plants with nutrients affecting the plant's physiological processes, which are essential instruments in chlorophyll synthesis and are related to the number of nutrients absorbed by the plants (Rehakova *et al.*, 2004). Moreover, the role of potassium sulfate in increasing photosynthesis pigments may be attributed to the role of potassium in the opening and closing of leaf stomata which control the movement of CO_2 into the plant and enhancement of photosynthetic rate. Furthermore, the presence of the sulfur element would increase the uptake of magnesium, which is an essential element for chlorophyll biosynthesis (Hussain *et al.*, 2014).

The increased thickness and weights of roots and leaves might be due to the role of zeolite as a soil conditioner in improving water retention capacity and assisting water distribution through sandy soils. Therefore, holding nutrients became more accessible to beet plants during the growth period (Khodaei and Asilan, 2012). At the same time, a significant increase in root diameter, fresh and foliage weights in plants is mainly due to the role of potassium fertilizer on protein synthesis, stomatal regulation, enzyme activation, water relation, and photosynthesis in plants which increases root growth and improves drought resistance (Enan, 2016).

The positive effect of interaction between zeolite rates and potassium sulfate levels has appeared on root diameter and fresh weight ha^{-1} in both seasons. The results may be attributed to the application of zeolite, which might be favorable to increase the availability of elements nutrition and cations exchange compared with the soil that was left without zeolite. Hence, thicker and heavier roots were obtained which was also confirmed by Ramesh and Reddy (2011) and Jarosz *et al*. (2022). This is while not neglecting the positive role of potassium sulfate in its effect on growth traits (Mehran and Samad, 2013; Mekdad *et al*., 2021).

The application of zeolite significantly increased sucrose percentage and root potassium content which may be due to a positive correlation between sucrose concentration and the number of cambium rings, as well as, the distance between rings that caused an increase in root diameter and thus increased sucrose percentage. On the other hand, the increases in sucrose percentage and root potassium content, in addition to a decrease in sodium and alpha-amino N contents, come as a result of expressing the potassium role in increasing enzyme activity and the concentration of soluble substances in the xylem, in limited sodium adsorption by plants (Liang, 1999). Nevertheless, Enan (2016) explained that there are positive trends of the sugar beet plant selectivity for potassium over sodium when applying 100 and/or 75 kg K_2SO_4 fed^{-1} which significantly decreased root sodium and alpha-amino-N contents, which constitute part of the impurities in roots juice.

The significant and ascending increase in extractable sugar percentage and quality index is due to the addition of zeolite to sandy soil. This result could be attributed to values aforementioned of sucrose and lower values of alpha-amino N content. As for the effect of potassium fertilizer on these traits, these results may again be attributable to the experimental soil suffering from low potassium content. Otherwise, for both seasons, sugar lost to molasses percentage was not affected by K-sulfate levels, which in turn affects the juice purity, and consequently affects the extracted sugar. Nemeat-Alla *et al*. (2021) found that fertilizing beet plants with 7.5 kg K-humate fed^{-1} increased extracted sugar percentage values, following a decreased/loss to molasses, and thus improving the quality index.

Soils treated with zeolite positively increased root, top, and sugar yields ha^{-1} as compared with soil untreated with zeolite. Such an increase in these traits may be accredited to the role of zeolite as reported before that zeolites can absorb up to 60% of the water volume, hence, providing water to the root of plants for a longer time (De-Smedt *et al.*, 2017). Furthermore, its increased cation exchange capacity encourages nutrient access to plants. Thus, increasing root and sugar yields fed^{-1} under sandy soil conditions. Likewise, the positive effect of potassium increases crop yields mainly by activating many enzymes involved in different metabolic processes in plants. It also promotes nutrient and water uptake due to its osmotic functions and develops resistance to drought (Draycott, 2006). Similarly, the experimental soil used was sandy textured and suffered potassium deficiency, which was less than the critical limit due to leaching and less K ions retention on soil particles. Hence, it gives a good response to the potassium sulfate application.

The increases in root and top yields ha^{-1} may be attributed to the following reasons; the positive effect of zeolite and potassium and their effect on root attributes, and assimilations of photosynthetic pigments, which are reflected in the yields of the top, root, and finally sugar ha^{-1}, potassium sulfate effect on beet plants, as well as, the effect of zeolite on sandy soil (Enan, 2016; Cairo *et al.*, 2017). In the same context, the positive effect of the interaction between the studied factors on sugar yield ha^{-1} in the second season could be due to extra nutrients supplied by the mineral, increases soil cation exchange capacity, water retention in the root zone, and decreasing mineral components leaching (Jakkula and Wani, 2018). Furthermore, the studied zeolite contained exchangeable potassium estimated at 1.90 % as shown in Table 1.

CONCLUSION

Based on the results of this study, treating sandy soil by adding 1,428 kg of zeolite ha^{-1} at seedbed preparation to improve water and nutrients content, along with fertilizing beet plants with 238 kg potassium sulfate ha^{-1}, can be recommended.

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