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EVALUATION OF FELDSPAR AND BENTONITE AS SOIL AMENDMENTS AND THEIR EFFECT WITH FOLIAR SILICON APPLICATION ON SANDY SOIL PROPERTIES AND MAIZE PRODUCTIVITY

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ABSTRACT: A field experiment was conducted along the two successive summer seasons of 2020 and 2021 under sandy soil conditions at Ismailia Agricultural Research Station of Ismailia Governorate, Egypt. This study aims to evaluate the effect of bentonite and feldspar application as soil amendments (A) at a rate of 2.4 Mg ha^{-1} and 4 rates of foliar spray of potassium silicate (Si) i.e. 0,100,150 and 200 mg l^{-1} on yield of maize plant (Zea mays *L.*) and sand soil properties. The experimental treatments (12 treatments) were arranged in a split-plot design. The obtained results illustrated an improvement in soil properties i.e. bulk density, total porosity, field capacity, wilting point, available water, pore size distribution, and soil content of available NPK. There were significant increases in N, P, and K uptake by maize grain. The highest values in grain and stover yield of maize plant as attained at treatments of Feldspar*Si_{200} and bentonite*Si_{150}. Using feldspar and bentonite can play an important role to improve the properties of sandy soil and the productivity of maize plants.

Key words: Feldspar; Bentonite; Potassium silicate; Maize plant and Sandy soil.

INTRODUCTION

There are three categories of natural soil conditioning materials like green and livestock manures as well as, soil amendments such as bentonite, feldspar, silicon, etc. But to avoid environmental pollution and to preserve the multi-soil functions and its sustainable production, it is preferable to treat weak both physical and chemical properties of sandy soil using natural soil amendments for safe and sustainable agriculture in sandy soil (Tallai, 2001).

Bentonite is clay and colloid-rich material consisting of montmorillonite minerals. Softened in water and their swelling capacity can reach their volume of 15-20 times. This gives it the ability to make an aggregation of the massive sand grains. Thus bentonite has a great ability to improve the soil moisture parameters of sandy soils (Tallai *et al.*, 2008).

Feldspar is potassium aluminum silicate (70% SiO_2, 10% K_2O, and 18% Al_2O_3). It has also a positive effect on soil structure and soil aggregation, thus it can increase the water-holding capacity of sandy soil by about 10-15% (Matichenkove *et al.*, 2009).

Spraying potassium silicate solution in suitable concentration (100 - 200 mg l-1 Si) has a dual effect on the plant and soil, especially with the addition of soil amendments of bentonite and feldspar, where it could improve the retentive capacity of sandy soil for water and nutrients (Matichenkove *et al.*, 2009). It can also increase plant height and yield due to the increased gibberellic acid amount in the plants (Hwang *et al.*, 2008).

Maize (Zea mays *L.*) is the most important grain in Egypt. Approximately 8 million tons of maize grain are produced in Egypt. But maize needs about 700 mm of water per feddan at the season. At maturity, each plant will have consumed about 150 L of water and in feddan about 20,000 plants. Accordingly, successful maize production in sandy soil mainly depends on the correct application of soil conditions to preserve moisture content and nutrients, and this necessitates the use of natural amendments (Osman *et al.*, 2008).

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This study aims to evaluate the influence of soil amendments and different rates of foliar silicon application on soil properties and maize productivity in sandy soil.

MATERIALS AND METHODS

A field experiment was conducted on sandy soil, at Ismailia Agricultural Research Station, Egypt (Lat. 30º 35⁻ – 41º 9⁻ N, Long. 32º 10⁻ - 45º 83⁻ E), during two successive summer seasons of 2020 and 2021 to study the influence of soil amendments (feldspar and bentonite) and different rates of foliar silicon application on soil properties and maize productivity in sandy soil.

The experimental treatments were arranged in a split-plot design with three replicates (12 treatments). The main plots were represented by soil amendments application, while the applications of silicon were represented by subplots. The experiment treatments were: (1) three treatments of soil amendments (A) control (without application), Feldspar at a rate of 2.4 Mg/ha, and bentonite at a rate of 2.4 Mg/ha (2) Four levels of foliar spraying by potassium silicate solution at rates of 0, 100, 150, and 200 mg l^{-1} (Si) after 15, 30, 45, 75, and 90 days of maize sawing using 12 l/ha.

Soil samples at 0-30 cm depth for each application from the experiments were taken before cultivation to determine the main soil's physical and chemical properties (Table, 1). All farming practices of the wheat plant under sandy soil conditions were carried out according to Agriculture Ministry of Egypt. Soil amendments were added before sowing. All experimental units were fertilized by Nitrogen as ammonium sulfate (200 g N kg^{-1}) at a rate of 285.6 Kg N ha^{-1}. Phosphorus was applied in the form of superphosphate (0.068 kg P kg^{-1}) at a rate of 16.09 P ha^{-1} during the final stage of land preparation for planting and potassium was added in the form of potassium sulfate (0.398 kg K kg^{-1}) at a rate of 95 kg K ha^{-1} in two equal doses after sowing and flowering.

The experiment was irrigated by a fixed sprinkler system (10 X 10 m) with discharge 1.3 m^3/h/fed at pressure 2.5 bar of each sprinkler. The irrigation rate was according to the evapotranspiration rates of Erian (1989) at Ismailia Station during the summer season.

After harvesting disturbed and undisturbed soil samples were collected to determine soil properties. Bulk density with its corresponding soil moisture content was determined by core samples. Total porosity was computed according to the following equation: TP= $(1 - B_d/P_d) \times 100$ where: TP is total porosity, B_d is bulk density and P_d is particle density (2.65 g/cm^3). Soil Moisture-Tension Characteristic Curves are determined by using the pressure-membrane technique. Pore size diameters were determined for the ranges of soil matric according to Bashour and Sayegh (2007). The disturbed soil samples were analyzed for their content of available N, P and K described by Page et al. (1982).

The statistical analysis of the obtained data was performed according to Senedecor and Cochran (1980), and the treatments means were compared using LSD at a 0.05 level of probability.

Table (1). The main characteristic of the studied soil.

Particle size distribution (%)				Texture class	Organic matter (%)	Available nutrients (mg/kg soil)			*pH	*EC (dSm^{-1})	*SP	$CaCO_3$ (%)
Coarse sand	Fine sand	Silt	Clay			N	P	K				
46.55	43.55	5.4	4.5	Sandy	0.42	18.65	8.42	37.5	7.38	0.45	21.5	0.9
Soil anions (mmole l^{-1})				Soil cations (mmole l^{-1})				Bulk density (Mgm^{-3})	Total porosity (%)	Field capacity (%)	Wilting point (%)	Available water (%)
$HCO3^-$	Cl^-	$SO4^{-2}$	$CO3^{-2}$	Ca^{+2}	Mg^{+2}	K^+	Na^+					
2.21	1.66	0.66	0	1.29	1.76	0.24	1.24	1.77	33.21	20.61	5.65	14.96

*pH soil: water suspension at 1: 2.5, EC in soil saturation extract, SP: saturation percent

RESULTS AND DISCUSSION

Yield of maize plant

Results in Table (2) showed a positive and significant increase of feldspar and bentonite as a soil amendment on the ear, grain, and stover yield of the maize plant. These increases due to feldspar compared with control were 16.72, 21.00, and 12.25 % for ear, stover, and grain yield, respectively while, the increases resulting from bentonite application were 61.83, 78.06, and 53.52 % respectively. It is worthy to note that, the addition of bentonite gave values better than the application of feldspar in all yield characters and there were significant differences between them. These results may be due to that bentonite play an important role in sandy soil providing plants with its needs of sufficient nutrients that should recover from high yield with good quality. These findings are in accordance with those obtained by El-Dardiry, and Abd El-Hady (2015), and Zhang *et al.* (2020).

Regarding the effect of the foliar application of silicon on maize yield, data in Table 2 indicated that maize plants treated by foliar application of silicon, at any rate, gave significant increases in grain and stover yield of maize plant as compared with untreated plants. The highest grain and stover yield was obtained with the rate of 200 mg l^{-1} compared with other rates of foliar silicon. These results are in agreement with those obtained by Hawang *et al.* (2008) and Salem (2017).

Table(2). Effect of soil amendments and the different rates of silicon application on yield of maize plant (average of two seasons).

Soil amendments (A)	Silicon (mg/l)	Yield of ear maize (Mg/ha)	Yield of grain (Mg/ha)	Yield of stover (Mg/ha)
Control	0	5.76	2.71	5.74
	100	6.91	2.95	6.70
	150	7.15	3.50	7.68
	200	7.22	3.60	8.30
Means		6.76	3.19	7.10
Feldspar	0	6.94	3.38	7.20
	100	7.34	3.48	7.73
	150	7.61	3.70	8.30
	200	9.67	4.87	8.66
Means		7.89	3.86	7.97
Bentonite	0	9.89	5.28	9.48
	100	10.01	5.50	10.30
	150	11.64	5.90	11.64
	200	12.12	6.02	12.17
Means		10.91	5.68	10.90
$LSD_{0.05}$		A=1.25 Si=1.11 A*Si=1.72	A=0.76 Si=0. 63 A*Si=0.35	A=0.22 Si=0.16 A*Si=0.68

Concerning the double interaction between soil amendments and different rates of foliar silicon application, data in Table 2 cleared that the addition of feldspar and bentonite as soil amendments with foliar silicon gave a positive and significant effect on maize yield i.e. ear, grain and stover. It is worth noting that treatment of feldspar with foliar silicon at a rate of 200 mg l^{-1} gave higher values in grain and stover yield whereas, the highest values of maize yield were obtained with treatment of bentonite and foliar silicon at a rate of 150 mg l^{-1} with the non-significant difference between bentonite and foliar silicon at a rate of 200 mg l^{-1}. These results are in the same line with El-Kholy *et al.* (2000), El-Dardiry and Abd El-Hady (2015), and Salem (2017).

Nutrient uptake

Data presented in Table (3) indicated that NPK uptake by maize grain was affected significantly by the application of soil amendments. Also, data cleared that, bentonite treatment resulted in a higher N and P uptake by grain maize than feldspar treatments. This might due to the important role of bentonite to improve the capacity for sandy soil which reflects to increase the nutrient uptake by the plant The results confirm those of Croker *et al.* (2004), Salem (2017), and El-Dardiry and Abd El-Hady (2015). On contrary, the highest values of K uptake were obtained under feldspar treatment. The increase in available K would be accompanied by high nutrient uptake. Potassium enhances plant growth and consequently increases the uptake of nutrients (Abdel-Salam and Shams 2012).

Table (3). Effect of soil amendments and the different rates of silicon application on NPK uptake by the grain of maize plant (average of two seasons).

Soil amendments (A)	Silicon (mg l^{-1})	Uptake (kg/ha)		
		N	P	K
Control	0	16.80	6.24	10.32
	100	21.84	9.12	12.48
	150	30.24	12.24	16.08
	200	31.92	13.92	18.00
Means		25.20	10.38	14.22
Feldspar	0	16.92	7.03	14.92
	100	43.68	13.92	70.32
	150	54.72	17.76	84.48
	200	72.48	24.00	89.76
Means		46.95	15.68	64.87
Bentonite	0	17.22	7.29	12.34
	100	80.40	26.40	33.36
	150	93.36	32.40	44.64
	200	96.24	34.80	58.80
Means		71.81	25.22	37.29
$LSD_{0.05}$		A=1.73 Si=5.62 AxSi=18.76	A=2.61 Si=2.01 AxSi=7.25	A=15.55 Si=4.10 AxSi=17.03

n.s: non-significant at the 5% levels of probability at the L.S.D test.

Results in the same Table (3) showed a significant effect of foliar Si at different rates on NPK uptake by grains of the maize plant. The highest values of NPK uptake were obtained at a rate of 200 mg l^{-1} of foliar silicon as compared with the other rates. These results are in agreement with Salem (2017) who reported that the positive effect of silicon attributed to plants supplied with silicon maintaining an upright growth habit due to silicon deposition in cell walls, consequently leading to an increase in metabolism, plant growth, dry matter, and nutrient uptake.

Concerning the di-interaction effect between the soil amendments and foliar Si application, results showed a significant increase in NPK uptake by grain. The highest values of NPK uptake by grain in all cases were obtained at the treatment of bentonite * Si 200 mg l^{-1} with a non-significant difference with the treatment of bentonite * Si 150 mg l^{-1}. This finding agrees with El-Dardiry and Abd El-Hady (2015) and El-Edfawy (2021).

Soil content of available NPK

The statistical analysis of the obtained results in Table (4) showed sandy soil content of available N, P and K in relation to the studied treatments indicated that the feldspar and bentonite had a significant effect on the increasing availability of NPK in the soil after maize harvesting compared with the untreated one (control). The corresponding values by using feldspar were 86.31, 51.04, and 162.20 % for N, P, and K respectively while, these values by bentonite were 52.94, 60.88, and 73.98 % respectively.

Concerning the individual effect of the foliar application of silicon, the obtained results demonstrated that application of the foliar silicon, at any rate, had a significant increase in soil content of available NPK. (El-Dardiry and Abd El-Hady, 2015 and Salem, 2017).

Table (4). Effect of soil amendments and the different rates of silicon application on available NPK in soil (average of two seasons).

Soil amendments	Silicon (ppm)	Available nutrients (mg/ kg soil)		
		N	P	K
Control	0	22.34	10.21	38.5
	100	30.01	11.02	39.02
	150	32.2	12.10	42.00
	200	31.00	11.70	40.20
Means		28.89	11.26	39.93
Feldspar	0	24.20	10.29	41.20
	100	36.30	12.90	47.32
	150	39.08	15.30	56.11
	200	37.15	14.02	55.91
Means		34.18	13.13	50.57
Bentonite	0	26.40	11.01	42.92
	100	40.11	13.20	45.81
	150	43.81	15.39	49.21
	200	42.21	14.52	47.55
Means		38.13	13.53	45.94
$LSD_{0.05}$		A=2.66 Si=2.94 AxSi=1.85	A=0.34 Si=1.17 AxSi=1.25	A=3.63 Si=1.23 AxSi=2.61

With respect to the di-interaction effect of soil amendments and foliar application of silicon data presented in Table 4 cleared that, the soil content of available NPK was significantly increased by all combined treatments more than those resulting from their individual applications. The treatment of feldspar or bentonite plus Si at a rate of 150 mg l^{-1} with three determined nutrients gave values similar to or better than treatment of feldspar or bentonite plus Si at a rate of 200 mg l^{-1}. This is due to bentonite having been shown to increase growth rates and increase the availability of macronutrients in sandy soil. Also in this respect, the addition of feldspar could enhance the available NPK through producing organic acid that releases P and K which stimulated growth and nutrient uptake by the maize plant. Moreover, the application of silicon compound prevents the strong fixation of phosphorous fertilizer, hence the available P increase. This finding agrees with Hassan and Abd-Wahab (2013), Seddik *et al.*, (2016), and Salem (2017).

Physical properties

Data in Table (5) show the effect of studied treatments on the physical properties of the studied soil. Results cleared that, the addition of soil amendments decreased the drainable pores. The decreasing percentages were 1.33 and 3.10 % for feldspar and bentonite, respectively as compared with untreated soil. For the silicon application, drainable pores ranged between 20.8 with (0 Si foliar) and 19.4 with (200 mg l^{-1} Si foliar). As regards the interaction effect between soil amendments and the levels of silicon foliar application data indicated that the lowest value was associated with bentonite treatment with 200 mg l-1 Si foliar).

Table (5). Effect of soil amendments and the different rates of silicon application on physical properties of the studied soil (average of two seasons).

Soil amendments (A)	Silicon (Si) (ppm)	Bulk density (g/cm3)	Total porosity (%)	Field capacity (%)	Wilting point (%)	Available water (%)	Pore size distribution of total soil volume (%)		
							drainable pores	water-holding pores	capillary pores
Control	0	1.77	33.2	20.0	5.8	14.2	21.4	4.8	6.3
	100	1.78	32.8	19.2	5.4	13.8	19.0	6.9	6.4
	150	1.79	32.5	20.0	5.3	14.7	21.0	4.3	7.9
	200	1.76	33.6	20.7	6.0	14.7	20.0	5.5	7.8
Means		1.78	33.02	19.98	5.63	14.4	20.35	5.38	7.10
Feldspar	0	1.64	38.1	25.2	8.1	17.1	20.6	7.5	7.4
	100	1.63	38.5	25.8	7.5	18.3	21.9	6.7	7.9
	150	1.61	39.2	26.2	7.7	18.5	18.9	6.5	7.5
	200	1.62	38.9	25.5	7.9	17.6	18.9	6.9	7.7
Means		1.63	3868	25.68	7.80	17.9	20.08	6.90	7.63
Bentonite	0	1.56	41.1	36.2	11.3	24.9	20.3	10.2	10.3
	100	1.55	41.5	36.6	11.7	24.9	19.7	11.5	10.9
	150	1.53	42.3	37.7	10.9	26.8	19.5	11.9	10.7
	200	1.55	41.5	36.3	10.6	25.7	19.4	11.3	10.6
Means		1.55	41.60	36.70	11.13	25.6	19.72	11.23	10.63

Results in Table (5) indicated that the addition of bentonite as a soil amendment increased the average values for total porosity, available water, water-holding pores, and capillary pores by 25.98, 77.78, 108.74, and 49. 72 % respectively as compared with untreated soil. While values of bulk density decreased by 12.92 %. The previous values were somewhat low with the addition of feldspar. It recorded 4.57, 24.31, 28.25 and 7.46%, respectively. While bulk density decreased by 2.25 %. Also, data reveal that the addition of bentonite along with different levels of silicon was most effective in increasing the values of total porosity, available water, water-holding pores, and capillary pores as well as decreasing the values of bulk density. The given data in the same Table showed that application of soil amendments in combination with different levels of silicon raised water retained at both field capacity and wilting point. These results are in good agreement with those obtained by Seddik (2006) and Mi *et al.* (2017).

Based on these results, bentonite has a positive effect more than feldspar because it contains clay that has a high exchange capacity which can make aggregates for massive sand grains. Aggregates are a good structure to maintain suitable moisture for the plants in sandy soil. Seddik *et al.* (2016) and Salem (2017) mentioned that spraying with silicon at a concentration of 150-200 mg l-1 is the best level for making soil aggregation.

Conclusion

From the above-mentioned results, we can be concluded that using feldspar and bentonite as natural sources combined with foliar silicon application improved the yield and nutritional status of the maize plant and also improved the physical properties of sandy soil. Bentonite widely used on coarse-textured Ismailia sandy soil it is a promising technology to increase maize production. Using the naturally deposited materials would be beneficial for farmers and save high costs of chemical fertilizers.

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تقييم الفلسبار والبنتونيت كمحسنات تربة مع الإضافة الورقية للسليكون وتأثيرها على الخواص الطبيعية للأرض الرملية وإنتاجية نبات الذرة الشامية

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الملخص العربى

أقيمت تجربة حقلية خلال موسمي صيف ٢٠٢٠ و٢٠٢١ فى الأرض الرملية فى محطة بحوث الإسماعيلية التابعة لمركز البحوث الزراعية بمحافظة الإسماعيلية – مصر. تهدف الدراسة لتقييم تأثير إضافة البنتونيت والفلسبار كمصلحات للتربة بمعدل 2.4 ميجا جرام / هكتار وأربعة معدلات من الرش بسليكات البوتاسيوم وهى صفرو ١٠٠و ١٥٥و ٢٠٠ ملليجرام /الليتر على محصول نبات الذرة الشامية وخواص الأرض الرملية. صممت التجربة بنظام القطاعات تامة العشوائية. وأوضحت النتائج المتحصل عليها التحسن الأيجابى لخواص التربة تحت الدراسة وهى الكثافة الظاهرية - المسامية الكلية - نسبة الرطوبة عند السعة الحقلية ومعامل الذبول والماء الميسر - التوزيع الحجمى للمسام – والمحتوى من **NPK** الميسر فى التربة. وكان هناك زيادة معنوية فى **NPK** الممتص بواسطة حبوب نبات الذرة وكانت أعلى قيم لمحصول الحبوب والقش لنبات الذرة فى المعاملة (فلسبار + سليكات بوتاسيوم بمعدل ٢٠٠ ملليجرام /الليتر) والمعاملة (بنتونيت + سليكات بوتاسيوم بمعدل ٢٠٠ ملليجرام /الليتر). وكان لإضافة الفلسبار والبنتونيت دورا مهما فى تحسين خواص الأرض الرملية وانتاجية نبات الذرة الشامية.