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Effect of Soil Amendments and Foliar Application of Potassium Silicate on Wheat Plants Grown under Sodicity Conditions

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ABSTRACT

Nowadays, degraded soils reclamation *e.g.,* sodic soils is the main target for Egypt Government to face the great gap between food production and consumption. The high exchangeable sodium on soil colloids is a plant stress factor due to its role in reducing soil aggregates. To face this challenges, two field experiments were carried out aiming at evaluating the impact of soil amendments as main plots *i.e.* sugar lime mud and agricultural gypsum, and foliar application of potassium silicate at different rates [0.0 (control), 750 and 1500 mg $L^{-1} K_2SiO_3$] as sub-plots on wheat plants grown on soil having ESP value of 15.9%. Both soil amendments improved sodic soil properties, where the superior amendment was gypsum followed by sugar lime mud compared to untreated soil, and this improvement reflected on plant performance. The rate of 1500 mg L^{-1} K_2SiO_3 possessed the best performance, while the rate of 750 mg $L^{-1}K_2SiO_3$ came in the second-order and lately control treatment. Generally, the best performance of wheat plants grown under sodicity condition was realized when plants were treated with gypsum and potassium silicate at rate of 1500 mg L^{-1}, while the lowest performance was recorded when plants were not treated (without soil and foliar applications). The studied materials enhanced the synthesis of chlorophyll in wheat plant tissues, and this may be the reason for increasing the ability to tolerate sodicity. Also, sugar lime mud has a great opportunity to be included in the fertilization programs for degraded soil especially from an economic point of view.

Keywords: Sodic soil, soil amendments, potassium silicate and wheat plants.

INTRODUCTION

Sodic soils originate mainly in regions with little precipitation (Qadir *et al.* 2008). Soil degradation resulting from sodicity is a main environmental threat to agricultural productivity and soil fertility in arid and semi-arid regions of the world (Alcívar *et al.* 2018). In Egypt, the North Delta contains the biggest area of sodic and saline soils (about 46% of the total area) (El-Ramady *et al.* 2018). Under sodic soil conditions, the destruction of soil structure is done by clay dispersion due to high exchangeable Na^+ on the soil colloids (Sonbol *et al.* 2001 and Alcívar *et al.* 2018). Sodicity has a negative influence on plants growth, and leads to generation of reactive oxygen species (ROS), inducing morphological and physiological changes, increased ion toxicity, decreasing leaf water potential, and altering the biochemical processes (Doklega *et al.* 2021).

One of the protective ways from soil sodicity stress is using soil conditioners *e.g.* agricultural gypsum, which causes enhancement of sodic soil properties, thus increasing tolerance of plant against sodicity conditions where it has a calcium content (Ca^{2+}) of 23%, which enables Na^+ displacement on the cation exchange sites of the soil colloids as well as gypsum has a sulfur content of 19% (Sahin *et al.* 2020). Many studies confirmed that soil addition of agricultural gypsum to sodic soil could accelerate Na^+ leaching, and subsequently raising exchangeable calcium percentage and declining exchangeable sodium percentage (Bayoumy *et al.* 2019 and El-Hadidi *et al.* 2020). Fisher (2011) reported that gypsum led to raise soil aggregates due to the beneficial effect of Ca^{2+} on soil forming stable aggregates. Therefore, improving aggregation of soil resulting salt leaching as a result of soil addition of gypsum.

Annually, large amounts of sugar industrial wastes from sugar beet factories is producing like sugar lime mud and are not exploited. Moreover, it may cause problems to the environment. Little studies were carried out to find out a holistic approach for recycling sugar lime mud. Mohamed (2020) found that soil addition of sugar lime mud to sodic soil having ESP value of 22% cause a decline of this value up to ….

Potassium silicate is used for agricultural purposes as silicon (Si) and potassium (K) amendment sources (Moussa and Shama, 2019 and El-Gazzar *et al.* 2020). Potassium is very essential for both the basic physiological functions of plants like proteins synthesis, sugars and starch formation and cell division as well as it plays a key role in the maintenance of the water situation within plant tissues (Pandey and Mahiwal, 2020). While Silicon (Si) stimulates plant growth and enhances productivity across crops. Moreover, its application improves plant biomass and productivity under varying stress circumstances (Deshmukh *et al.* 2017). Understanding the link between the protective role of potassium silicate against environmental stress is still limited.

Therefore, this paper aims at evaluating the impact of soil amendments *i.e.* sugar lime mud and gypsum as well as foliar application of different rates of potassium silicate

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on wheat plants grown on sodic soil and find out the best treatment under sodicity stress.

MATERIALS AND METHODS

1.**Experimental Setup**.

Two field trials were performed at a private farm located at El-Burullus District, Kafr El-Sheikh Governorate, Egypt during the two consecutive winter seasons of 2019/2020 and 2020/2021. Wheat plant (*Triticum aestivum* L, var Sakha 93, salt-resistant cultivar) was chosen as a model crop to study the influence of soil amendments [control (without soil addition), sugar lime mud and agricultural gypsum] as main plots and foliar application of different rates of potassium silicate [0.0 (control), 750 and 1500 mg $L^{-1}K_2SiO_3$] as sub plots on improving plant performance under sodicity condition. The trial execution (9.0 treatments) was implemented in a split-plot design with three replicates, where the subplot area was 6.44 m^2 (2.3 m width and 2.8 m length).

Agricultural gypsum ($CaSO_4$. $2H_2O$) having calcium content of 22.9 g $100g^{-1}$ and sulfur content of 17.9 g $100g^{-1}$ was obtained from El Shafeey company, Giza, Egypt. Also, it has a purity of 98.3 % with a pH value of 7.8 and an EC value of 2.5 dSm^{-1} (1: 5 agricultural gypsum amendment: water).It was thoroughly mixed with the surface of the studied sodic soil layer (0-30 cm) in single application three month before wheat sowing at 100% of gypsum requirement (100 of GR equivalent 9.70 Mg ha^{-1}). GR (Mg fed^{-1}) was calculated according to FAO and IIASA (2000) as follows:

$$GR = \frac{\text{Initial soil ESP (15.9\%)} - \text{Required soil ESP(10\%)}}{100} \text{ x CEC (40.0 cmol kg}^{-1}\text{) x 1.72}$$

Through the three months before sowing, the soil was irrigated after soil addition of agricultural gypsum up to saturation limit every 15 days to get rid of Na^+. The height of added water above the soil surface was about 10 cm. The studied soil annually was cultivating with sugar beet plants only.

Sugar lime mud was obtained from Delta Sugar Factory, Kafr El-Sheikh, Egypt. It contained 35% $CaCO_3$, 7.0 % organic matter with a pH value of 8.8 and an EC value of 7.5 dSm^{-1} also having N of 3.6 g kg^{-1}, P of 5.75 g kg^{-1} and K of 2.25 g kg^{-1}. The soil addition of sugar lime mud was as similar as gypsum exactly at the same rate (9.70 Mg ha^{-1}) with the same leaching process of Na^+.

Gypsum requirements and sugar lime mud were ploughed with soil only in the 1st season.

Potassium silicate was obtained from El-Gamhoria Company, El- Mansoura, Egypt then its solutions were prepared at the above-mentioned rates, where the foliar application was done at periods of 20, 40, and 60 days from sowing at a volume of 900 L ha^{-1} by hand sprayer.

Wheat grains were obtained from Ministry of Agriculture and Land Reclamation and sown on 10th of November at a rate of 145 kg ha^{-1} in both growing seasons (2019/2020 and 2020/2021).

The normal agricultural practices as well as N, P and K fertilization were done for the wheat production according to MALR. Irrigation was done under flood system, where the number of irrigations was 5. Harvesting wheat plants was done on 16th of April during the both seasons.

2.Soil Sampling.

Before soil addition of studied conditioners, a composite soil sample was taken from the experimental site at a depth of 0-30 cm and analyzed according to Dane and Topp (2020) for physical properties and Sparks *et al.* (2020) for chemical properties , where the studied soil possessed a clayey texture and contained 24% of sand, 26% of silt and 50% of clay with pH value of 8.67 and EC value of 3.10 dSm^{-1} also its organic matter content was low (1.08%) having available nitrogen of 53.6 mg kg^{-1}, available phosphorus of 5.95 mg kg^{-1} and available potassium with 230.9 mg kg^{-1}. Also, the studied soil possessed ESP value of 15.9% and CEC value of 40 c mol $kg^{-1,}$ bulk density value of 1.40 Mg m^{-3} and total porosity value of 46.15%.

3.Measurement traits.

1. At a period of 65 days after wheat sowing

From each sub-plot, random samples of ten wheat plants were taken to determine the following criteria:

a- Growth criteria *i.e.* plant height (cm) and chlorophyll content (SPAD, value).

b- Superoxide dismutase (SOD) was analyzed using method of Kumar *et al.* (2012).

c- Malondialdehyde (MDA) was determined according to Heath and Packer (1968).

d- Phenol content was determined according to Bouyahya *et al.* (2016).

2. At harvest stage.

From each sub-plot, random samples of ten wheat plants were taken to estimate wheat yield, its components and some qualitative traits as follows:

a- Yield and its components: No. of grain $spike^{-1}$, spike weight, weight of 1000 grain and grain yield

b- Nutrient status of grains: nitrogen (using kjeldahl method), phosphorus (using spectrophotometer apparatus) and potassium (using flam photometer apparatus) contents of wheat grain were determined according to Jones *et al.* (1991), where the oven-dried barley grains were ground then wet digested by a mixture of sulfuric, and perchloric acids (1:1).

c- Qualitative parameters of grains: Protein content in wheat grain was calculated by using the following formula: Protein % = (N) × 5.75 as described by Anonymous, (1990), while total carbohydrates in wheat grain were determined according to Cipollini Jr *et al.* (1994).

d- Soil analysis: Soil samples from each sub-plot were taken after harvesting wheat plants to determine exchangeable sodium percentage (ESP), exchangeable calcium percentage (ECaP) according to Sparks *et al.* (2020), removal sodium efficiency (RSE) according the equation of Amer (2017) as well as bulk density (Bd) and total soil porosity % (TP) according to Dane and Topp (2020), where the following equations were used.

$$\textbf{ESP} = Na^+ / (Na^+ + K^+ + Ca^{2+} + Mg^{2+}) \times 100.$$

$$\textbf{Bd (Mg m}^{-3}\textbf{)} = M_s/V_t$$

$$TP\% = 1 - \frac{\text{Bulk density}}{\text{Real density}} \times 100.$$

$$\textbf{RSE} = (ESPi - ESPf) \times 100/ESPi$$

4.Statistical Analysis.

It was done according to Gomez and Gomez, 1984, using CoStat (Version 6.303, CoHort, USA, 1998–2004)].

RESULTS AND DISCUSSION

1.Performance at 65 Days from Sowing.

Addition of soil amendments [sugar lime mud and gypsum] and foliar application of different rates of potassium silicate [0.0 (control), 750 and 1500 mg $L^{-1}K_2SiO_3$] significantly affected growth criteria *i.e.* plant height (cm) and chlorophyll content (SPAD value) as well as self-production of antioxidants *i.e*. superoxide dismutase (SOD, unit g^{-1} $protein^{-1}$), Malondialdehyde (MDA, unit g^{-1} $protein^{-1}$) and phenol content (mg g^{-1} F.W) of wheat plants grown under sodicity condition at 65 days from sowing during seasons of 2019/2021 and 2020/2021 (Table1).

a- Growth criteria (plant height and chlorophyll content):

The wheat plants grown under sodicity condition and treated with100% of gypsum requirements (equivalent 9.70 Mg ha^{-1}) before sowing possessed the highest values of plant height and chlorophyll content followed by that treated with sugar lime mud amendment at the same rate (9.70 Mg ha^{-1}), while wheat plants untreated with studied soil amendments possessed the lowest values of both plant height and chlorophyll content. Generally, both studied conditioners could improve studied sodic soil properties, which reflected on wheat plant performance but gypsum was more superior to sugar lime mud. Gypsum superiority is due to that calcium replaced exchangeable sodium on soil colloids, therefore the prevalence of calcic clay and increasing soil aggregates as well as enhancing soil aeration (Ilyas, *et al.* 1997). While the beneficial effect of sugar lime mud compared to corresponding untreated soil may be attributed to its content of organic matter (7%), which have a great role in improving soil fertility. Similar results were obtained by Kheir and Kamara (2019) who consider one of the first researchers studying the effect of sugar lime mud on Egyptian soils.

Table 1. Effect of soil amendments, foliar application of potassium silicate and their interactions on performance of wheat plants grown under sodicity condition at 65 days from sowing during seasons of 2019/2020 and 2020/2021(combined data over both seasons).

Characteristics Treatments		Growth criteria: Plant height, cm	Growth criteria: Chlorophyll, SPAD	Antioxidants: Superoxide dismutase(SOD), unit $g^{-1}protein^{-1}$	Antioxidants: Malondialdehyde (MDA), unit g^{-1} $protein^{-1}$	Antioxidants: Phenol, mg g^{-1} F.W
Soil amendments						
Control (Without soil addition)		63.89c	36.25c	27.76a	9.08a	6.24a
Sugar lime mud		66.74b	38.48b	23.55b	6.88b	4.62b
Gypsum		69.39a	40.64a	20.45c	5.33c	3.31c
LSD at 5%		1.67	0.18	0.22	0.05	0.05
Foliar application						
Control (without foliar application)		65.79b	37.84c	24.88a	7.70a	5.15a
Potassium silicate (at rat of 750mg $L^{-1}K_2SiO_3$)		66.59b	38.45b	23.97b	7.06b	4.72b
Potassium silicate (at rat of 1500mg $L^{-1}K_2SiO_3$)		67.64a	39.09a	22.92c	6.51c	4.31c
LSD at 5%		0.91	0.19	0.13	0.03	0.07
Interaction						
Control	Control	63.27f	35.88h	28.55a	9.73a	6.68a
	750 mg $L^{-1}K_2SiO_3$	63.60f	36.05h	28.09b	9.07b	6.26b
	1500 mg $L^{-1}K_2SiO_3$	64.80ef	36.83g	26.66c	8.43c	5.79c
Sugar lime mud	Control	65.73de	37.54f	25.13d	7.74d	5.29d
	750 mg $L^{-1}K_2SiO_3$	66.83cd	38.56e	23.38e	6.80e	4.53e
	1500 mg $L^{-1}K_2SiO_3$	67.67c	39.36d	22.15f	6.10f	4.05f
Gypsum	Control	68.37bc	40.09c	20.96g	5.65g	3.49g
	750 mg $L^{-1}K_2SiO_3$	69.33ab	40.74b	20.44h	5.32h	3.36h
	1500 mg $L^{-1}K_2SiO_3$	70.47a	41.10a	19.94i	5.01i	3.10i
LSD at 5%		1.58	0.33	0.23	0.05	0.12

Regarding the foliar application of potassium silicate, the rate of 1500 mg L^{-1} K_2SiO_3 was the superior one followed by the rate of 1500 mg $L^{-1}K_2SiO_3$ and lately the rate of 0.0 mg $L^{-1}K_2SiO_3$ (control treatment). On the other words, plant height and chlorophyll content wheat plants grown under sodicity condition increased as potassium silicate rate increased. The high superiority of potassium silicate compared to control treatment is due to that this fertilizer is a source of highly soluble K and Si, where potassium has a vital role in cell division and maintenance of the water situation within plant tissues (Jaiswal ,2016). In addition, the role of silica in building and supporting cell structures within plant tissue (Tubana *et al.* 2016).

Concerning the interaction effect, the highest values of aforementioned traits were realized when wheat plants grown under sodicity condition were treated with gypsum and sprayed with potassium silicate at rate of 1500 mg $L^{-1}K_2SiO_3$. However, the lowest values of aforementioned traits were recorded when wheat plants grown under sodicity condition were not treated neither by soil amendments nor by potassium silicate (without both soil and foliar application).

b- Superoxide dismutase (SOD) Malondialdehyde (MDA) and phenol content:

It is known that plant's self-production of antioxidants increases in tissues under any environmental stress in order to protect the plant from the harmful of these stresses. Nevertheless, the continuing stress for a long time, the plant's self-production of these antioxidants declines (Latef, 2014). This fact applied to the antioxidants content in wheat straw, where sodicity reduced wheat plant performance through overproduction of free radicals or as known reactive oxygen species (ROS) that cause damage to different macromolecules and cellular structures, therefore wheat plants were forced to secrete more amounts of these antioxidants to overcome these ROS (Doklega *et al.* 2021).

On other words, sodicity stress of soil (control treatment) led to raise superoxide dismutase (SOD) malondialdehyde (MDA) and phenol contents in wheat straw at period of 65 days from sowing, where the cultivation without any both soil additions and foliar applications caused an increase of wheat self-production from SOD,MDA and phenol to scavenge the ROS, therefore increase of sodicity stress tolerance. Also, the increase of wheat plant's self-production from these antioxidants may be due to that exchangeable sodium on colloids caused a dispersion of soil particles that negatively affected the absorption of the nutrients by the roots, which reflected on the plant's self-production of antioxidants.

In contrast to sodium, calcium in both gypsum and sugar lime mud caused aggregation in soil particles. On the other words, the control treatment (without soil conditioners application) recorded the highest values of these antioxidants compared to treating with both gypsum, and sugar lime mud, respectively.

Also, wheat plants sprayed with potassium silicate at rate of 1500 mg $L^{-1}K_2SiO_3$ produced the lowest values of SOD,MDA and phenol, while the second rate(750 mg $L^{-1}K_2SiO_3$) came in the second order, whilst the highest values were realized with untreated plants (without foliar application of K_2SiO_3). The results agree with Shahid *et al.* (2015) who found that foliar application of silicon led to the declination of activities of antioxidant enzymes under salinity stress.

Generally, it can be concluded that all studied treatments (soil amendments *i.e.* sugar lime mud and gypsum as well as foliar application of potassium silicate) have a beneficial effect on reducing wheat plant's requirements from SOD, MDA and phenol self-production. This is attributed to the vital role of gypsum and sugar lime mud as well as potassium silicate in scavenging ROS in the chloroplast as well as their role in regulating wheat plant physiology, photosynthesis and immunological enhancement.

The obtained findings are in harmony with the obtained results of Doklega *et al.* (2021) who stated that antioxidants production in red cabbage plant tissues increased under sodicity stress to protect the plant from this stress but with the continuing stress for a long time and gypsum have a beneficial role in increasing red cabbage plant tolerance to sodicity and scavenging ROS. Beside, Ibrahim *et al.* (2020) found that deficit irrigation increased root/shoot ratio, malondialdehyde (MDA) and proline as well as enzymatic antioxidants production in leaves of maize plants, while foliar applications of potassium silicate relatively alleviated water stress-induced damage and the self-production of plant from these antioxidants.

2.Performance at Harvest Stage.

Soil amendments [control (without soil addition), sugar lime mud and gypsum] and foliar application of different rates of potassium silicate [0.0 (control), 750 and 1500 mg $L^{-1}K_2SiO_3$] significantly affected wheat yield and its components *i.e.* No. of grain spike^{-1}, spike weight, weight of 1000 grain and grain yield (Table 2) as well as nutrient status *i.e.* N, P, K and qualitative criteria of grains *i.e* protein and carbohydrates (Table 3).

a- Yield and its components:

Data of Table 2 show that wheat plants treated with gypsum before sowing possessed the highest values of No. of grain spike^{-1}, spike weight (g), 1000 grain weight (g) and grain yield (Mg h^{-1}) under sodicity stress followed by that treated with sugar lime mud amendment, while wheat plants untreated with soil amendments obtained the lowest values of all aforementioned traits.

Table 2. Effect of soil amendments, foliar application of potassium silicate and their interactions on yield and its components of wheat plants grown under sodicity condition at harvest stage during seasons of 2019/2020 and 2020/2021(combined data over both seasons).

Characteristics / Treatments		No of grain spike^{-1}	Spike weight, g	1000 grain Weight, g	Grain yield, Mg h^{-1}
Soil amendments					
Control (Without soil addition)		40.00c	3.70c	37.91c	3.26c
Sugar mud		45.33b	4.67b	40.47b	3.81b
Gypsum		51.33a	5.38a	42.66a	4.34a
LSD at 5%		1.90	0.08	0.30	0.08
Foliar application					
Control (without foliar application)		43.33c	4.35c	39.58c	3.62c
Potassium silicate (at rat of 750mg $L^{-1}K_2SiO_3$)		45.56b	4.59b	40.39b	3.81b
Potassium silicate (at rat of 1500mg $L^{-1}K_2SiO_3$)		47.78a	4.80a	41.08a	3.98a
LSD at 5%		0.83	0.06	0.57	0.06
Interaction					
Control	Control	37.67h	3.50i	37.08h	3.12i
	750 mg $L^{-1}K_2SiO_3$	40.33g	3.68h	37.92gh	3.23h
	1500 mg $L^{-1}K_2SiO_3$	42.00f	3.93g	38.74fg	3.42g
Sugar mud	Control	43.67e	4.33f	39.55ef	3.54f
	750 mg $L^{-1}K_2SiO_3$	45.67d	4.69e	40.50de	3.85e
	1500 mg $L^{-1}K_2SiO_3$	46.67d	4.97d	41.36cd	4.06d
Gypsum	Control	48.67c	5.22c	42.11bc	4.22c
	750 mg $L^{-1}K_2SiO_3$	50.67b	5.40b	42.74ab	4.34b
	1500 mg $L^{-1}K_2SiO_3$	54.67a	5.51a	43.12a	4.48a
LSD at 5%		1.45	0.10	0.98	0.11

Regarding the foliar application of potassium silicate, the rate of 1500 mg $L^{-1}K_2SiO_3$ gave the highest values of No. of grain $spike^{-1}$, spike weight, 1000 grain weight and grain yield, while the rate of 750 mg $L^{-1}K_2SiO_3$ came in the second-order and lately control treatment (without foliar application). The effective role of potassium silicate in improving the wheat yield and its components under sodicity condition may be attributed to increasing water contents in wheat and photosynthetic efficiency as mentioned by Osman *et al.* (2017). Beside, Bybordi, (2014*)* reported that potassium silicate increased wheat yield under salt stress. Our results are in the line with those obtained by Ibrahim *et al.* (2016) who stated that supplementation silicon decreases of uptake Na^+ by wheat plants grown on salt-affected soil.

Concerning the interaction effect, the highest values of No. of grain $spike^{-1}$, spike weight, 1000 grain weight and grain yield were recorded when wheat plants grown under sodicity condition were treated with gypsum and sprayed with potassium silicate at rate of 1500 mg $L^{-1}K_2SiO_3$, while the lowest values of aforementioned traits were recorded when wheat plants grown under sodicity condition were not treated with both soil amendments and potassium silicate (without both soil and foliar application).

Generally, the effect of studied treatments on plant height and chlorophyll content reflected on wheat yield and its components. Our results are in agreement with the obtained by Ibrahim *et al.* (2020) and Doklega *et al.* (2021).

b- Nutrient status and qualitative traits of grains:

Table 3 shows an improvement of wheat plant height and chlorophyll content due to either studied soil conditioners or foliar applications of potassium silicate positively reflected on wheat grain quality and their nutrient status. The grains of wheat plants treated with gypsum had the highest values of N, P, K**,** protein and carbohydrates contents under sodic soil salinity stress followed by grains of wheat plants treated with sugar lime mud, while grain of wheat plants untreated with soil conditioners possessed the lowest values of nutrient status and qualitative traits in wheat grains. The gypsum application improved the soil aggregates and this may be reflected on root activity due to increasing soil aeration, thus increasing nutrients absorption, while the superiority of sugar lime may be attributed to its content from organic matter (7%).

Data of Table 3 also indicate that values of all nutrients status and qualitative traits of wheat grain increased as rate of potassium silicate increased. Generally, potassium silicate caused to enhance the plant status and this led to increased absorption of nutrients which, in turn, moved to wheat grain. Also, increasing grain proteins and carbohydrates may be a result of the role of potassium silicate in increasing the photosynthetic process and/or increasing the translocation of nutrients in plants, which are essential in increasing the biosynthesis of both grain proteins and carbohydrates (Hellal *et al.* 2012).

Table 3. Effect soil amendments, foliar application of potassium silicate and their interactions on nutrient status and qualitative traits of wheat grain plants grown under sodicity condition at harvest stage during seasons of 2019/2021 and 2020/2021(combined data over both seasons).

Characteristics		Nutrient status ,%			Qualitative traits ,%	
Treatments		N	P	K	Protein	Carbohydrates
Soil amendments						
Control (Without soil addition)		1.88c	0.168c	2.12c	10.82c	62.26c
Sugar mud		2.01b	0.188b	2.28b	11.56b	64.78b
Gypsum		2.16a	0.211a	2.43a	12.40a	67.29a
LSD at 5%		0.04	0.003	0.01	0.24	0.06
Foliar application						
Control (without foliar application)		1.97c	0.182c	2.22c	11.35c	64.03c
Potassium silicate (at rat of 750mg $L^{-1}K_2SiO_3$)		2.01b	0.189b	2.28b	11.58b	64.71b
Potassium silicate (at rat of 1500 mg $L^{-1}K_2SiO_3$)		2.06a	0.195a	2.33a	11.86a	65.59a
LSD at 5%		0.04	0.001	0.02	0.20	0.31
Interaction						
Control	Control	1.84h	0.161i	2.06i	10.60h	61.57i
	750 mg $L^{-1}K_2SiO_3$	1.88gh	0.169h	2.12h	10.79gh	62.15h
	1500 mg $L^{-1}K_2SiO_3$	1.93fg	0.175g	2.18g	11.08fg	63.05g
Sugar mud	Control	1.97ef	0.183f	2.23f	11.31ef	64.01f
	750 mg $L^{-1}K_2SiO_3$	2.01de	0.188e	2.29e	11.56de	64.73e
	1500 mg $L^{-1}K_2SiO_3$	2.06cd	0.193d	2.33d	11.83cd	65.61d
Gypsum	Control	2.11bc	0.203c	2.39c	12.15bc	66.51c
	750 mg $L^{-1}K_2SiO_3$	2.15ab	0.211b	2.43b	12.39ab	67.24b
	1500 mg $L^{-1}K_2SiO_3$	2.20a	0.218a	2.48a	12.67a	68.12a
LSD at 5%		0.06	0.002	0.03	0.35	0.54

Concerning the interaction effect, the highest values of aforementioned traits were recorded when wheat plants grown under sodicity condition were treated with gypsum and sprayed with potassium silicate at rate of 1500 mg $L^{-1}K_2SiO_3$, while the lowest values of aforementioned traits were recorded when wheat plants grown under sodicity condition were not treated with both soil amendments and potassium silicate (without both soil and foliar application).

A similar observation was reported by Osman *et al.* (2017) and Bayoumy *et al.* (2019).

3- Soil Properties.

Post-harvest soil analysis (Figs1, 2, 3, 4 and 5) illustrated that studied sodic soil properties after wheat harvest i.e. exchangeable sodium percentage (ESP), exchangeable calcium percentage (ECaP) , removal sodium efficiency (RSE,%), bulk density (Bd, Mg m^{-3}) and total soil porosity (TP,%) pronouncedly differed as a result of studied soil amendments. Foliar application of potassium silicate possessed an unclear impact on the aforementioned soil properties..

With soil amendments, ESP values were pronouncedly decreased, whilst RSE values were pronouncedly increased as well as ECaP values were pronouncedly increased comparing with corresponding untreated sodic soil, where the highest effect was owing to gypsum followed by sugar lime mud.

The superiority of gypsum is due to increasing soluble calcium ions in soil solution as a result of its soil addition, thus Ca^{2+} replaces exchangeable Na^{+} on surfaces of sodic soil colloids, therefore the aforementioned trend occurred. These findings are in agreement with the obtained results of Abo-Ogiala and Khalafallah (2019) who reported that gypsum soil application to saline-sodic soils followed by irrigation caused increasing of sodium in leached water and decrease of ESP of soil. While the positive impact of sugar lime mud compared to corresponding untreated sodic soil in decreasing ESP value and increasing ECaP value may be due to its content of organic matter, where O.M have a vital role in reducing ESP of sodic soil (Mohamed, 2020).

Fig. 4 revealed that soil addition of both gypsum and sugar lime mud led to reducing soil bulk density compared to corresponding untreated sodic soil, where the decline owing to gypsum was more than sugar lime mud. Also, total porosity percentage of studied sodic soil increased and enhanced in soil amended by agricultural gypsum followed by that amended by sugar lime mud (Fig 5) compared to corresponding untreated sodic soil and these Increases may be attributed to the role of Ca^{2+} in aggregation process and improving soil structure. Similar results were obtained by Doklega *et al.* (2021).

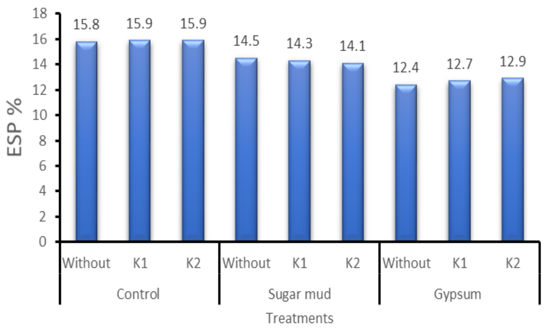

Fig 1. Effect soil amendments and foliar application of potassium silicate on average exchangeable sodium percentage (ESP) value of studied sodic soil after wheat harvest during seasons of 2019/2021 and 2020/2021(combined data over both seasons).

Control: without soil addition; Without: without foliar application of potassium silicate; K1: foliar application of potassium silicate at rat of 750mg $L^{-1}K_2SiO_3$ and K2: foliar application of potassium silicate at rat of 1500mg $L^{-1}K_2SiO_3$.

Fig 2. Effect soil amendments and foliar application of potassium silicate on removal sodium efficiency (RSE, %)during seasons of 2019/2021 and 2020/2021(combined data over both seasons).

Control: without soil addition; Without: without foliar application of potassium silicate; K1: foliar application of potassium silicate at rat of 750mg $L^{-1}K_2SiO_3$ and K2: foliar application of potassium silicate at rat of 1500mg $L^{-1}K_2SiO_3$.

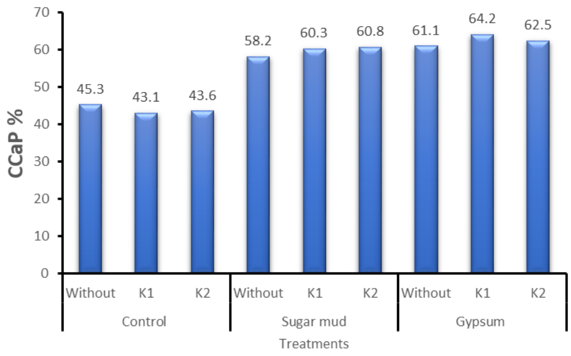

Fig 3. Effect soil amendments and foliar application of potassium silicate on average exchangeable calcium percentage (ECaP) value of studied sodic soil after wheat harvest during seasons of 2019/2021 and 2020/2021(combined data over both seasons).

Control: without soil addition; Without: without foliar application of potassium silicate; K1: foliar application of potassium silicate at rat of 750mg $L^{-1}K_2SiO_3$ and K2: foliar application of potassium silicate at rat of 1500mg $L^{-1}K_2SiO_3$.

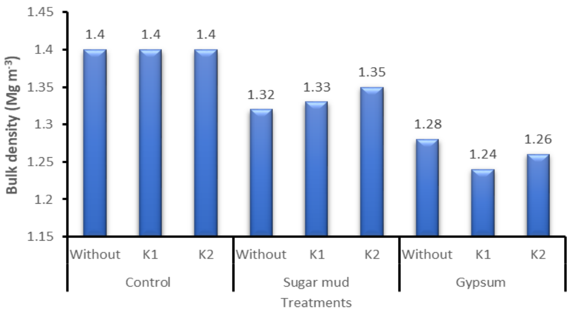

Fig 4. Effect soil amendments and foliar application of potassium silicate on average bulk density (Bd, Mg m^{-3}) value of studied sodic soil after wheat harvest during seasons of 2019/2021 and 2020/2021(combined data over both seasons).

Control: without soil addition; Without: without foliar application of potassium silicate; K1: foliar application of potassium silicate at rat of 750mg $L^{-1}K_2SiO_3$ and K2: foliar application of potassium silicate at rat of 1500mg $L^{-1}K_2SiO_3$.

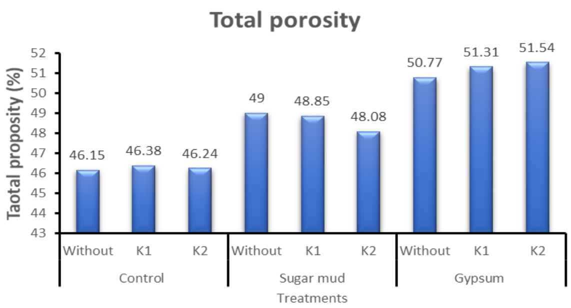

Fig 5. Effect soil amendments and foliar application of potassium silicate on average total porosity (TP, %) value of studied sodic soil after wheat harvest during season of 2019/2021 and 2020/ 2021 (combined data over both seasons).

Control: without soil addition; Without: without foliar application of potassium silicate; K1: foliar application of potassium silicate at rat of 750mg $L^{-1}K_2SiO_3$ and K2: foliar application of potassium silicate at rat of 1500mg $L^{-1}K_2SiO_3$.

CONCLUSION

Findings of the current paper confirmed the role of agricultural gypsum in reclamation of sodic soil, also showed that the sugar mud have appositive role in in reclamation of this soil as well as the foliar application of potassium silicate have a vital role in alleviating the hazard effects of sodicity on wheat plants.

It can be concluded that treating wheat plants grown on sodic soil by agricultural gypsum at 100 of GR under foliar application of potassium silicate at rate of 1500 mg L^{-1} K_2SiO_3 at period of 20, 45, and 60 days from wheat sowing is the best treatment, but sugar lime mud has a great opportunity to be included in the fertilization programs for degraded soil such as sodic soil especially from an economic point of view due to its the low cost of its usage in agriculture in addition to it may cause problems to the environment.

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تأثير محسنات التربة والرش الورقي لسيليكات البوتاسيوم على نباتات القمح النامي تحت ظروف القلوية

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في الوقت الحاضر، يعد استصلاح الأراضي المتدهورة، كالأراضي الصودية، هو الهدف الرئيسي للحكومة المصرية لمواجهة الفجوة الكبيرة بين إنتاج واستهلاك الغذاء. زيادة الصوديوم المتبادل على معقد التربة يعتبر عامل إجهاد نباتي بسبب دورة في تفرقة حبيبات التربة. لذلك، تم تنفيذ تجربتين حقليتين بهدف تقييم تأثير محسنات التربة كمعاملات رئيسية [طينة السكر الجيرية، جبس زراعي] والرش الورقي بمعدلات مختلفة من سليكات البوتاسيوم [٠,٠ و٧٥٠ و١٥٠٠ جزء فى المليون] كمعاملات فرعية على نباتات القمح النامي بتربة قيمة نسبة الصوديوم المتبادل بها ١٥,٩. أظهرت النتائج أن محسنات التربة المدروسة حسنت من خصائص التربة القلوية حيث كان الجبس هو الأكثر تفوقا يليه طينة السكر الجيرية مقارنة بالتربة الغير معاملة (كنترول) وهذا انعكس على أداء القمح. أيضا، وجد ان المعدل ١٥٠٠ جزء في المليون امتلك الأداء الأفضل يليه المعدل ٧٥٠ جزء في المليون من سليكات البوتاسيوم بينما معاملة الكنترول تأتي أخيرا (بدوش رش ورقي). بمعنى آخر، تم تحقيق أفضل أداء لنباتات القمح النامي تحت ظروف القلوية عند معاملة النباتات بالجبس ورشها بسيليكات البوتاسيوم بمعدل ١٥٠٠ جزء في المليون، بينما تم تسجيل أقل أداء عند عدم معاملة النباتات بكل من محسنات التربة وسيليكات البوتاسيوم (بدون إضافات أرضية او ورقية). بشكل عام، عززت المواد المدروسة تخليق الكلوروفيل في أنسجة نبات القمح وقد يكون هذا هو السبب في زيادة القدرة على تحمل القلوية. أيضًا، يتمتع طينة السكر الجيرية بفرصة كبيرة لإدراجها في برامج التسميد للأراضي المتدهورة خاصة من الناحية الاقتصادية.