Current Science International Volume : 09 | Issue : 04| Oct.- Dec. | 2020
EISSN:2706-7920 ISSN: 2077-4435 Pages: 656-665
DOI: 10.36632/csi/2020.9.4.59

Assessment of the Effect of Nano Sulfur on Some Soil Properties and Maize Productivity in Saline Soil

Esmaeil M. A., S. H. Abd Elghany, A.K. Abdel Fattah and A.A. Arafat

Soils, Water and Environ. Res. Institute, ARC, Giza, Egypt.

Received: 20 Oct. 2020 / Accepted 15 Dec. 2020 / Publication date: 25 Dec. 2020

ABSTRACT
A filed experiment was conducted at Sahl El-Hossinia agricultural research station, El-Sharkia Governorate, Egypt, during two summer seasons 2019 and 2020 to study the effect of nano sulfur on some soil chemical and physical properties and maize productivity in saline soil. The treatments consisted of: control (mineral sulfur 100kg/fed), three nano sulfur treatments (5, 10 and 15 kg/fed). In both seasons, the experiment was carried out in a complete randomized block design with three replicates. The results showed a slight decrease in soil pH, while there was a significant decrease in EC values in all the studied treatments as compared to control. Also, there was an improvement in some soil physical properties. Similarly, the values of hydraulic conductivity and total porosity had been increased significantly, while bulk density values were decreased significantly in the treated plots as compared to control. Soil content of available macronutrients (nitrogen, phosphorous and potassium) and micronutrients (iron, manganese and zinc) were significantly increased after application of the nano sulfur as compared to control. The treatment of nano S 15 kg/fed was the best one in increasing soil available content of macro and micronutrients. It increased the soil available content of nitrogen, phosphorous and potassium by about 17, 29 and 20 % than control, respectively. The same treatment increased the soil content of available iron, manganese and zinc by about 24 , 27 and 29 % than control, respectively. Also, all treatments led to a significant increase in the maize seeds content of macro and micronutrients. The maize productivity (grains and straw yield) was also increased significantly as a result of improvement of soil chemical and physical properties and increase of soil content of available macro and micro nutrients. The best treatment was nano S 15 kg/fed, it increased the grains and straw yields by rates 38 and 34 %, respectively as compared to control. This may be attributed to that addition of the used amendment was oxidized to sulfate then sulfuric acid that reduced soil pH which caused nutrients to be more soluble hence more available for plant uptake.

***Keywords*: Nano sulfur, maize, soil properties, saline soil.**

1. Introduction

Among environmental stresses, soil salinity is one of the most important threats to sustainable agriculture of arid and semi-arid regions of world. Soil salinity, limitations of water, global food requirements and urbanization is forcing agriculture to more marginal lands (Fischer *et al.*, 2010). It is a major environmental stress that drastically affects plants growth by creating low osmotic potential outside the plants. Increasing salinity of agricultural land had a negative impact on food production. Enhancing tolerance to salinity stress in crop plants is necessary in order to increase productivity with limited water supplies and high salinity. There is an imperative to develop an efficient and economical strategy for effective use of salt affected soils, which are, usually, reclaimed by chemical methods (Hosseini *et al.*, 2003).

Despite of the good results of mineral fertilizers, it has many disadvantages like soil contamination and the speed loss. It has been reported that key macronutrient elements, including N, P, and K, applied to the soil are lost by percents ranged between 30–45 %, causing a considerable loss of these nutrients (Chen and Wei, 2018). Furthermore, growers tend to use repeated applications of these fertilizers in order to achieve desired higher yields, which contrarily can lead to a decrease in soil fertility and increase salt concentrations and soil contamination. New approaches and technologies are required to be fulfilled in an economically and environmentally sustainable manner. Materials that are of up to 100 nm particle size in at least one dimension are generally classified as

Corresponding Author: Esmaeil M. A., Soils, Water and Environ. Res. Institute, ARC, Giza, Egypt.
Email: gawad2012@yahoo.com

nanomaterials, and are the basis for nanotechnology (Kim *et al.*, 2018). There are various types of nanomaterials such as copper (Cu), aluminum (Al), silver (Ag), gold (Au), Sulfur (S) zinc (Zn) and zinc oxide (ZnO), silica (Si) (Tan *et al.*, 2017). Given the unique properties of nanomaterials such as high surface-to-volume ratio, controlled-release kinetics to targeted sites and sorption capacity, nanotechnology has a high relevance for the design and use of new fertilizers (Perez *et al.*, 2018). The interaction of nanomaterials and fertilizers, due to the high reactivity of nanomaterials, results in an increased and effective absorption of nutritional elements and essential compounds for plants (Prasad *et al.*, 2017).

Sulfur is recognized as the fourth major nutrient after nitrogen (N), phosphorus (P) and potassium (K). It is an essential element for plant growth as it helps in synthesis of peptides, which contain cysteine like glutathione, various secondary metabolites, vitamins (B, biotine and thiamine) and chlorophyll in the cell (Abdallah *et al.*, 2010). Sulfur not only increasing crop production and quality of the produce, but also improves soil conditions for healthy crop growth (El-Tarabily *et al.*, 2006).

Sulphur application to soil plays an important role in soil such as reducing soil pH, improving soil water relations, and increasing availability of nutrient elements. Ahmed *et al.* (2016) suggested that the application of sulfur is an effective option in improving the chemical properties, like pH, electric conductivity (EC) and Sodium adsorption rate (SAR) of salt affected soils by decreasing their values and subsequently yield attribute of rice crop. Application of S fertilizer in salt affected soils is a viable procedure to counteract uptake of unnecessary toxic elements (Na^+ and Cl^-), which encourage selectivity of K/Na and ability of calcium ion to decrease the harmful impacts of sodium ions in plants (Zaman *et al.*, 2002). The residual effect of sulfur application was recently studied by Abdel Halim (2001) where pH decreased by 7.2, 7.0 and 1.2 % for the three successive seasons, respectively. He attributed that to the long term oxidation of applied elemental sulfur into sulfates (SO_4^{-2}) and formation of sulfuric acid providing more H^{and} ions in soil. Sulfur application as an amendment could be oxidized biologically in soil to produce H_2SO_4 which is capable to mobilize base cations from the soil. The H^+ ion in the acidic water displaces the cations from the exchange sites, reduces the exchangeable cations and increases the concentrations of these cations in the soil solution, hence decreasing soil EC. Mahmoud *et al.* (2013) and Nie *et al.* (2012) who reported that S fertilization in combination with NPK increased the soil organic carbon of the soil. In addition, elemental sulfur can improve soil physical properties, it can be oxidized by many soil microorganisms and forming sulfuric acid, consequently it reacts with soil $CaCO_3$ resulting in $CaSO_4$. The latter can be ionized to Ca^{2+} and SO_4^{2-}, then Ca^{2+} can be improved soil aggregation and permeability (Awadalla *et al.*, 2003).

Application of sulfur also led to increase the soil content of available macro and micro nutrients. Karimizarchi *et al.* (2014) deduced a significance increase in available concentrations of macro and macronutrients after sulfur application by rates 0.5, 1 and 2 g. kg^{-1}. The considerable increase in release of soil nutrients can be attributed to the effect of elemental S to amend soil pH, and the release of plant nutrients from unavailable pools to soil solution. It is well accepted that high concentrations of hydrogen ions may increase plant nutrient availability in soils by displacement of cations from exchangeable sites changing the oxidation state of nutrients; high concentrations of hydrogen may also enhance nutrient uptake by plants (Viani *et al.* 2014). This increase in soil content of available nutrients may be due to the controlled, slow release and lowest loss of nanofertilizers compared to conventional fertilizers.

Maize is called “King of cereals” because of its productivity potential compared to any other cereal crop. Being an exhaustive crop, it has very high nutrient requirement and its productivity is closely depends on nutrient management system. Fatma *et al.* (2019) deduced that increasing S application increased significantly maize fresh and dry weight at 60 days harvest. The highest rate of Sulfur application recorded the highest fresh weight and dry weight. Salem *et al.* (2017) found that sulfur application by rate 200 kg/fed increased grain and straw yield by about 21.1 and 19.6 %. While 250 kg S/fed had increased these yields by rates 29.96 and 31.90%, respectively. Sulfur application at the rate of 300 kg/fed, resulted in significant percent increases in grain yield, straw yield and biological yield estimated by 24.3%, 24.7% and 24.5%, as compared with the control. Also, sulfur application, at the rate of 300 kg S/fed, induced significant improvement and resulted in 22.31% and 23.33% increases in N and P uptake by maize grains as compared with the zero S (Hassanein *et al.*, 2017).Applications of silver (Ag) and sulfur (S) nanoparticles (20 nm; 0.05, 0.5, 1.5, 2 and 2.5 mg

L^{-1}) suspensions were tested on germination and growth of *Solanum lycopersicum* L. under two levels (150 and 100 mM) of salinity and observed that the germination rate, germination percentage, seedling fresh and dry weights and root length were improved under salinity (Ashour and Mahmoud 2017).

The aim of this study is evaluation the effect of nano sulfur on some soil chemical and physical properties and maize productivity in saline soil.

Materials and methods

A filed experiment was conducted at Sahl El-Hossinia agricultural research station, El-Sharkia Governorate, Egypt, during two summer seasons 2019 and 2020 to study the effect of nano sulfur on soil chemical and physical properties and maize productivity in saline soil. The studied area located at 31° 8' 12.461" N latitude and 31° 52' 15.496" E Longitude. Soil samples from surface layer (0 - 90 cm) was taken, air-dried , ground good mixed , sieved through a 2 mm sieve, kept and analyzed for the physical and chemical soil properties before sowing and after maize harvesting according to the methods described by Klute (1986); Page *et al.* (1982) and Cottenie *et al.* (1982). The main physical and chemical properties before planting were recorded in Table (1).

In both seasons, the experiment was carried out in a complete randomized block design with three replicates. Super phosphate (15.5 % P_2O_5) was added at 200 kg super phosphate/fed during soil preparation. Urea (46 % N) was used as N fertilizer at application rate of 120 kg N/fed, where it's applied in 3 equal doses after 21, 45 and 60 days of planting. Potassium sulphate (48 % K_2O) at 50 kg/fed was added on two equal doses after 21 and 45 days of planting.

Table 1: Physical and chemical properties of soil before planting.

Particle size distribution (%)				Texture		
Sand	**Silt**	**Clay**				
29.24	19.50	51.26		Clay		
Soil depth (cm)	**pH (1:2.5)**	**EC (dSm^{-1})**	**O.M (%)**	**H.C (cm.h^{-1})**	**B.D (g/cm^3)**	**T.P (%)**
0 – 30 cm	8.09	9.01	0.51	0.021	1.29	47.68
30 – 60 cm	8.11	9.03	0.50	0.018	1.31	47.49
60 – 90 cm	8.12	9.07	0.48	0.017	1.32	47.36
Mean	**8.11**	**9.04**	**0.50**	**0.019**	**1.31**	**47.51**
Soil depth (cm)	**Macronutrients (mg/kg)**			**Micronutrients (mg/kg)**		
	N	**P**	**K**	**Fe**	**Mn**	**Zn**
0 – 30 cm	38.05	4.73	172.62	3.01	1.93	0.61
30 – 60 cm	37.70	4.71	171.31	2.97	1.91	0.60
60 – 90 cm	37.11	4.67	169.07	2.96	1.88	0.60
Mean	**37.62**	**4.70**	**171.00**	**2.98**	**1.91**	**0.60**

El-Salam Canal (Nile water mixed with agricultural drainage water 1:1) was the irrigation water resource in the studied area. The main properties of irrigation water were carried out as described by Richards (1954) and the obtained data were recorded in Table (2). The treatments of soil amendments were carried out during soil preparation and mixed with the surface soil (0- 15 cm). The added treatments were as follows:

1. Control (mineral sulfur 100 kg/fed).
2. Nano sulfur (5 kg/fed).
3. Nano sulfur (10 kg/fed).
4. Nano sulfur (15 kg/fed).

Table 2: Irrigation water properties

pH	**EC**	**Cations**				**Anions**			
	(dSm^{-1})	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{and}**	**Cl^{-}**	**CO_3^{2-}**	**HCO_3^{-}**	**SO_4^{2-}**
8.07	1.64	3.21	4.54	8.21	0.43	6.83	-	3.87	5.69

1. Preparation of nano sulfur:

Nano sulfur particles (NSP) were prepared by dissolving of adequate amount of freshly prepared potassium poly sulfide in water dispersion medium containing solvent as ethanol and polymer stabilizer (poly vinyl alcohol). Then corresponding amount of sulfuric acid was added drop-wisely for neutralization with agitation of the reaction system at about 40°C for a specified amount of time, instantaneous white suspension of sulphur nano particles is formed stable for several days for using. The structure of sulfur particles was characterized by a transmission electron microscope(TEM) (JEOL Electron Microscope, Model: JEM-2100), the sulfur nanoparticles prepared via this method have an average diameter of about 20nm, a narrow size distribution, uniform spherical shape, and high purity (Zhao *et al.*, 2006) Fig.(1).

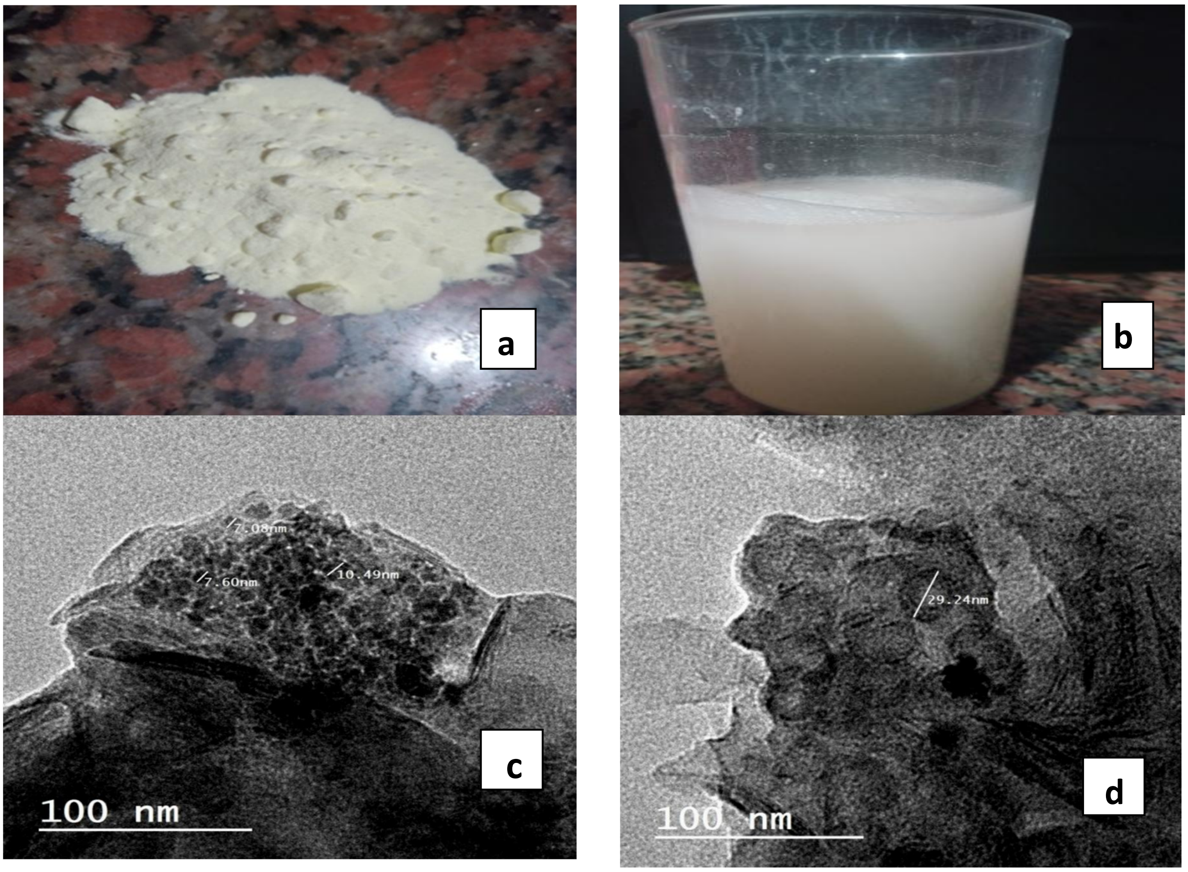

Fig.1: (a) sulfur powder, (b) sulfur nano particle suspension, (c,d) TEM images of different sizes of nano sulfur.

The area of each experimental unit plot was 16 m^2 (4*4 m). Maize (*Zea mays L., var single cross 168*) supplied by Field Crop Res. Inst. ARC, was sown on the 24th of May 2019, and 2020. Maize was harvested on 2 September 2019 and 2020.

After harvest, soil samples have been collected from three layers 0-30, 30-60 and 60-90 cm for all plots. The soil samples were air-dried and analyzed for some chemical characteristics. Soil pH and organic matter were estimated according to the methods described by Page *et al.* (1982). The total soluble salts (EC) were determined in soil paste extract as dsm^{-1} Jackson (1973). The soil content of available macronutrients (N, P, and K) and micronutrients (Fe, Mn, and Zn) in soil was determined according to the methods described by Cottenie *et al.* (1982).Particle size distribution was carried out by ,the pipette method described by Gee and Bauder (1986) using sodium hexametaphosphate as a dispersing agent. Soil bulk density was determined using the undisturbed soil column according to Richards (1954). Total soil porosity was calculated as percentage from the obtained values of real and bulk densities (Richards 1954). Also, field capacity was determined according to the method of Richards (1954).

The oven dried plant part samples were ground and digested using H_2SO_4 and $HClO_4$ acids mixture according to the methods described by (Chapman and Pratt 1961). The plant contents of N, P, K, Fe, Mn and Zn were determined in plant digestion using the methods described by Cottenie *et al.* (1982). Data were statistically analyzed according to one-way analysis of variance (ANOVA) and were determined the statistical significance of the treatment effects at p = 0.05 by using SPSS.

Results and Discussions

1. Soil pH, electrical conductivity (EC) and organic matter content (OM):

It is clear from the data in Table (3), that the soil reaction (pH) values were slightly reduced as a result of nano sulfur application. pH values indicated that the treatment of nano S 15 kg/fed was the best treatment in decreasing pH values. This may be due to the microbial oxidization of sulfur to sulfuric acid that decreased soil reaction pH. This result is in accordance with that obtained by Karimizarchi *et al.* (2014) who found a negative relationship between sulfur application rate and soil pH that reflected successful oxidation of elemental sulfur. Similar conclusions were also reported by Hammad *et al.* (2007) who found that elemental S is oxidized by microorganisms in soil to sulfuric acid which reduces soil pH.

Concerning soil electrical conductivity (EC), data in Table (3) showed that it had been decreased significantly in all the treatments as compared to control. The best treatment decreased EC values was nano S 15 kg/fed followed by nano S 10 kg/fed then nano S 5 kg/fed, these treatments decreased soil EC values by rates 36 , 27 and 15 %, respectively as compared to control. This decrease in EC values was may be due to that sulfur application as an amendment could be oxidized biologically in soil to produce H_2SO_4 which is capable to mobilize base cations from the soil. The H^{and} ion in the acidic water displaces the cations from the exchange sites, reduces the exchangeable cations and increases the concentrations of these cations in the soil solution then washed out by irrigation water, hence decreasing soil EC. Also, there was a significant decrease in EC values between the studied soil layers. The surface layer (0-30 cm) has the lowest EC values. This may be due to that the added treatments were mixed with the soil in this layer, and also due to leaching of soluble salts from surface layer to the other subsurface layers. Similar results were obtained by Mahmoud *et al.* (2013). Also Zayed *et al.* (2017) found that application of 600 kg S/ha significantly decreased the values of pH and EC due to sulfur oxidation to sulfuric acid which in turn reacts with lime present in the soil to soluble calcium form which remove Na^+ from soil absorption complex leading to a decrease in EC values. These results are in agreement with those of Ashour and Mahmoud (2017) who deduced a decrease in EC values after application of nano silver and sulfur.

Table 3: Soil pH, EC and OM content in the soil as affected by the studied treatments

Treatments	Soil depth (cm)	pH (1:2.5)	EC (dSm^{-1})	OM (%)
Control	0 – 30	8.10	7.86	0.52
	30 – 60	8.12	7.92	0.51
	60 – 90	8.10	7.99	0.51
	Mean	**8.11**	**7.92^d**	**0.51^c**
Nano S (5 kg/fed)	0 – 30	8.01	6.70	0.56
	30 – 60	7.99	6.76	0.55
	60 – 90	8.02	6.79	0.54
	Mean	**8.01**	**6.75^c**	**0.55^b**
Nano S (10 kg/fed)	0 – 30	7.96	5.79	0.59
	30 – 60	7.95	5.81	0.58
	60 – 90	7.95	5.84	0.56
	Mean	**7.95**	**5.81^b**	**0.58^b**
Nano S (15 kg/fed)	0 – 30	7.89	5.00	0.65
	30 – 60	7.90	5.03	0.64
	60 – 90	7.93	5.08	0.61
	Mean	**7.91**	**5.04^a**	**0.63^a**
	L.S.D (0.05)	-	A = 0.05	A = 0.03
		-	B = 0.01	B = ns

A = Soil treatment B = Soil depth

2. Hydraulic conductivity, bulk density and total porosity in the studied soil as affected by different treatments

It is clear from the data illustrated in Table (4) that there was a significant increase in the values of hydraulic conductivity and total porosity, while there was a significant decrease in bulk density values in all of the added treatments as compared to control. While there was no significant difference in values of hydraulic conductivity, bulk density and total porosity between soil layers.

Nano S 15 kg/fed was the best treatment that improved these properties followed by nano S 10 kg/fed. It decreased bulk density values by about 9 %, while it increased values of hydraulic conductivity and total porosity by percents 100 and 12 % respectively.

Elemental sulfur can be oxidized by many soil microorganisms and forming sulfuric acid, consequently it react with soil $CaCO_3$ resulting in $CaSO_4$. The latter can be ionized to Ca^{2+} and SO_4^{2-}, then Ca^{2+} can be improved soil aggregation and permeability. These results are in agreement with those by Awadalla *et al.* (2003). Also, the improvement of these physical properties may be due to oxidation of elemental sulfur to sulfuric acid which in turn reacts with lime present in the soil to soluble calcium form which removes Na^+ from soil absorption complex leading to improving soil aggregates and drainage system that leading to improvement of bulk density (Helmy *et al.*, 2013).

Table 4: Hydraulic conductivity, bulk density and total porosity in the studied soil as affected by different treatments

Treatments	Soil depth (cm)	H.C ($cm.h^{-1}$)	B.D (g/cm^3)	T.P (%)
Control	0 – 30	0.021	1.27	50.16
	30 – 60	0.020	1.29	49.36
	60 – 90	0.021	1.30	49.13
	Mean	**0.021^d**	**1.29^d**	**49.55^d**
Nano S (5 kg/fed)	0 – 30	0.032	1.23	52.06
	30 – 60	0.030	1.24	51.52
	60 – 90	0.029	1.24	51.28
	Mean	**0.030^c**	**1.24^c**	**51.62^c**
Nano S (10 kg/fed)	0 – 30	0.037	1.18	53.96
	30 – 60	0.036	1.20	53.83
	60 – 90	0.035	1.22	53.47
	Mean	**0.036^b**	**1.20^b**	**53.75^b**
Nano S (15 kg/fed)	0 – 30	0.045	1.17	56.13
	30 – 60	0.042	1.16	55.76
	60 – 90	0.041	1.17	55.51
	Mean	**0.043^a**	**1.17^a**	**55.80^a**
	L.S.D (0.05)	A = 0.004 B = ns	A = 0.02 B = ns	A = 0.18 B = ns

A = Soil treatment B = Soil depth

3. Soil available macro and micronutrients:

It can be deduced from the data in Table (5) that there was no significant difference in values of soil available macro and micronutrients between soil layers, while the used sulfur treatments significantly increased these values as compared to control. The best treatment in increasing the macro and micronutrients concentrations was nano S 15 kg/fed, followed by nano S 10 kg/fed, then nano S 5 kg/fed. It is clear from these values, that the treatment nano S 15 kg/fed had increased the soil available concentrations of nitrogen, phosphorous and potassium by about 17 , 29 and 20 % than control, respectively. While this treatment increased the soil available concentration of iron, manganese and zinc by about 24 , 27 and 29 % than control, respectively.

This result is in agreement with that of Karimizarchi *et al.* (2014) that deduced a significance increase in available concentrations of macro and macronutrients after sulfur application by rates 0.5 , 1 and 2 $g.kg^{-1}$. The increase in P-availability due to S application was obvious by the S role in decreasing soil pH, which helped in transformation of insoluble P to available form. The considerable increase in release of soil nutrients can be attributed to the effect of elemental S to amend soil pH, and the release of plant nutrients from unavailable pools to soil solution.

In line with our findings, it is well accepted that high concentrations of hydrogen ions may increase plant nutrient availability in soils by displacement of cations from exchangeable sites changing the oxidation state of nutrients; high concentrations of hydrogen may also enhance nutrient uptake by plants (Viani *et al.* 2014). This increase in soil content of available nutrients may be due to the controlled, slow release and lowest loss of nanofertilizers compared to conventional fertilizers, it has been reported that key macronutrient elements, including N, P, and K, applied to the soil are lost by percents ranged between 30–45 %, causing a considerable loss of these nutrients (Chen and Wei 2018).

Table 5: Available macro and micronutrients in the soil as affected by the studied treatments.

Treatments	Soil depth (cm)	Available macronutrients ($mg.kg^{-1}$)			Available micronutrients ($mg.kg^{-1}$)		
		N	P	K	Fe	Mn	Zn
Control	0 – 30	41.91	5.41	178.72	3.41	2.49	0.66
	30 – 60	39.58	5.26	180.60	3.37	2.45	0.64
	60 – 90	38.32	5.13	181.96	3.32	2.42	0.60
	Mean	**39.94^{c}**	**5.27^{d}**	**180.43^{d}**	**3.37^{d}**	**2.45^{d}**	**0.63^{d}**
Nano S (5 kg/fed)	0 – 30	43.21	5.81	194.96	3.83	2.80	0.70
	30 – 60	41.80	5.88	192.62	3.80	2.74	0.69
	60 – 90	39.72	5.94	191.84	3.78	2.70	0.69
	Mean	**41.58^{c}**	**5.88^{c}**	**193.14^{c}**	**3.80^{c}**	**2.75^{c}**	**0.69^{c}**
Nano S (10 kg/fed)	0 – 30	44.61	6.46	209.15	4.05	2.91	0.73
	30 – 60	43.04	6.33	207.30	4.02	2.92	0.75
	60 – 90	43.37	6.42	208.91	4.00	2.94	0.73
	Mean	**43.67^{b}**	**6.40^{b}**	**208.45^{b}**	**4.02^{b}**	**2.92^{b}**	**0.74^{b}**
Nano S (15 kg/fed)	0 – 30	47.26	6.91	216.51	4.17	3.16	0.83
	30 – 60	47.33	6.82	218.90	4.18	3.12	0.80
	60 – 90	46.12	6.69	215.87	4.20	3.09	0.79
	Mean	**46.90^{a}**	**6.81^{a}**	**217.09^{a}**	**4.18^{a}**	**3.12^{a}**	**0.81^{a}**
	L.S.D (0.05)	A = 1.22 B = ns	A = 0.12 B = ns	A = 1.90 B = ns	A = 0.08 B = ns	A = 0.13 B = ns	A = 0.03 B = ns

A = Soil treatment B = Soil depth

4. Macro and micronutrients contents in the maize seeds as affected by the studied treatments:

The data of macro and micronutrients contents in maize grains (Table 6) showed that all treatments significantly increased these contents as compared to control. The best treatment was nano S 15 kg/fed. It increased the grain contents of N, P and K by percents 25, 22 and 24 %, respectively. While the same treatment increased the grain concentrations of Fe, Mn and Zn by percents 20, 29 and 26 %, respectively.

Table 6: macro and micronutrients content in the maize seeds as affected by the studied treatments.

Treatments	Macronutrients (%)			Micronutrients ($mg.kg^{-1}$)		
	N	P	K	Fe	Mn	Zn
Control	1.75^{d}	0.26^{c}	1.70^{d}	68.23^{d}	44.38^{d}	30.61^{d}
Nano S(5 kg/fed)	1.92^{c}	0.30^{ab}	1.89^{c}	75.04^{c}	50.82^{c}	33.35^{c}
Nano S(10 kg/fed)	2.01^{b}	0.32^{a}	2.00^{b}	77.43^{b}	53.46^{b}	35.43^{b}
Nano S(15 kg/fed)	2.18^{a}	0.33^{a}	2.10^{a}	81.61^{a}	57.20^{a}	38.51^{a}
L.S.D (0.05)	0.08	0.03	0.07	1.04	0.32	0.75

These results are in agreement with those of Fatma *et al.* (2019) who found that maize shoot P concentration increased by 16 and 69 %, while root P concentration increased by 27 at 50 and 100 kg S Fed^{-1}.These findings are in line with those of Ali, (2008) who observed that the N and P uptake by maize grains were affected significantly by S-application. Also, Eisa *et al.* (2003) recorded that sulfur application exhibited a relatively high content of N, P and K in maize grains and straw. Also, Hassanein *et al.* (2017) found that sulfur application, at the rate of 300 kg S/fed, induced significant improvement and resulted in 22.31 % and 23.33 % increases in N and P uptake by maize grains as compared with the zero S. The increase in plant nutrients after application of nanofertilizers was may be due to that these nutrients are encapsulated/coated with nanomaterial that led to control and slow delivery of one or more nutrients in order to satisfy the imperative nutrient requirements of plants. This advantage of slow nutrient delivery makes nutrients can be released over 40-50 days in a slow release fashion rather than the 4-10 days by the conventional fertilizers (Chen and Wei 2018).

5. Maize productivity as affected by the used treatments:

The data of maize yield as illustrated in Table (7) show that all of the used sulfur additions significantly increased the yield parameters of maize as compared to control. The best addition was nano S 15 kg/fed, it increased the grains yield, straw yield and weight of 100 seeds by about 38 , 34 and 23 %, respectively. The increase in maize yield can be attributed to an increase in soil nutrients availability due to a moderate reduction in soil pH that led to increase of plant uptake of macro and micronutrients.

This result is in agreement with that of Karimizarchi *et al.* (2014) who found a significance increase in maize biomass production by about 36 and 45 % after using sulfur as soil amendment by rates 0.5 and 1 $g.kg^{-1}$, respectively. Also Fatma *et al.* (2019) deduced that increasing S application increased significantly maize fresh and dry weight at 60 days harvest. The highest rate of Sulfur application recorded the highest fresh weight and dry weight. Also Hassanein *et al.* (2017) found that sulfur application seasonally, at the rate of 300 kg/fed, resulted in significant percent increases in grain yield, straw yield and biological yield estimated by 24.3%, 24.7% and 24.5%, as compared with the control. This increase in corn productivity after using nano sulfur as compared to mineral sulfur (control) may be due to that application of nano sulfur caused increase in the germination rate, germination percentage, seedling fresh and dry weights and root length were improved under salinity (Ashour and Mahmoud 2017).

Table 7: Maize productivity as affected by the used treatments

Treatments	Grain yield ($ton.fed^{-1}$)	Straw yield ($ton.fed^{-1}$)	Weight of 100 seeds (gm)
Control	3.02^{d}	2.10^{d}	26.21^{d}
Nano S (5 kg/fed)	3.56^{c}	2.47^{c}	28.31^{c}
Nano S (10 kg/fed)	3.74^{b}	2.61^{b}	29.87^{b}
Nano S (15 kg/fed)	4.17^{a}	2.82^{a}	32.25^{a}
L.S.D (0.05)	0.07	0.10	0.18

Conclusion

The utilization of nano sulphur as a cost effective and readily available source of soil amendment at sufficient rates is recommended to address soil fertility problems. The improved maize yield in soils receiving elemental sulphur was due to an increase in macro (N, P and K) and micronutrients (Fe, Mn and Zn) concentrations at a sufficient level. This is attributed to the decrease in soil pH resulting from the acidifying effect of nano sulphur. Also, nano sulfur can improve soil physical properties, it can be oxidized by many soil microorganisms and forming sulfuric acid, consequently it react with soil $CaCO_3$ resulting in $CaSO_4$. The latter can be ionized to Ca^{2+} and SO_4^{2-}, then Ca^{2+} can be improved soil aggregation and permeability. The effect of nano sulfur was better than that of mineral sulfur due to the unique properties of nanomaterials such as high surface-to-volume ratio, controlled-release kinetics to targeted sites.

References

Abdallah, M., L. Dubousset, F. Meuriot, P. Etienne, J.C. Avice,and A. Ourry, 2010. Effect of mineral sulphur availability on nitrogen and sulphur uptake and remobilization during the vegetative growth of *Brassica napus L.* J. Exp. Bot., 61(10): 2335-2346.

Abdel-Halim, A.K., 2001. Effect of sulphur application on the main morophological, physical, chemical, and micromorphological properties of soils, and on production of some field crops. M.Sc. Thesis, Fac. Agric., Alex. Univ., Egypt.

Ahmed, K., G. Qadir, A.R. Jami, A.I. Saqib, M.Q. Nawaz, M.A. Kamal, and E. Haq, 2016. Strategies for soil amelioration using sulphur in salt affected soil. Cercetari Agronomice in Moldova, 3 (167): 5-16.

Ali, M.M.A., 2008. The use of some microbial and agricultural treatments for improving productivity of sandy calcareous soils.M. Se. Thesis, Dept. of Soils and Water, Assiut University. Egypt.

Ashour H.A. and A.W.M. Mahmoud, 2017. Response of *Jatropha integerrima* plants irrigated with different levels of saline water to nano silicon and gypsum, J. Agric. Stud. 5, 136–160.

Awadalla, A.A., M.M. Salib and S.P. Ibrahim, 2003. Response of maize yield grown on calcareous soil to some organic and inorganic amendments under irrigation with saline soil drainage water. Egypt. J. Appl Sci., 18 (3): 366-381.

Chapman, H.D. and P.F. Pratt, 1961. Methods of Analysis for Soils, Plants and Waters. Agric. Pupl. Univ.,of California, Reversid.

Chen, X.W. and X. Wei, 2018. Controlled-release Fertilizers As a Means to Reduce Nitrogen Leaching and Runoff in Container-grown Plant Production, Nitrogen in Agriculture-Updates, InTech, 33–52.

Cottenie, A., M. Verloo, L. Kiekens, G. Velgh and R. Camerlynch, 1982. Chemical analysis of plants and soils, Lab". Anal Agrochem State Univ. Ghent Belgium, 63

Eisa, S.A., Sh. El-Borhamy and A. El-Basouny, 2003. Efficiency of mineral fertilizers and elemental sulfur application for maize grown on calcareous soil. Egypt. J. Appl. Sci., 18 (12B): 793-804.

El-Tarabily, K.A., A.S. Abdou, E.S. Maher,and M. Satoshi, 2006. Isolation and characterization of sulfuroxidizing bacteria, including strains of Rhizobium, from calcareous sandy soils and their effects on nutrient uptake and growth of maize (*Zea mays* L.). Aus. J. Agric. Res., 57(1):101-111.

Fatma K. Sherif, H.A. El-Attar and Hoda A. Argeaa, 2019. Monitoring P Efficiencies and Corn Yield by VAM and Sulfur Application in Calcareous Soils. Alexandria Science Exchange Journal, 34(1): 44-54.

Fischer, T., M. Veste, W. Wiehe and P. Lange, 2010. Water repellency and pore clogging atearly successional stages of microbiotic crusts on inland dunes, Brandenburg, NEGermany. CATENA 80 (1), 47–52.

Gee, G.W. and J.W. Bauder, 1986. Particle size analysis in Methods of Soil Analysis (Klute, Ed. Part1.Agron.9. 15: 383- 409. Am. Soc. Agron. Madison. Wisconsin. U.S.A).

Gharmakher, H.N., J.M. Machet, N. Beaudoin, and S. Recous, 2009. Estimation of sulphur mineralization and relationships withnitrogen and carbon in soils. Biol. Fertil. Soils. 45: 297-304.

Giweta M., M.F. Dyck, S.S. Malhi, D. Puurveen and J.A. Robertson, 2014. Long-term S-fertilization increases carbon sequestration in a sulfur-deficient soil. Can. J. Soil. Sci. 94: 295-301.

Hammad, S.A., Kh.H. El-Hamdi, M.A. Abou El-Soud, and G.M.A. El-Sanat, 2007. Effect of some soil amendments application on the productivity of wheat and soybean, mobility and availability of nitrogen. J. Agric. Sci. Mansoura Univ. 32 (9): 7953-7965 .

Hassanein, G.H., M.M. El-Dsouky, M.M.M. Ahmed and M.M.A.A. Zahran, 2017. Effect of some Cultural Treatments, Elemental Sulfur Application and N-fertilization Levels on the Productivity of Maize and Fertility of Calcareous Sandy Soil.Assiut J. Agric. Sci., 48 (1): (286-302).

Helmy, A.M., Kh.A. Shaban, and M.G. Abdel Kader, 2013. Rhizobium bio fertilization with orwithout mineral fertilization for a new cowpea cultivar (Kafer El-Sheikh) grown under salineconditions. Zagazig J. of Agric. Res., 40 (5): 891- 906.

Hosseini, K.M., A.A. Powell, and I.J. Bimgham, 2003.The interaction between salinity stress and seed vigor during germination of soybean seeds. Seed Sci. Technol. 31,715-725.

Jackson, M.L., 1973. Soil Chemical Analysis. Prentice-Hall of Indian Private limited. New Delhi, India.

Karimizarchi, M., H. Aminuddin, M.Y. Khanif and O. Radziah, 2014. Elemental Sulphur Application Effects on Nutrient Availability and Sweet Maize (*Zea mays L.*) Response in a High pH Soil of Malaysia. Malaysian Journal of Soil Science, 18: 75-86.

Kim D.Y., A. Kadam, S. Shinde, R.G. Saratale, J. Patra and G. Ghodake, 2018. Recent developments in nanotechnology transforming the agricultural sector: a transition replete with opportunities, J. Sci. Food Agric. 98: 849–864.

Klute, A.,1986. Methods of Analysis.Part 1, Soil Physical Properties, ASA and SSSA, Madison, WI.

Mahmood, A.M., N. Yazdanpanah, L.R. Sinobas, E. Pazira and A. Neshat, 2013. Reclamation of calcareous saline sodic soil with different amendments (I): Redistribution of soluble cations within the soil profile. Agric. Water Management 120:30 – 38.

Nie, S., S. Huang, S. Zhang, D. Guo, Q. Zhang, and D. Bao, 2012.Effects of various fertilizations on soil organic carbon and total nitrogen in winter wheat-summer corn rotation in the Huang-Huai-Hai Plain of China, J. Food. Agric. Environ. 10: 567-572.

Page, A.L., R.H. Miller, and D.R. Keeney, 1982. "Methods of soil analysis .II., Chemical and Microbiogical properties". 2nd Ed. Madison, Wisconsim . U.S.A.

Perez, A.A., E.M. Lopez, C. Guzman and K. Esquivel, 2018. A general overview of the benefits and possible negative effects of the nanotechnology in horticulture, Sci. Hortic. 238: 126–137.

Prasad, R., A. Bhattacharyya and Q.D. Nguyen, 2017. Nanotechnology in sustainable agriculture: recent developments, challenges, and perspectives, Front. Microbiol, 8: 1014.

Richards, A.L., 1954. Diagnosis and Improvement of Saline and Alkali Soils U.S. Dept. Agric. Hand Book. No 60, U.S.Covt. Print. Office, Washington, D.C.

Salem, H.M., A.H. Abd-El-Hameed, R.A. Hussien and M.S. Mohamed, 2017. Implications of applying superphosphate-P, rock-P, compost and sulphur singly or in combinations to Maize (*Zea mays*) on yield and NPK content. International Conference on Plant Nutrition and Soil Science (PNSS2016).

Tan W., W. Du, A.C. Barrios, R. Armendariz, N.Z. Mena, Z. Ji, C.H. Chang, J.I. Zink, J.A. Viezcas, J.R. Videa and J.L. Torresdey, 2017. Surface coating changes the physiological and biochemical impacts of nano-TiO2 in basil (Ocimum basilicum) plants, Environ. Pollut. 222: 64–72.

Viani, R.A.G., R.R. Rodriguesb, T.E. Dawsonc, H. Lambersd and R.S. Oliveira, 2014. Soil pH accounts for differences in species distribution and leaf nutrient concentrations of Brazilian woodland savannah and seasonally dry forest species. Perspectives in Plant Ecology, Evolution and Systematics.http://dx.doi. org/10.1016/j.ppees.2014.02.001.

Yurembram, G.S., H. Chandra, and V. Kumar, 2015. Status ofavailable macro and micronutrients in the soils of someshwarwatershed in Almora district of Uttarakhan. The Ecoscan. 9(3&4):725-730.

Zaman, B., A. Ali, M. Salim, and B.H. Niazi, 2002. Role of sulphur for potassium/sodium ratio in sunflower under saline conditions. Helia, 25(37): 69-78.

Zayed, B.A., M.S.M. Abdel-Aal and G.A Deweedar, 2017. Response of Rice Yield and Soil to Sulfur Application under Water and Salinity Stresses. Egypt. J. Agron. 39(3):239- 249.

Zhao, Y. J., S. Yang, K. Yu, Z. Wang, and H. Zhang, 2006. Powder Tech., 162, 83.