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Influence of Sulphur Compost Application on Some Chemical Properties of Calcareous Soil and Consequent Responses of *HordeumVulgare* L. Plants

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AMELIORATION of calcareous soil is essential to increase crop production and preserve the ecological environment in arid and semiarid regions. A pot experiment was carried out at the greenhouse of Soil Science Department, Faculty of Agriculture, Menoufia University, Shebin El-Kom, Egypt to evaluate the efficiency of amending a calcareous soil with two type of sulphur compost for improving soil properties and its content of available macro-and micro-nutrients and growth of barley plants. Two types of sulphur compost were produced, the first one from adding S to compost during composting (DS) process and the other from mixing S with non-sulfurized compost after composting (AS). The additional S rates for both two types of compost were 1.0, 2.0 and 3.0 %. Before planting, each one of sulphur compost was applied at rates of 0.0, 10.0 and 20.0g kg^{-1} and mixed well with the soil. After 70 days of planting the plants were harvested. Dry matter yield of the harvested and its content of nutrients were determined. Also, a soil sample was taken and analyzed for some chemical properties and its content of available nutrients.The data showed that, compared to the control, both two types of applied sulphur compost had a positive effect on the studied soil properties and the growth parameters of cultivated plants. A decrease in calcareous soil pH, EC and the content of $CaCO_3$was observed, however an increase in soil CEC, OM and available macro- and micronutrients as a result of sulphur compost applications was induced. Sulphur compost applications were associated by an increase in plant dry matter yield and its content of macro- and micronutrients. So, the ameliorative influence of sulphur compost especially that carried out during the composting period on chemical properties and productivity of calcareous soil clearly occurred.

Keywords: Calcareous soil, Sulphur compost, Nutrients availability, Nutrients uptake and Barley plant.

Introduction

The calcareous soils in Egypt are estimated to be around 0.65 million feddans (feddan= 4200 m^2) (Hassan, 2012). The soils are considered calcareous when they contain calcium carbonate under partial pressure for CO_2 in the air (Balba, 1987). It was added that, although the content of calcium carbonate may be very few (5 g kg^{-1}) for instance, yet this soil is considered calcareous, and there are some calcareous soils contain 70% calcium carbonate. Obreza and Morgan (2008) defined the calcareous soils as alkaline (pH > 7.0) due to the presence of excess calcium carbonate ($CaCO_3$). These soils can contain from 1% to more than 25% $CaCO_3$ by weight, with pH in range of 7.6 to 8.4. Cultivation of calcareous soils presents many challenges, such as low water holding capacity, high infiltration rate, poor structure, low organic matter (OM) and clay content, low CEC, loss of nutrients via leaching or deep percolation, surface crusting and cracking, high pH and loss of nitrogen (N) fertilizers, low availability of nutrients particularly phosphorous (P) and micronutrients,

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and a nutritional imbalance between elements such as potassium (K), magnesium (Mg) and calcium (Ca) (El-Hady and Abo-Sedera, 2006). Under such severe conditions, desired yield levels are difficult to attain.

The addition of organic amendments improves soil chemical and physical properties, initiates nutrient cycling, and provides a functioning environment for vegetation. The formed organic acids of compost creating a favorable environment for solubilization of macro and micronutrients (Nada, 2011). An increase in total C in the form of OM leads to an increase in CEC, thereby increasing the number of exchange sites for available mineral nutrients for plant uptake (Pandey and Shukla, 2006). Addition of compost to sandy calcareous soil increased N, P and K availability in the soil after cultivation, while the values of pH slightly decreased (Mohamed et al., 2008). Depending on the pH of the compost and of the native soil, compost addition may raise or lower the soil/compost blend's pH. Ashour (2003) found that, the application of organic manure in calcareous soil reduced the EC value of the soil paste extract. Abdel-Aziz (2010) showed that, the highest mean values of available N, P and K were owing to application of organic conditioner. Nada (2011) and El-Gamal (2015) reported the application of compost in soil significantly improved contents in soil available N, P and K as compared with control. Abu-Elela (2002) found that, the application different organic amendments on calcareous soil significantly increased DTPA- extractable micronutrients (Fe, Zn, Mn and Cu).The applied organic matter reduced soil pH and consequent by increased the available micronutrients contents. The metal-organic complex formed might account for such a result. While, Li et al. (2007) mentioned that the Cu and Mn concentration did not significantly change, but Zn and Fe concentration increased with increasing soil organic matter content.

Sulfur present in soil in the form of organic (ester sulphate and carbon bounded sulfur) and in inorganic form (sulphate and sulphite), but it is primarily taken up by the plant as sulphate (SO_4^{-2}) ion. Awadalla et al. (2007) noted that, the lower values of EC, pH, SAR and ESP in calcareous soil were attained by increasing rate of sulphur. Addition of sulphur at different rates in calcareous soil gave the highest values of CEC (Negm et al., 2002). El-Sherbiny (2007) found that soil pH and EC values of soil profile gave a high significant decrease especially the soil with addition sulphur. Also, Shaban and EL-Sherief (2007) mentioned that, the relative increase in the released nutrients of N, P, K, Fe, Zn, Mn and Cu occurred at the highest rates of applied sulphur. Applied S and compost together showed a slight increase in the values of available N, P and K (Abdel-Aziz, 2010).

Hoda (2010) found that the application of organic matter combined with S greatly increased available NPK content. Zaman et al. (2011) reported that most of the growth and yield parameters increased progressively with increasing the rate of sulphur application. Also, Fathi et al. (2015) concluded that the application of organic manure and elemental sulphur caused a significant increase in growth, yield of sesame and its components than the control treatment.

Barley (*HordeumVulgare* L.) is one of the most dependable cereal crops in harsh environment that is grown in semiarid areas as well as in cold, short- season areas. Local varieties and landraces of barley occupy nearly 80% of the cultivated areas in west Asia and North Africa and these should be collected before they are losing (Qadir et al., 2008).

This study mainly carried out to evaluate the effect of two types of sulphur-compost which treated with S during and after composting on some chemical properties and the content of available macro-and micronutrients of calcareous soil. Also, the effect of sulphur compost on plant growth parameters and its content of nutrients was studied.

Materials and Methods

This experiment was carried out at greenhouse of Soil Sciences Department, Faculty of Agriculture, Menoufia University, Shebin El-Kom, Egypt to study the timing effect of mixing the sulphur with the composted organic materials on calcareous soil properties and plant growth.

Soil sampling

Surface soil samples (0- 20 cm) represented newly reclaimed calcareous soils of Egypt were collected from Village 6, Abu El-Matamir (30°54'55.31"N, 30°09'31.95"E), EL-Behara Governorate, Egypt. The collected soil samples were air-dried, ground, mixed together and then sieved through a 2 mm sieve. A part of the prepared fine soil was analyzed for some physical and chemical properties as well as its content of available macro- and micronutrients according to the methods described by Klute and Dirksen (1986), Cottenie et al. (1982) and Page et al. (1982). The obtained data are recorded in Table 1. Another portion of this fine fraction was used in the greenhouse experiments as mentioned in the following sections.

The applied compost

The used compost was prepared under the greenhouse conditions of Faculty of Agriculture, Menoufia University, Shebin El-Kom, Egypt. The compost was prepared in polyethylene pots of 50 cm diameters, and 100 cm depth, each pot contained about 20 kg of air-dried mixture maize stalks (MS) and farmyard manure (FYM). The compost raw materials were mixed at C/N ratio of 30:1, which equivalent the 1.86: 1.0 ratio of MS: FYM (w/w). The mixture was divided separately to 4 partsto produce four types of sulphur compost. The four sections of sulphur compost were, CS0 (compost mixtures without S), CS1 (compost mixture and 1.0 % S w/w), CS2 (compost mixture and 2.0 % S) and CS3 (compost mixture and 3.0 % S). An activating mixture containing 3.2g $Ca(H_2PO_4)_2$, 10g $CaCO_3$, 0.32g urea and 100 m/l of fresh fertile soil-water suspension (1:5) was added. Each pile was properly moistened to reach about (50- 60%) of its water holding capacity and left to decompose for 60 days. During this period, all piles were turned upside down every 15 days starting from the top and sides into the center to enhance the aerobic decay process. Additional water was sprayed during the turning process to keep moisture content of each pile at almost 60 % of water holding capacity. Representative sample of heaps were manually taken at the end of composting period (60 days). These samples were air dried, ground and analyzed for chemical properties (pH, EC , its content of OM and its Total-N), also their available macronutrients (N, P, K, Ca, Mg and S) and micronutrients (Fe, Zn, Mn and Cu) contents were estimated according to the methods described by Cottenie et al. (1982) and Page et al. (1982). The obtained data were recorded in Table 2.

TABLE 1. Some physical and chemical properties and available nutrients content of the used calcareous soil

Soil physiochemical properties

Particle size distribution (%)			**Textural grade**	**pH**	**OM** (%)	**$CaCO_3$**(%)	**CEC** ($cmolkg^{-1}$)
Sand	**Silt**	**Clay**					
78.50	10.30	11.20	Sandy	8.40	0.55	13.95	10.20

Soil salinity

EC (dSm^{-1})	**Soluble cations** ($meqL^{-1}$)				**Soluble anions** ($meqL^{-1}$)			
	Ca^{2+}	**Mg^{2+}**	**K^+**	**Na^+**	**CO_3^{2-}**	**HCO_3^-**	**Cl^-**	**SO_4^{2-}**
1.42	3.32	1.40	0.12	9.10	0.00	3.15	6.90	3.89

Soil available nutrients ($mg\ kg^{-1}$)

Available macronutrients						**Available micronutrients**			
N	**P**	**K**	**S**	**Ca**	**Mg**	**Fe**	**Zn**	**Mn**	**Cu**
45.25	4.35	925.00	7.62	20.28	10.42	4.90	1.89	6.25	0.78

TABLE 2. Some physical and chemical properties and available nutrients content of the used sulphur compost

Compost types	pH	EC (dSm^{-1})	OM (%)	OC (%)	TN (%)	C/N ratio
CS0	6.88	2.24	42.65	24.74	1.60	15.46
CS1	6.88	2.54	41.55	24.10	1.67	14.43
CS2	6.78	2.63	40.10	23.26	1.75	13.29
CS3	6.64	2.74	38.50	22.33	1.81	12.34

Compost types	Available macronutrients ($mgkg^{-1}$)						Available micronutrients ($mgkg^{-1}$)			
	N	P	K	S	Ca	Mg	Fe	Zn	Mn	Cu
CS0	888.0	711.0	2016.0	296.0	694.0	5913.0	403.0	61.0	518.0	17.0
CS1	905.0	739.0	2041.0	10980.0	694.0	5245.0	508.0	66.0	523.0	20.0
CS2	945.0	827.0	2114.0	20740.0	693.0	4792.0	650.0	69.0	529.0	26.0
CS3	1003.0	797.0	2262.0	29910.0	649.0	4731.0	811.0	72.0	618.0	28.0

CS0= compost without sulphur, CS1= compost with 1% sulphur, CS2 = compost with 2 % Sulphur, CS3 = compost with 3 % Sulphur, EC = electrical conductivity, OC = organic Carbon, TN = total nitrogen.

Pot experiment

The studied treatments were arranged in three way completely randomize blocks design with three replicates. A 54 plastic pots with 20 cm diameter and 25 cm depth were used. Each pot was filled with 5 kg of fine calcareous soil. The pots were divided into two main groups (27 pots/ main group) representing treatments of sulphur compost types. The first main group was the compost treated with S during composting (DS), while the second main group was the non-sulfurized compost mixed with S after composting (AS). The pots of each main group were divided into three subgroups (9 pot/ subgroup) representing compost treated during and/or composting with sulphur at 1.0%, 2.0% and 3.0% mixed ratios. After that the pots of each subgroup were divided into three sub subgroups (3 pots or replicates/ sub subgroup) representing application rates of each type of sulphur compost (0.0, 10.0 and 20.0 gkg^{-1}). All treatments of compost and sulphur were carried out separately before planting. Also, before planting super phosphate (15.5% P_2O_5) was applied at rate of 200 kg/fed (200 mg/kg).

Each pot was sown by 10 grains of barley plant (*Hordeum vulgar* L.) variety Giza 123 at 2 cm depth in 20 November 2015. The pots were irrigated with tap water at 60 % of WHC for each treatment. After complete germination, the plants in each pot were thinned at 5 plants. Irrigation water was added every 5 days to keep the moisture content at 60% WHC. After 20 days of planting the pots were fertilized by ammonium nitrate (33.5 % N) at rate of 100 kg/fed (100 mg/kg). At the same time, the pot was received potassium chloride (48% K_2O) at rate of 100 kg/fed (100 mg/kg). Another and equal dose of ammonium nitrate and potassium chloride was added after 42 days of planting. All N and K applications were carried out with irrigation water. At the end of the experimental period (70 days from sowing), the plants of each pot were harvested, washed up with tap water to remove any soil particles, then separated to roots and shoots. Afterwards, the plants portioned were air-dried, then divided into two parts. The first one was dried at 105 °C to determine the dry weight and the second parts were dried at 70 °C to determine its mineral composition, after that ground and kept for chemical analysis.

Dried plant samples (equivalent to 0.5 gm) were digested with a mixture of concentrated sulphuric (H_2SO_4) acid and perchloric acid ($HClO_4$) at a ratio of 3:1 according to Chapman and Pratt (1961). Then, the plant digests were diluted with distilled water to a volume of 100 mL. Aliquots from this digest was analyzed for the content of macro and micronutrients, according to Cottenie et al. (1982). Also, soil samples were taken separately from each replicate and prepared for determining the selected soil chemical properties and its content of available macro- and micronutrients according to the above-mentioned standard methods.

Statistical analysis

Obtained data were statistically analyzed according to Snedecor and Cochran (1989). The Duncan's Multiple Range test (Duncan, 1955) was used to compare different treatment means in each group of means to see which are significantly different. Significantly different was calculated at a 5% level of probability. Also, correlation coefficient analysis was carried out between some of selected soil properties.

Results and Discussion

Effect of the studied compost treatments on soil properties

The presented data in Table 3 show that the beneficial effect of the applied DS compost on the mentioned determined parameters excelled that one of the AS composts. These effects of decreasing soil pH, EC and $CaCO_3$ and increasing soil OM and CEC were more significant in favor of DS than AS treatments. For both types of applied sulphur compost (DS and AS), it was found that increasing mixing rate of S was associated by a more significantly decrease in soil pH, EC and its content (%) of $CaCO_3$. While, soil CEC and OM content were enhanced significantly with increasing addition rates of sulphur to the applied compost. The influence of the applied rates of compost (AS and DS) on the determined soil properties followed the order S3 >S2 >S1. This may be ascribed to the higher content of the added sulphur. The results revealed also that raising the application rates of both types of added compost DS and AS significantly reduced soil pH,EC and $CaCO_3$, however it remarkably augmented soil content of OM and CEC. Increased CEC could be due to increasing the soil OM content formed from the applied compost and in turn the presence of a greater number of functional groups. These results agree with those obtained by Stamfordet al. (2002), El-Maddah et al. (2012), Hashemimajd et al. (2012) and El-Gamal (2015).

TABLE 3. Effects of timing of additive S, its rates and compost application rates on selected soil chemical properties

Studied treatments	pH 1:2.5 (soil: water) susp.	EC (dSm^{-1}) 1:5 (soil: water) extract	OM (%)	CEC ($cmolkg^{-1}$)	$CaCO_3$ (%)
a)- Effect of timing of additive sulphur					
DS	7.90 b	1.18 b	0.72 a	12.63 a	12.02 b
AS	7.94 a	1.21 a	0.69 b	12.35 b	12.12 a
b)- Effect of sulphur application rates (%)					
S1 (1)	8.01 a	1.26 a	0.73 a	12.14 c	12.59 a
S2 (2)	7.95 b	1.22 b	0.70 b	12.54 b	11.99 b
S3 (3)	7.81 c	1.11 c	0.67 c	12.79 a	11.64 c
c)- Effect of sulphur-compost application rates ($g\ kg^{-1}$)					
C1 (0)	8.19 a	1.35 a	0.56 c	10.52 c	13.72 a
C2 (10)	7.86 b	1.19 b	0.74 b	12.88 b	11.57 b
C3 (20)	7.72 c	1.06 c	0.81 a	14.06 a	10.92 c
F test					
S timing * S rates	ns	ns	ns	**	ns
S timing *compost rates	**	**	ns	**	**
S rates * compost rates	**	**	**	**	**
S timing *S rates *compost rates	ns	**	ns	**	ns

DS = compost treated with sulphur during composting, AS = compost (CS0) treated with sulphur after composting, ns, *, ** are nonsignificant, significant at $P < 0.05$, significant at 0.01, respectively, The mean values within each column followed by same letters are not significantly different at 5% level of probability.

TABLE 4. Effects of timing of additive S, its rates and compost application rates on soil macronutrients content ($mg\ kg^{-1}$).

Moreover, the results (Table 3, F-test) showed that, the soil pH and $CaCO_3$were significantly affected by the interaction of (S timing × compost rates) and (S rates × compost rates). For soil EC, a positive significant interaction of all the studied factors (except of S timing × S rates) was also evident. All possibility of four interaction are significantly affected in the soil CEC values. In contrast, soil OM contents were significantly affected by only the interaction between sulfur rates and compost rates.

Effect of the studied compost treatments on soil content of available macronutrients

The presented data in Table 4 illustrate a marked significant increase in calcareous soil content (mg/kg) of available macronutrients (N, P, K, Ca, Mg and S) as a result of application the two types of sulphur-compost (DS and AS). Calcareous soil content of available macronutrients varied widely from nutrient to another depending on: the initial contents of these nutrients in the soil, the used sulphur compost, mixed rate of sulphur and the effect of sulphur compost on calcareous soil properties especially soil pH and its content of $CaCO_3$ (Awadalla et al., 2007). The determined available macronutrients content of experimental soil followed the order: K > N > Ca > Mg > S > P. This trend was consistent with the chemical properties of calcareous soil effect on macro nutrients availability and its transformation from a form to another (Obreza and Morgan, 2008).

The availability of all measured macronutrients in the investigated soil increased significantly with elevating both types of compost application rates (C3> C2> C1). The highest content of these nutrients was induced with the highest addition rate of S compost (S3) followed by that found with the treatments of S2 while the treatments of S1 was associated by the lower content. Also, the soil treated with DS compost showed the highest and significant contents of available macronutrients compared to the other treatments of AS compost. This trend was observed with all the tested macronutrients. These findings may be attributed to the improvements that occurred in calcareous soil chemical properties owing to the application of these amendments such as increases in soil CEC and OM and a decrease in its pH and the content of $CaCO_3$. For example, the relationships between soil pH and its macronutrients contents as affected by different studied treatments are illustrated in Fig 1. Different examined macronutrients revealed a strongly high inverse correlation with soil pH. The percentage effect (R^2) of independent pH values on changing soil content of available N, P, K, Ca, Mg and S was 92%, 91%, 96%, 95%, 95% and 98%, respectively. Likewise, the effect of soil $CaCO_3$, where the changes were 97%, 95%, 91%, 98%, 94% and 98% for soil content of available N, P, K, Ca, Mg and S, respectively (data not shown). The obtained results are similar to those found by Hashemimajd et al. (2012) and El-Gamal (2015).

Studied treatments	N	P	K	Ca	Mg	S
a)- Effect of timing of additive sulphur						
DS	60.00 a	5.33 a	1018.3 a	23.09 a	11.41 a	9.47 a
AS	59.05 b	5.20 b	990.7 b	22.67 b	11.14 b	9.19 b
b)- Effect of sulphur application rates (%)						
S1 (1)	55.82 c	5.05 c	966.3 c	21.82 c	10.86 c	8.71 c
S2 (2)	60.23 b	5.30 b	995.7 b	23.03 b	11.29 b	9.32 b
S3 (3)	62.53 a	5.45 a	1051.5 a	23.79 a	11.67 a	9.98 a
c)- Effect of sulphur-compost application rates (g kg^{-1})						
C1 (0)	44.68 c	4.19 c	907.9 c	20.84 c	10.31 c	7.50 c
C2 (10)	63.19 b	5.43 b	1023.7 b	23.93 b	11.59 b	9.82 b
C3 (20)	70.71 a	6.18 a	1081.8 a	20.16 a	11.92 a	10.69 a
F test						
S timing * S rates	ns	ns	ns	ns	*	ns
S timing * compost rates	*	ns	**	**	**	**
S rates * compost rates	**	**	**	**	**	**
S timing *S rates *compost rates	ns	ns	ns	ns	*	ns

DS = compost treated with sulphur during composting, AS = compost (CS0) treated with sulphur after composting, ns, *, ** are nonsignificant, significant at $P < 0.05$, significant at 0.01, respectively, The mean values within each column followed by same letters are not significantly different at 5% level of probability.

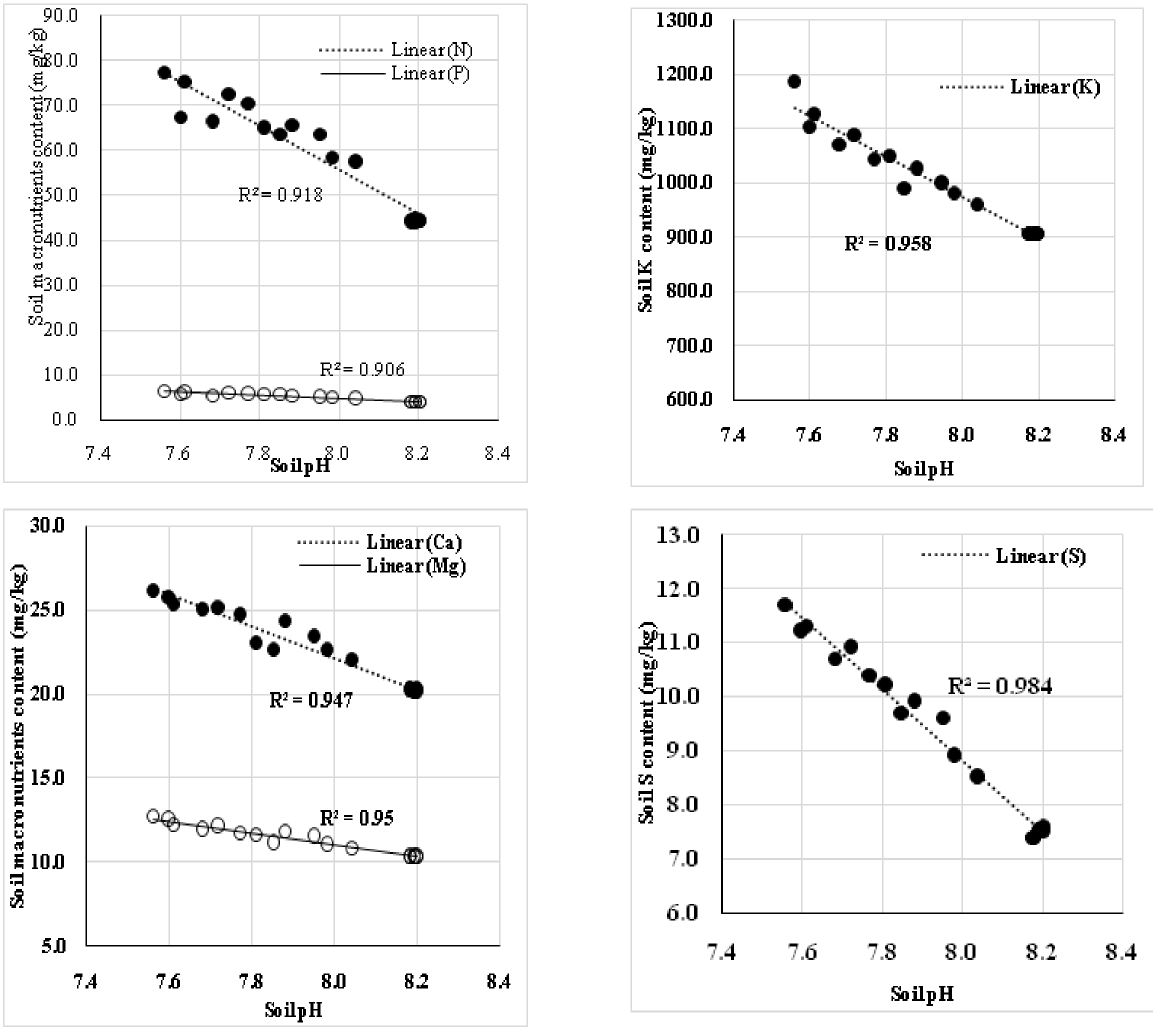

Fig. 1. Correlations among soil pH and soil macronutrients content as affected by different treatments of applied sulphur compost.

Also, data in Table (4, F-test) showed the effects of interaction among different studied factors on soil macronutrients content. The effect of (S rates × compost rates) interactions was significant on all studied soil macronutrients. Also, the same trend was found with (S timing × compost rates) interaction except for their effects on the soil content of P, which was not significant.

Effect of the studied compost treatments on soil content of available micronutrients

The effect of both types of applied compost (DS and AS) and their different additive rates on increasing the available Fe, Zn, Mn and Cucontents in the studied calcareous soils are shown in Table 5. Adding both types of compost significantly increased the soil content of all determined micronutrients. The soil treated with DS compost have a higher and significant contents of micronutrients than that fertilized with AS compost. With both types of the used sulphur compost, the treatment of S3 compost achieved the highest enhancing impact on the available micronutrients content of the tested soil, followed by S2, while the lowest one was found in the soil fertilized with S1 treatment. That may be due to the effects of sulphur on decreasing soil pH and in consequently increasing the availability of soil micronutrients (Nada, 2011). Also, data in Table 5 reveals that raising the application rates of both types (DS and AS) of compost significantly increased the studied soil content of micronutrients (Fe, Zn, Mn and Cu), wherever the highest rate of applied compost (20g kg^{-1}) obviously promoted soil content of the determined micronutrients. That may be ascribed to the minimizing effect of added compost on soil pH, either to its higher content of that micronutrients (El-Sherbiny, 2007). Soil available micronutrients content as a function of soil pH of different studied treatments are shown in Fig 2. There is a strong inverse relationship between soil pH and their contents of micronutrients. The percentage effect (R^2) of pH values on changing soil content of available Fe, Zn, Mn and Cu was 94%, 95%, 95% and 96%, respectively. The compost, itself, is a source of macro- and micro-nutrients that release slowly to soils upon organic amendment decomposition (Farid et al., 2018). Moreover, this amendmentinduced the formation of soluble organo-metal complexes that probably improved the availability of nutrients in soil (Elshony et al., 2019).

Furthermore, data in Table (5, F-test) showed a high significant effect of the interaction of both (Stiming× compostrates) and(Srates × compostrates) on all evaluated soil micronutrients. Also, a positive significant of (Stiming×Srates × compostrates) interaction was evident on soil content of Mg and S available nutrients. These means high integration between the studied main 3 factors, which is reflected in their combined effect

TABLE 5. Effects of timing of additive S, its rates and compost application rates on soil micronutrients content (mg kg-1).

Studied treatments	Fe	Zn	Mn	Cu
a)- Effect of timing of additive sulphur				
DS	6.04 a	2.80 a	7.61 a	1.30 a
AS	5.81 b	2.63 b	7.35 b	1.22 b
b)- Effect of sulphur application rates (%)				
S1 (1)	5.57 c	2.31 c	7.00 c	1.07 c
S2 (2)	5.97 b	2.73 b	7.52 b	1.25 b
S3 (3)	6.27 a	3.12 a	7.91 a	1.45 a
c)- Effect of sulphur-compost application rates (g kg^{-1})				
C1 (0)	4.85 c	1.81 c	6.12 c	0.75 c
C2 (10)	6.12 b	2.88 b	7.87 b	1.37 b
C3 (20)	6.83 a	3.47 a	8.45 a	1.67 a
F test				
S timing * S rates	ns	ns	ns	*
S timing *compost rates	**	**	**	**
S rates * compost rates	**	**	**	**
S timing * S rates * compost rates	ns	**	ns	**

DS = compost treated with sulphur during composting, AS = compost (CS0) treated with sulphur after composting, ns, *, ** are nonsignificant, significant at P < 0.05, significant at 0.01, respectively, The mean values within each column followed by same letters are not significantly different at 5% level of probability.

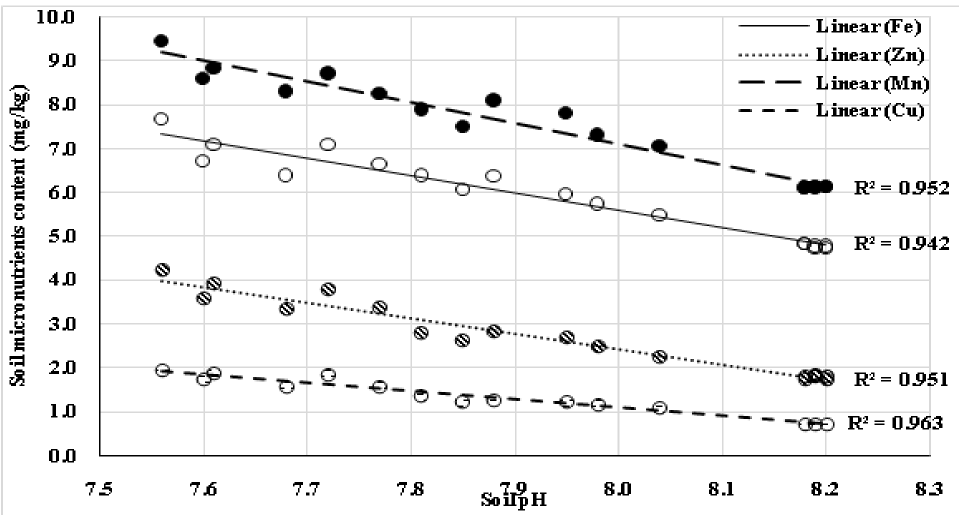

Fig. 2. Correlations among soil pH and soil micronutrients content as affected by different treatments of applied sulphur compost.

on the tested soilmicronutrients.

Dry matter yield of barley plants

Data of dry matter yield (g/pot) of both roots and shoots of barley plants grown in a calcareous soil amended with different types of sulphur compost (DS and AS) and their different applying rates have been recorded in Table 6 and illustrated by Fig 3. The data illustrate that, with the two timing of S applications either at during (DS) or after (AS) composting period, increasing the rate of added S composts significantly enhanced the dry weight of barley plants (roots and shoots). A significant difference among different studied treatments (compost rates, compost types and its S doses) for plant dry matter yield (roots and shoots) was obviously observed. For both types of S compost, the plants grown in the soil treated with 20 g kg^{-1} (C3 treatment) recorded the highest and significant content of dry weight for both roots and shoots, however the lowest content was recorded with the control treatments (C1). Plant grown on the calcareous soil mixed with DS compost recorded higher significant values of dry matter yield than those cultivated in the soil fertilized by AS treatments.With respect to control, the soil amended with compost treated with the highest S rates (DS3 and AS3) demonstrated the higher significant positive effect on plant dry matter yield, compared to the effects of DS1 and AS1 compost treatment (Fig. 3). These increases were found in the soils treated with the used different application rated of sulphur compost (DS and AS). S applications to organic materials during composting improve different compost properties and chemical composition which reflect on soil properties (physical, chemical and biological) and fertility. This reflection would be intimated with augmenting the availability of nutrients and its uptake by plants, consequently, its fresh and dry matter yield (El-Sharawy, 2008 and Belal, 2011). These findings may be attributed to the enhancing effect of S on plant growth and activation of many biochemical processes within different plant tissues (Marschner, 1995) and also its effect on improving calcareous soil properties such as the decrease of soil pH and its content of $CaCO_3$ followed by more increase of nutrients availability and uptake by plants. Probably, the organic amendment ameliorated soil hydro-physical characteristics as well as water productivity (Abd El-Halim, 2019); hence, improved root and shoot yield of barely.

Moreover, data in Table 6, (F-test) showed a positive effect on dry matter yield of all four possibilities interaction have been reported in various plant parts (roots and shoots). This means the growing plants were affected positively and significantly by all the interactions between the studied factors, which reflects also the extent of the poverty of the

TABLE 6. Effects of timing of additive S, its rates and compost application rates on dry weight (g/pot) of barley plants grown in calcareous soil

Studied treatments	Roots	Shoots
a)- Effect of timing of additive sulphur		
DS	7.16 a	20.62 a
AS	6.56 b	18.96 b
b)- Effect of sulphur application rates (%)		
S1 (1)	6.30 c	18.62 c
S2 (2)	6.89 b	19.80 b
S3 (3)	7.40 a	20.95 a
c)- Effect of sulphur-compost application rates (g kg^{-1})		
C1 (0)	5.23 c	16.57 c
C2 (10)	7.31 b	20.78 b
C3 (20)	8.04 a	22.02 a
F test		
S timing * S rates	**	**
S timing * compost rates	**	**
S rates * compost rates	**	**
S timing * S rates * compost rates	**	**

DS = compost treated with sulphur during composting, AS = compost (CS0) treated with sulphur after composting, ns, *, ** are nonsignificant, significant at $P < 0.05$, significant at 0.01, respectively, The mean values within each column followed by same letters are not significantly different at 5% level of probability.

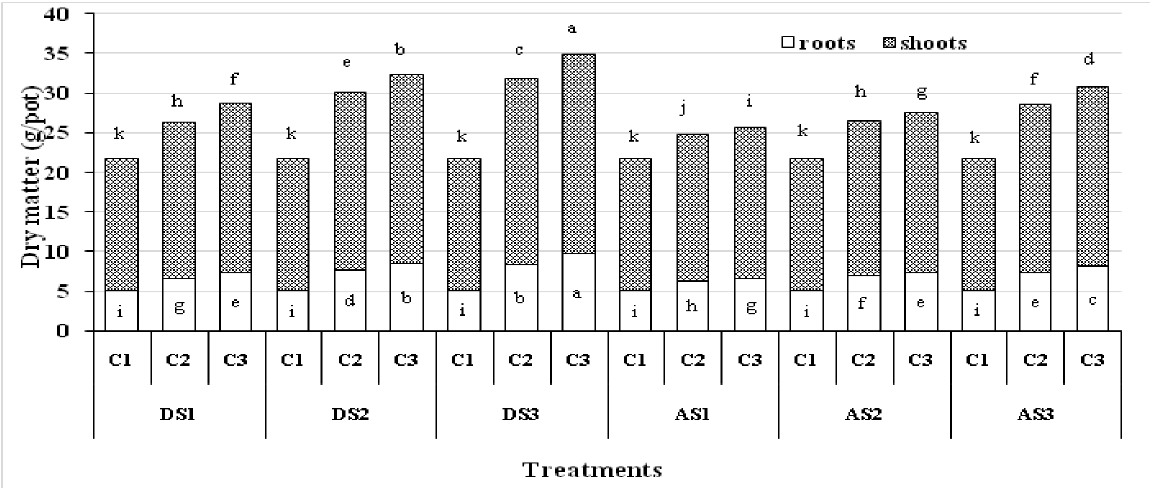

Fig. 3. Effect of timing of additive S, its rates and compost application rates on dry weight (g/pot) for both roots and shoots of barley plants grown in calcareous soil

DS = compost treated with sulphur during composting, AS = compost (CS0) treated with sulphur after composting, DS1, DS2, DS3= compost treated with 1%, 2%, 3% sulphur respectively during composting period, AS1, AS2, AS3= non-sulfurized compost (CS0) which mixed with 1%, 2%, 3% sulphur respectively after composting. C1, C2, C3 = compost application rate of 0.0, 10, 20 g kg^{-1} respectively, inside basic (roots) and on the top (shoots) of columns, the columns labeled with the same letters are not significantly different at 5% level of probability.

investigated calcareous soil (Abou Hussien, 1999).

Macronutrients uptake by barley plants

The presented data in Tables 7 and 8 show that, amended calcareous soil with the two types of S compost (DS, AS) clearly stimulated the macronutrients (N, P, K, Ca, Mg, S) uptake (mg/pot) by both roots and shoots compared to the un-amended soils (control), respectively. The highest significant uptake was found with the plants grown on the soil fertilized by the highest application rate of compost (20 g kg^{-1}). Similar results indicate that amending a calcareous soil with organic amendments improved NPK uptake by Jerusalem Artichoke (Awad and Ahmed, 2019). With all treatments of the tested sulphur compost sulphur compost, the uptake of the determined macronutrients can be arranged as follows: N > Ca > K > S > Mg > P for both roots and shoots. Constantly, the values of these nutrients uptake were higher in shoots than roots. The research results (Tables 7 and 8) elucidate a higher significant promoting effects of both DS and AS compost treatments on the macronutrients uptake by plant. Obviously and with respect to untreated soils, the plants grown on the soil fertilized by DS treatments gave the highest significant uptake values of measured macronutrients than those grown on the soil treated by AS. Also, increasing sulphur additives doses with either DS or AS compost produce an increase of the macronutrients uptake, where the greatest uptake was found in the plants grown under the treatment of S3 followed by the treatment of S2 and S1.This trend nearly is in harmony with the soil content of available content of these nutrients which resulted from improving soil chemical properties influenced by sulphur compost applications. There are strongly appositive relationships between soil available macronutrients and their uptake by barely plants under different studied treatment (Fig. 4). Soil macronutrients have altered their uptake by plant at rates of 95%, 94%, 94% and 95% for N, P, K and Ca, respectively. The significant differences recorded in plant macronutrients uptake suggest that placement of sulphur compost (DS and AS) probably affected nutrient release pattern and the eventual quantity of nutrients available to plant roots for absorption and utilization for growth. An earlier study by Badawy et al. (2011); Belal, 2011 and Saffari et al. (2013) found a significant increase effect of placement of compostand/or sulphur manure on macronutrients uptake.

Also, all combination of DS and AS treatments produced a strong interaction on all measured macronutrients in barley roots (Table 7, F-test). The same trend appeared with plant shoots, except for the effect of (S timing × S rates) and (S timing × S rates × compost rates) interactions on the N uptake, which was not significant (Table 8, F-test). There is a great complementarity between the main factors under study, which is evident from the results of all the possibilities of combination

TABLE 7. Effects of timing of additive S, its rates and compost application rates on macronutrients uptake (mg/pot) by roots of barley plants grown in calcareous soil.

Studied treatments	N	P	K	Ca	Mg	S
a)- Effect of timing of additive sulphur						
DS	114.98 a	46.84 a	85.16 a	89.74 a	77.77 a	72.01 a
AS	100.24 b	38.14 b	70.01 b	79.14 b	66.29 b	57.00 b
b)- Effect of sulphur application rates (%)						
S1 (1)	94.38 c	36.42 c	64.29 c	74.81 c	62.91 c	49.12 c
S2 (2)	108.25 b	42.21 b	79.48 b	84.47 b	72.17 b	65.53 b
S3 (3)	120.20 a	48.83 a	88.99 a	94.03 a	81.01 a	78.86 a
c)- Effect of sulphur-compost application rates (g kg^{-1})						
C1 (0)	59.45 c	14.47 c	35.48 c	53.33 c	43.44 c	22.76 c
C2 (10)	121.27 b	51.44 b	90.51 b	93.48 b	77.45 b	69.53 b
C3 (20)	142.11 a	61.56 a	106.77 a	106.49 a	95.20 a	101.23 a
F test						
S timing * S rates	**	**	**	**	**	**
S timing * compost rates	**	**	**	**	**	**
S rates * compost rates	**	**	**	**	**	**
S timing *S rates *compost rates	**	**	**	**	**	**

DS = compost treated with sulphur during composting, AS = compost (CS0) treated with sulphur after composting, ns, *, ** are nonsignificant, significant at P < 0.05, significant at 0.01, respectively, The mean values within each column followed by same letters are not significantly different at 5% level of probability.

TABLE 8. Effects of timing of additive S, its rates and compost application rates on macronutrients uptake (mg/pot) by shoots of barley plants grown in calcareous soil.

Studied treatments	N	P	K	Ca	Mg	S
a)- Effect of timing of additive sulphur						
DS	317.29 a	89.07 a	136.77 a	154.46 a	106.40 a	145.45 a
AS	275.54 b	76.69 b	114.85 b	136.06 b	87.28 b	121.25 b
b)- Effect of sulphur application rates (%)						
S1 (1)	267.06 c	71.53 c	109.28 c	128.38 c	78.66 c	112.97 c
S2 (2)	294.77 b	80.52 b	b 126.48	144.41 b	98.64 b	134.61 b
S3 (3)	327.43 a	96.59 a	141.68 a	162.98 a	113.21 a	152.47 a
c)- Effect of sulphur-compost application rates (g kg^{-1})						
C1 (0)	184.68 c	60.82 c	84.77 c	87.30 c	49.27 c	64.43 c
C2 (10)	330.71 b	85.63 b	135.04 b	161.79 b	108.48 b	155.66 b
C3 (20)	373.87 a	102.19 a	157.63 a	186.69 a	132.76 a	179.96 a
F test						
S timing * S rates	ns	**	**	**	**	**
S timing * compost rates	**	**	**	**	**	**
S rates * compost rates	**	**	**	**	**	**
S timing *S rates *compost rates	ns	**	**	**	**	*

DS = compost treated with sulphur during composting, AS = compost (CS0) treated with sulphur after composting, ns, *, ** are nonsignificant, significant at P < 0.05, significant at 0.01, respectively, The mean values within each column followed by same letters are not significantly different at 5% level of probability.

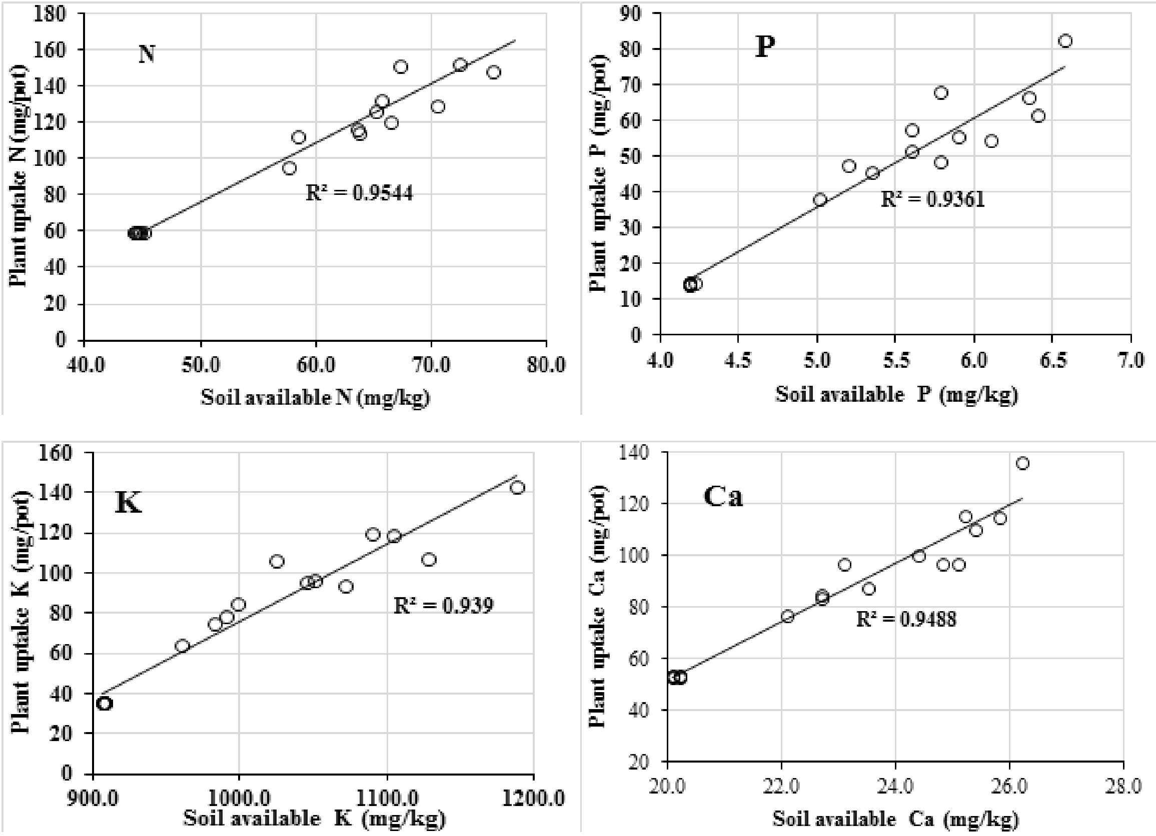

Fig. 4. Correlations among selected soil available macronutrients and the possibilities of their uptake by barely plants under different treatments of applied sulphur compost.

between these factors, which are reflected in the uptake of plant macronutrients.

Micronutrients uptake by barley plants

Micronutrients (Fe, Mn, Zn and Cu) uptake (mg/pot) by barley plants (roots and shoots) grown ona calcareous soil affected by different treatments of sulphur compost mixtures were determined and the obtained data were recorded in Tables 9, (roots) and 10, (shoots). With respect to control (C1, 0.0%) treatment, increasing the application rates (C2, 10% and C3, 20%) of compost to amended soil led to significant increases in the uptake of micronutrients by plants. This trend was clearly found in both aerial and underground parts of sowed barley plant, wherever the highest values were recorded to the shoots (Table, 10). Probably, the organic amendment increased the utilization of soil nutrients by plants, *e.g.* Fe (Hamad and Tantawy, 2018), Mn, Zn and Cu (Abou Hussien et al., 2019 and Faiyad et al., 2019). Also, the results reveal that there were clear significant increases in the plant uptake of the determined micronutrients with increasing application rates of S for both types of applied sulphur compost (DS and AS). Furthermore, the obtained results revealed that micronutrients uptake by both roots and shoots of barley plants grown on the soil treated by DS were higher than those found in the plants grown on the soil mixed by AS compost. It was apparent that, plant cultivated in soil treated with high addition rates S3 (3%) of the used sulphur compost gave the highest content of the measured micronutrients, compared to the plants grown in untreated soils. With the same treatment of sulphur compost mixtures, the high uptake was recorded with Fe followed by that of Mn, while the lowest one was found with Zn and/or Cu. This arrangement may be related to the role of each nutrient in the metabolism reactions in the plant cells. Also, the availability of the nutrients in the soil and its relationship to the soil pH has a significant impact (Gohar, 2011, Islam, 2012, Shaban et al., 2012 and El-Gamal, 2015).

Addition of S obviously increased the effects of applied compost on the micronutrients uptakes by barley plant (Tables 9 and 10, F-test). Generally, timing and/or additive rates of S affected significantly on the compost application rates in micronutrients uptake by plants (positive interaction). This trend was shown with all measured micronutrients. Decreasing soil pH that resulted from the applied sulphur compost can induce soil micronutrients efficiency. These

TABLE 9. Effects of timing of additive S, its rates and compost application rates on micronutrients uptake (mg/pot) by roots of barley plants grown in calcareous soil.

Studied treatments	Fe	Zn	Mn	Cu
a)- Effect of timing of additive sulphur				
DS	0.52 a	0.08 a	0.20 a	0.25 a
AS	0.43 b	0.06 b	0.16 b	0.22 b
b)- Effect of sulphur application rates (%)				
S1 (1)	0.37 c	0.05 c	0.14 c	0.21 c
S2 (2)	0.47 b	0.07 b	0.18 b	0.23 b
S3 (3)	0.59 a	0.09 a	0.23 a	0.25 a
c)- Effect of sulphur-compost application rates (g kg^{-1})				
C1 (0)	0.23 c	0.02 c	0.07 c	0.16 c
C2 (10)	0.59 b	0.08 b	0.22 b	0.25 b
C3 (20)	0.65 a	0.10 a	0.26 a	0.29 a
F test				
S timing * S rates	**	ns	ns	ns
S timing * compost rates	**	*	**	**
S rates * compost rates	**	**	**	**
S timing *S rates *compost rates	**	ns	ns	ns

DS = compost treated with sulphur during composting, AS = compost (CS0) treated with sulphur after composting, ns, *, ** are nonsignificant, significant at $P < 0.05$, significant at 0.01, respectively, The mean values within each column followed by same letters are not significantly different at 5% level of probability.

TABLE 10. Effects of timing of additive S, its rates and compost application rates on micronutrients uptake (mg/pot) by shoots of barley plants grown in calcareous soil.

Studied treatments	Fe	Zn	Mn	Cu
a)- Effect of timing of additive sulphur				
DS	48.89 a	5.52 a	33.21 a	1.36 a
AS	41.81 b	4.47 b	29.07 b	1.15 b
b)- Effect of sulphur application rates (%)				
S1 (1)	39.68 c	4.27 c	27.28 c	0.97 c
S2 (2)	46.03 b	4.93 b	31.37 b	1.29 b
S3 (3)	50.33 a	5.80 a	34.77 a	1.52 a
c)- Effect of sulphur-compost application rates (g kg^{-1})				
C1 (0)	28.43 c	2.40 c	22.07 c	0.57 c
C2 (10)	50.91 b	5.83 b	32.81 b	1.49 b
C3 (20)	56.71 a	6.77 a	38.53 a	1.71 a
F test				
S timing * S rates	**	**	ns	**
S timing * compost rates	**	**	**	**
S rates * compost rates	**	**	**	**
S timing *S rates *compost rates	ns	**	ns	**

DS = compost treated with sulphur during composting, AS = compost (CS0) treated with sulphur after composting, ns, *, ** are nonsignificant, significant at $P < 0.05$, significant at 0.01, respectively, The mean values within each column followed by same letters are not significantly different at 5% level of probability.

findings were in agreements with the effect of both S and compost applications on both soil chemical properties especially the content of available micronutrients and plant growth.

Conclusion

The data obtained show the high efficiency of sulphur compost in improving the chemical properties of calcareous soil and increasing its content of available macro-and micronutrients and, also increased its productivity especially when S mixed with the composted organic materials during composting period.

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تأثير إضافة الكمبوست الكبريتي على بعض الصفات الكيميائية للتربة الجيرية والاستجابات المترتبة على نباتات الشعير (*HordeumVulgare* L.)

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استصلاح الاراضى الجيرية يعتبر من الأمور الضرورية لزيادة إنتاج المحاصيل والحفاظ على البيئة فى المناطق الجافة وشبة الجافة. أجريت هذه الدراسة فى تجربة أصص بصوبة قسم علوم الاراضى – كلية الزراعة – جامعة المنوفية – شبين الكوم – مصر لتقييم كفاءة إضافة نوعين من الكمبوست الكبريتي على بعض الخواص الكيميائية للأراضى الجيرية وكذلك محتواها من المغذيات الكبرى والصغرى الميسرة وأيضا التأثير على نمو نباتات الشعير. تم انتاج نوعين من الكمبوست الكبريتي . الأول نتج من إضافة الكبريت إلى الكمبوست أثناء عملية الكمر (DS) والثاني نتج من إضافة الكبريت إلى الكمبوست الغير كبريتي وذلك بعد الكمر (AS). كانت معدلات إضافة الكبريت لكلا النوعين من الكمبوست صفر، 1 ، 2 ، 3 %.قبل الزراعة أضيف كل من نوعي الكمبوست الكبريتي على حده عند معدلات إضافة صفر، 10، 20 جم/كجم وتم الخلط جيدا بالأرض وتم زراعة نيات الشعير. تم حصاد النبات بعد سبعين يوم و تقدير كل من الوزن الجاف وكذلك محتواه من المغذيات الكبرى والصغرى. أيضا أخذت عينة أرض من كل وحدة تجريبية وقدر لها بعض الخواص الكيميائية وكذلك المحتوى من المغذيات الكبرى والصغرى الميسرة.

أظهرت النتائج مقارنةً بالكنترول . انه كان هناك تأثير ايجابى لكلا نوعى الكمبوست الكبريتي على خواص التربة المدروسة وكذلك صفات النبات النامي فيها. أدى إضافة الكمبوست الكبريتي إلى حدوث نقصاً فى رقم حموضة الأرض وكذلك قيمة التوصيل الكهربي لها ومحتواها من كربونات الكالسيوم بينما حدث زيادة فى قيمة السعة التبادلية الكاتيونية للأرض وكذا محتواها من المادة العضوية وكذلك المحتوى من المغذيات الصغرى والكبرى الميسرة. وكان التأثير المصاحب لمعاملات الكمبوست الكبريتي المحضر أثناء عملية الكمر أعلى من تلك المصاحبة لمعاملات النوع الثاني. أيضا فقد صاحب إضافات الكمبوست الكبريتي زيادة فى المادة الجافة للنبات وكذلك محتواها من كل من المغذيات الكبرى والصغرى. لهذا فإنه من الضروري إضافة الكمبوست الكبريتي خاصة ذلك المحضر أثناء عملية الكمر إلى الأراضى الجيرية لتحسين خواصها وزيادة إنتاجيتها.