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Biochemical Properties of Calcareous Soil Affected by the Source of Sulphur-Organo Fertilizers

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SULPHUR application is one of the recommended approaches to improve soil fertility and plant production sustainability in calcareous soils, but different types of mineral or organo sulphur fertilizers may differ in their efficiency. This field experiment was established in calcareous soil of private farm in Nubaria, Beheira Governorate, Egypt through the winter season of 2021/2022 to study the effect of three sulphur fertilizers varied in their forms on chemical and biological soil properties as well as the productivity of faba bean (*Vicia faba* L., cv Nubaria 3). The examined sulphur forms were control (S0), elemental sulphur (ES 250 and ES 500), compost treated by sulphur (CS 250 and CS 500), and compost tea enriched by sulphur (CTS 250 and CTS 500), whereas 0, 250 and 500 are S application rates (kg fed^{-1}). The obtained results show that, compared to the (S0), all types of applied S fertilizers had a positive impact on the soil content of OM and available N, P, K, Ca, and S nutrients and CEC value, while having a negative effect on soil pH, EC and $CaCO_3$ content. Also, soil biological activity of dehydrogenase, phosphatase and urease increased significantly with increasing sulphur application (with all S forms) rates compared with untreated soil. Generally, the positive and/or negative effect of the studied S fertilizers on soil properties takes the order CTS > CS > ES. There is a significant increase in both seed and straw yields and their macronutrients (N, P, K, Ca, and S) content for the faba bean plant with the added rate of S in all three forms, with the highest yields recorded to CTS followed by CS and ES treatments. Therefore, sulphur fertilizers particularly those applied as sulphur-organo (CS and CTS) forms should be added to calcareous soil to improve its chemical and biological properties and increased its productivity.

Keywords: Biological properties, Chemical properties, Calcareous soil, Sulphur, Organo fertilizer.

1. Introduction

In Egypt, as a result of the increase in population and the lack of arable soil, it was necessary to reclaim the land to compensate for the shortfall in agricultural production (Wahba et al., 2019).The area of ancient land in the Nile Valley and Delta is already cultivated and used. Therefore, there is a need to expand the cultivated area to include mainly calcareous soils. From the east and west around the Nile Valley and the Delta, the soil content of calcium carbonate increases, reaching 30 to 80%. Generally, calcareous soils are characterized by the presence of calcium carbonate with more than 15% $CaCO_3$ and at least 5% more carbonate of the underlying layer and having a calcic horizon (FAO, 2023).Cultivation and production of crops in such soil faces many obstacles, such as its high content of $CaCO_3$, which reduces soil fertility and availability of nutrients, formation of surface crust, which affects germination and growth of crops, and finally low available moisture content (Abdel-Aal et al., 1990; Pearce and Bush, 1999). Calcareous soils are characterized by their low content of organic matter and available nitrogen (N).Also, a high pH level leads to a lack of phosphorus (P) and reduced the availability of micronutrients. Also, problems may arise in the availability and absorption of potassium (K) and magnesium (Mg) by the plant as a result of the imbalance between them and calcium (Wahba et al., 2018).

Compost obtained from the composting of agricultural wastes and plant residues can be used effectively as an organic fertilizer in the reclamation of calcareous soils (Hellal, 2007; Tavali, 2021). In this respect, several studies demonstrated that, the addition of compost led to a decreased pH value and increased the availability of macro and micronutrients in calcareous soil (Elgezery, 2016; Abou Hussien et al., 2019). As reported by Habib (2001) and Bezabeh et al. (2021), the uptake of N, P and K by plants was improved by increasing the dose of compost

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application in calcareous soil. This is certainly due to the increasing availability of these nutrients in the soil after being treated with compost (Abou Hussien et al., 2019, Manirakiza and Seker, 2020). Also, this is mainly due to the reduction of calcareous soil pH with the addition of compost, which reflects positively on the availability of nutrients (Abou Hussien et al., 2019). Saleem et al. (2022) indicated that, the addition of organic amendments (poultrymanure and/or vinasse) led to a great increase in barley yield and improve soil fauna and soil fertility in calcareous soils.

Otherwise, sulphur elements are used as a soil conditioner for reclamation of calcareous soil, which improves its chemical properties (Abou Hussien et al., 2017; Abdel Hafeez and Ewees, 2018). Sulfur is used as a soil acidifier to improve calcareous soils. In addition to providing sulfur as a nutrient, S is also used as a soil acidifier that neutralizes calcium carbonate ($CaCO_3$) with acid. This in turn leads to reduce soil pH and increasing nutrients availability (Negm et al., 2002; Wahba et al., 2019). Also, Wahdan et al. (2005) and El-Sherbiny (2007) reported that, calcareous soil pH and EC decreased, while its available macronutrients were increased after treated with sulphur.

Moreover, the combination of sulphur with compost (CS) raises the efficiency of compost and its effect on the chemical properties of calcareous soil (Abou Hussien et al., 2016 and 2020). The Cation exchangeable capacity (CEC), organic matter (OM) and availability of macronutrients (N, P and K) were increased while soil pH and $CaCO_3$ decreased by additions of CS especially in the surface layer of calcareous soil (Abou Hussien et al., 2017 and 2019). Also, the application of compost mixed with S gave a positive increase in fresh and dry yields of many cultivated crops in calcareous soil (Siam et al., 2008; El-Kouny, 2009; Ramzani et al., 2017). In addition, several studies have reported improving soil chemical and microbial properties and the availability of macronutrients in calcareous soil after the application of compost tea (Elbaalawy and Abou Hussien 2020; Abou Hussien et al., 2021; Mihoub et al., 2022).

However, few studies are known about the effect of different forms of organic and mineral sulfur fertilizers on calcareous soils.As well as the response of plants grown in calcareous soil to the addition of these sulfur forms.Thus, the current study aimed to investigate the effect of different forms of S fertilizers on (1) the chemical and biological properties of calcareous soil, (2) the available soil macronutrient contents, and (3) the response of different plant parameters of faba bean plant such as seeds and straw yields and their nutrient contents.

2. Materials and Methods

This study was carried out as a field experiment to study the effect of sulphur fertilizers in different forms on some chemical properties and biological activity of calcareous soil and its productivity of faba bean (*Vicia faba* L., cv Nubaria 3).

2.1. Soil location and soil sampling

Before planting, five surface soil samples (0-30 cm) were taken from the experimental soil located at Nubaria region (30^o 11' 33.26" N and 30^o 42' 37.06" E), Beheira Governorate, Egypt. These samples were air-dried, ground good, mixed, sieved through a 2 mm sieve, and then analyzed for some physical and chemical properties as described by Cottenie et al. (1982), Page et al. (1982), and Klute (1986). Other soil enzymes activities were determined in other fresh soil samples taken at the same soil depth. Soil dehydrogenase, phosphatase and urease activities were determined according to the methods described by Garcia et al. (1993), Tabatabai and Bremner (1969) and Nannipieri et al. (1980), respectively. The obtained data are recorded in Table (1).

2.2. Sulphur-organo fertilizers

In this study,two sulphur-organo fertilizers were used in addition to elemental sulphur (ES). The used ES was product of El Helb Company for Pesticides and Chemicals, New Damietta, Egypt, having 99% purity and pH 6.2. The first sulphur-organo fertilizer was sulphur compost (CS) produced from composted agricultural (animal and plant) residues as described by Abou Hussien et al. (2020 and 2021). This compost was produced with mixed ratio of ES at 5% (w/w) of the composted materials. The second sulphur-organo fertilizer was compost tea (CT) enriched by sulphur (CTS). The used CT was obtained from composted agricultural (animal and plant) residues without S application as described previously by Abou Hussien et al. (2017). Compost tea was prepared using the procedure line out before that by Abou Hussien et al. (2020). Whereas, the prepared final compost tea was riched with S by adding $6NH_2SO_4$ (1.84 g cm^{-3}) at the rate of 40 g S L^{-1} (w/v) (576.8 ml). The main chemical properties of both CS and CTS were determined according to the methods described by Page et al. (1982) and the obtained data are recorded in Table (2).

TABLE 1. Some physical, chemical and biological properties of the experimental calcareous soil.

Particle size distribution (%)			Texture class	pH	EC (dSm^{-1})	OM (%)
Sand	**Silt**	**Clay**				
75.30	13.30	11.40	Sandy	8.66	2.17	0.51
CEC ($cmolkg^{-1}$)	**CaCO$_3$** (%)	**Available macronutrient** ($mgkg^{-1}$)				
		N	**P**	**K**	**Ca**	**S**
12.10	15.18	33.50	3.86	375.0	21.50	6.40
Enzymes activity						
Dehydrogenase (µg TPF g^{-1} dry soil h^{-1})		**Alkalinephosphatase** (µg PNP g^{-1} dry soil h^{-1})			**Urease** (µg NH_4–N g^{-1} dry soil h^{-1})	
79.44		59.55			1.88	

pH = soil reactionmeasured in 1:2.5, soil: distilled water suspension**)**, **EC**= electrical conductivity(measured in 1:5, soil: distilled water extraction), **OM**= organic matter, **CEC**= Cation exchange capacity, **TPF**= Trihydrophenyl formazan, **PNP**= ρ-nitrophenol phosphate.

TABLE 2. The main chemical properties and nutrients content of the studied sulphur-organo fertilizers.

Properties	CS	CTS	Properties	CS	CTS
pH	6.85	6.25	**C/N ratio**	17.80	7.27
EC (dSm^{-1})	2.60	3.11	**Total P**	0.32 (%)	31.13 (gL^{-1})
OM	40.50 (%, w/w)	18.60 (%, w/v)	**Total K**	0.81 (%)	53.12 (gL^{-1})
Total OC	25.63 (%, w/w)	11.77 (%, w/v)	**Total Ca**	0.36 (%)	128.0(gL^{-1})
Total N	1.44 (%, w/w)	1.62 (%, w/v)	**Total S**	5.68 (%)	60.0 (gL^{-1})

CS= Sulphur compost, **CTS**= Compost tea riched by sulphur, **pH=** fertilizer reaction;measured in 1:5 (CS : water suspension) and for CTS in liquid solution, **EC**= Electrical conductivity; measured in 1:10 (CS : distilled water extraction) and for CTS in liquid solution, **OM**= organic matter, **OC**= Organic carbon.

2.3. Field experiment

This experiment was carried out on a calcareous soil of private farm in Nubaria, Beheira Governorate, Egypt to study the effect of three sulphur fertilizers varied in their forms and chemical composition on chemical and biological soil properties as well as its productivity of faba bean (*Vicia faba* L., cv Nubaria 3). To achieve these purposes the field trial was carried out through growing winter season of 2021/2022. The seed-bed was prepared as recommended for faba bean plant production under calcareous soil conditions of Nubaria area. Before planting, the experimental area (882 m^2) was fertilized by ordinary superphosphate (15.5% P_2O_5) at rate of 100 kg fed^{-1} (23.81 g m^{-2}). At the same time farmyard manure (FYM) was added at a rate of 10 Mg fed^{-1} (2.381 kg m^{-2}). Both P fertilizer and FYM were good mixed with the soil layer of 0-20 cm. The studied experimental treatments were arranged in one way randomized block design with three replicates. The experiment area was divided into equal 21 experimental plots with area of 42 m^2 (6 x 7 m) for each plot. These 21 plots were divided into seven groups representing S fertilizers treatments i.e. S0, ES 250, ES 500, CS 250, CS 500, CTS 250 and CTS 500, whereas 0, 250 and 500 were the application rates (kg fed^{-1}) of added S fertilizers. In addition, both ES and CS treatments were applied before planting and mixed with the surface layer (0-20 cm). For CS 250 and CS 500 treatments were carried out by adding 4401.5 and 8803.0 kg CS fed^{-1}. Whereas, CTS treatments were applied in four equal doses (62.5 and 125.0 kg S fed^{-1}) after 21, 33, 45 and 52 days of planting together with irrigation water. The total volume of CTS fertilizer was 4167 and 8334 L fed^{-1} which all mixed by irrigation water before used.After that,each plot was divided into ridges with 6 m length and 0.75 m apart.

Seeds of faba bean (Nubaria 3) were obtained from Field Crop Institute Research, Agriculture Research Center (ARC), Egypt. Directly before planting, the seeds were inoculated with gamma-irradiated vermiculite-based inoculation at a rate of 300 g specific Rhizobia (*Rhizobium leguminosarum*) per 50 kg seeds using 16 % Arabic gum solution as sticking agent. Two inoculated seeds were planted in each hole on 10 November 2021. The planting process was carried out at 2 cm depth and 15 cm between the holes. At the same day, all plots received N fertilizer in ammonium nitrate (33 % N) form at 50 kg fed^{-1} (11.905 g m^{-2}) with irrigation water through drip irrigation system. At 20 and 42 days of planting potassium fertilizer as potassium sulphate (K_2SO_4, 48% K_2O) was applied at a rate of 100 kg fed^{-1} (23.81 g m^{-2}). Other all farming processes of faba bean plant under calcareous soil conditions were carried out as recommended by Agriculture Ministry of Egypt.

At 70 old day, five plants as whole were taken from each replicate, washed gently to remove soil particles, and then the root bacterial nodules were counted for each plant. At harvesting day (120 day), the plants of each replicate were cut above the soil surface, separated into straw and seeds and weighted separately as kg fed^{-1}. At the same harvesting day, fresh soil sample of root zone was taken from each experimental unit and prepared for enzymes activities determinations. Other soil sample was taken and prepared for chemical determinations.

2.4. Soil chemical determinations

The taken soil samples were analyzed for pH, EC (dSm^{-1}), CEC (cmole kg^{-1}), content of OM (%) and $CaCO_3$ (%), and available nutrients i.e. N, P, K, Ca and S (mg kg^{-1}) according to the methods of Cottenie et al. (1982) and Page et al. (1982).

2.5. Soil bio determination

The soil samples of root zone were analyzed for the activities of dehydrogenase, urease, and phosphatase. Dehydrogenase activity was determined by Garcia et al. (1993) method, and expressed as µg TPF (Trihydrophenyl formazan) g^{-1} dry soil h^{-1}. Urease activity was measured according to the method of Nannipieri et al. (1980) and expressed as µg NH_4-N g^{-1} dry soil h^{-1}. Phosphatase activity was determined according to the method of Tabatabai and Bermner (1969) and expressed as µg PNP (***ρ***-nitrophenol phosphate) g^{-1} dry soil h^{-1}. Where alkaline phosphatase was estimated at pH 11.0 by measuring the ρ-nitrophenol produced after incubated soil with buffered disodium *ρ* -nitrophenol phosphate solution (10 mmol L^{-1} PNP) and toluene at 37 ^oC for one hour.

2.6. Plant determinations

A portion of each plant sample (seeds and straw) was taken, oven-dried at 70^o C for 42 hrs and ground. A 0.5 g of oven-dried plant sample was digested by 10 ml mixture of concentrated H_2SO_4 and $HClO_4$ (3:1 mixed ratio) on hot plate (270^o C) up to become clear (Chapman and Pratt, 1961). The clear digestion solution was diluted by distilled water up to 100 ml. This digest was analyzed for its content of N, P, K and Ca. Another 0.5 g plant sample was taken and digested using the mixture of concentrated HNO_3 and $HClO_4$ and complete the digesting process as described with the first sample. This digest was analyzed for its content of S. All plant analysis were carried according to Cottenie et al. (1982).

Furthermore, biological yield (BY, $kgfed^{-1}$), harvest index (HI, %) and sulphur use efficiency (SUE) were calculated by the following equations 1, 2 and 3, respectively, where SFR is the sulphur fertilizer rates ($kgfed^{-1}$).

$$BY = Seed\ Yield + Straw\ Yield \quad \textbf{Eq. 1}$$

$$HI = (Seed\ Yield / Biological\ Yield) * 100 \quad \textbf{Eq. 2}$$

$$SUE = Seed\ Yield / SFR \quad \textbf{Eq. 3}$$

2.7. Statistical analysis

Results for soil and plant were statistically analyzed (ANOVA) by using themethod mentioned by Snedecor and Cochran (1989). Mean separation among the treatments was done by using the least significant difference (LSD) test at 5% level of probability.

3. Results and Discussion

3.1. Soil chemical properties

The presented data in Table 3 show a significant effect of added S fertilizers either in mineral (ES) or organic (CS and CTS) form on the studied chemical properties of calcareous soil i.e. pH, EC (dSm^{-1}), CEC (cmole kg^{-1}) and the content (%) of OM and $CaCO_3$. The detail of these data reveals that, S applications in the three forms resulted in a decrease of soil pH, EC and the content of $CaCO_3$. This decrease effect of S fertilizers on soil pH, EC and $CaCO_3$ mainly attributed to the chemical and bio-oxidation of added S produced SO_2 which transformed into H_2SO_4. This means that, each one mole of oxidized S produced two moles of H^+ resulted in the increase of soil acidity (decreased soil pH) (Bolan and Hedley, 2003; Kissel et al., 2020). Also, the formed H_2SO_4 increased salts solublization and its leaching from the surface soil layers. As well as the found S in the soil as ions, oxides or acid converting large amounts of $CaCO_3$ to $CaSO_4$. Before that, Elgezery (2016), Abou Hussien et al. (2017) and recently Labanya et al. (2022) found a decrease in soil pH, EC and $CaCO_3$ in the calcareous soils fertilized by S in different forms.

With the same application rate of the added S forms, the data in Table 3 show that, the highest significant decrease of soil pH, EC and $CaCO_3$ was found in the soil fertilized by CTS followed by the treatment of CS and ES. This trend are in harmony with large amounts of acidic compounds associated CTS applications than these produced from CS and ES applications. The found decreases in soil pH, EC and $CaCO_3$ in relation with S sources was pointed before that by Abou Hussien et al. (2017 and 2020).

On the other hand, increasing rate of added the three forms of S fertilizers to calcareous soil resulted in a clear significant increase of soil OM content (%) and its CEC (cmole kg^{-1}) as shown in Table 3. According to the found increases in both OM and CEC, the used S forms takes the order: CS > CTS > ES. This order attributed to high stability of CS than the other two forms. The found increases in soil OM and CEC as a result of added sulphur compost was obtained by Elgezery (2016) and Abou Hussien et al. (2019, 2020 and 2021).

TABLE 3. Effect of sulphur-organo fertilizers in the chemical properties of calcareous soil.

SFR (kg fed^{-1})	pH	EC (dSm^{-1})	OM (%)	CEC (cmolkg^{-1})	$CaCO_3$ (%)
S0	8.65±0.03	2.15a ±0.02	0.52f ±0.01	12.11e ±0.03	15.18a ±0.04
ES 250	8.43±0.02	2.11b ±0.01	0.52f ±0.03	12.11e ±0.04	14.80b ±0.12
ES 500	8.22±0.01	1.98d ±0.05	0.54e ±0.02	12.14e ±0.02	13.50d ±0.10
CS 250	8.35±0.03	2.05c ±0.03	0.62c ±0.04	12.93c ±0.05	13.85c ±0.05
CS 500	8.05±0.01	1.90f ±0.01	0.73a ±0.01	14.50a ±0.07	13.05f ±0.03
CTS 250	8.18±0.03	1.93e ±0.02	0.59d ±0.05	12.50d ±0.04	13.35e ±0.11
CTS 500	7.97±0.01	1.80g ±0.04	0.67b ±0.01	13.35b ±0.03	12.75g ±0.05
LSD 0.05	-	**0.022**	**0.043**	**0.043**	**0.109**

SFR= Sulphur fertilizers and rates**, S0=** Control without sulphur fertilizer**, ES =** Elemental sulphur**, CS =** sulphur compost, **CTS =** Compost tea riched by sulphur, **pH =** soil reactionmeasured in 1:2.5, soil: distilled water suspension**)**, **EC**= electrical conductivity(measured in 1:5, soil: distilled water extraction), **OM**= organic matter, **CEC**= Cation exchange capacity, Means in a column with the same letter are not significantly different at the 5% level (mean values ± Stdev, n=3).

3.2. Soil available macronutrients

The presented data in Table 4 clear that, with the three S fertilizers, increasing of their application rate resulted in an increase calcareous soil content of available N, P, K, S and Ca with a wide variations. The available content of these nutrients was increased from 33.30, 3.85, 370.0, 6.32 and 21.20 mg kg^{-1} without S fertilization to 37.30, 5.95, 435.0, 48.50 and 25.22 mg kg^{-1} recorded relative increase of 12.01, 51.95, 17.57, 667.41 and 18.96 % for the content of available N, P, K, S and Ca in the soil fertilized by 500 kg S fed^{-1} as CTS, respectively. These relative changes values show the rate effect of S fertilization on nutrients availability which takes the order S > P > Ca >K>N. This trend is in harmony with the effect of added S fertilizers forms on soil chemical properties have a greater effect on these nutrients availability. Before that, Elgezery (2016) and Abou Hussien et al. (2020 and 2021) obtained on similar results under calcareous soil conditions.

With the same application rate of applied S fertilizers as shown in Table 4 reveals that, the highest contents of available N, P, K, Ca and S were found in the calcareous soil fertilized by CTS followed by these resulted from CS and ES applications. The superior effect of CS on the nutrients availability in calcareous soil in compared with that resulted from ES applications was found in the studies of Elgezery (2016) and Abou Hussien et al. (2017 and 2020).

TABLE 4. Effect of sulphur-organo fertilizers on calcareous soil contents of available nutrients.

SFR (kg fed^{-1})	N (mgkg^{-1})	P (mgkg^{-1})	K (mgkg^{-1})	S (mgkg^{-1})	Ca (mgkg^{-1})
S0	33.30g ±0.10	3.85g ±0.02	370.0g ±3.23	6.32g ±0.12	21.20g ±0.21
ES 250	33.72f ±0.12	3.98f ±0.06	375.0f ±4.11	18.18f ±0.32	21.80f ±0.25
ES 500	34.43d ±0.14	4.65d ±0.12	392.0d ±5.24	30.12c ±1.15	22.90d ±0.32
CS 250	34.13e ±0.11	4.50e ±0.05	380.0e ±3.17	20.30e ±1.06	22.13e ±0.23
CS 500	35.50b ±0.13	5.10b ±0.11	410.0b ±6.12	35.13b ±1.82	24.15b ±0.43
CTS 250	35.25c ±0.09	4.87c ±0.04	402.0c ±4.42	23.13d ±1.09	23.75c ±0.33
CTS 500	37.30a ±0.16	5.95a ±0.12	435.0a ±7.08	48.50a ±2.13	25.22a ±0.45
LSD 0.05	**0.133**	**0.093**	**4.131**	**1.716**	**0.260**

SFR= Sulphur fertilizers and rates**, S0=** Control without sulphur fertilizer**, ES =** Elemental sulphur**, CS =** sulphur compost, **CTS =** Compost tea riched by sulphur, Means in a column with the same letter are not significantly different at the 5% level (mean values ± Stdev, n=3).

3.3. Soil biological activities

a. Enzymes activities

The presented data in Table 5 showed a slight increase in the values of enzymes in the control treatment (S0) compared to those in Table 1.This increase may be due to the fact that the soil before planting was taken from uncultivated soil, while after planting it was taken from the rhizosphere, in which the soil and plants were treated with all the recommended agricultural operations. Clearly, data in Table 5 showed thatwith the three sources of S fertilizers in applications at a rate of 250 and 500 kg fed^{-1} in the calcareous soil resulted in a significant increase in the activities of three soil enzymes i.e. dehydrogenase, phosphatase and urease with a variation rate increases depending on enzyme type and application rates of the used S fertilizers. With the same application rate of added S fertilizers and according to the found increases of the enzymes activity under calcareous soil condition were found in the soil fertilized by CTS followed by those found in the soil received CS and ES treatments. For example, at application rate of 250 kg S fed^{-1}, the activity values were 95.13, 102.20 and 122.13 (µg TPF g^{-1} dry soil h^{-1}) for dehydrogenase, 68.80, 75.90 and 88.03 (µg PNP g^{-1} dry soil h^{-1}) for phosphatase, and 2.85, 3.43 and

4.05 (µg NH_4-N g^{-1} dry soil h^{-1}) for urease activity with the applications of ES, CS and CTS, respectively. These increases resulted the improve effect of added S fertilizers especially these in organo forms in calcareous soil properties such as the increase in soil content of OM and available nutrients as well as the decrease in soil pH and the content of $CaCO_3$ (Osman et al., 2021; Serage et al., 2022). In this respect, Abd El-Ghany et al. (2013) found a significant increases in the enzymes (dehydrogenase, phosphatase and urease) in the soil treated by organic and mineral fertilizers.

TABLE 5. Enzymes (dehydrogenase, phosphatase and urease) activity in calcareous soil affected by sulphur-organo fertilizers.

SFR (kg fed^{-1})	**Dehydrogenase** (µg TPF g^{-1} dry soil h^{-1})	**Alkaline phosphatase** (µg PNP g^{-1} dry soil h^{-1})	**Urease** (µg NH_4–N g^{-1} dry soil h^{-1})
S0	85.30f ±1.35	62.17g ±1.11	2.05g ±0.02
ES 250	95.13e ±2.17	68.80f ±2.09	2.85f ±0.07
ES 500	120.70c ±2.89	80.80d ±2.21	3.95d ±0.13
CS 250	102.20d ±2.41	75.90e ±2.01	3.43e ±0.10
CS 500	133.37b ±3.15	91.33b ±3.14	4.50b ±0.16
CTS 250	122.13c ±2.55	88.03c ±2.63	4.05c ±0.05
CTS 500	141.45a ±3.79	110.50a ±3.92	5.11a ±0.18
LSD 0.05	**1.452**	**1.979**	**0.093**

SFR= Sulphur fertilizers and rates**, S0=** Control without sulphur fertilizer**, ES =** Elemental sulphur**, CS =** sulphur compost, **CTS =** Compost tea riched by sulphur, **TPF**= Trihydrophenyl formazan, **PNP**= ρ-nitrophenol phosphate, Means in a column with the same letter are not significantly different at the 5% level (mean values ± Stdev, n=3).

b. Root bacterial nodules

Bacterial nodules formation on the leguminous plant roots takes as a indicator of biological activity. Data in Table 6 show a significant increase in the bacterial nodules number per plant as a result of S fertilizers applications. Under the experimental treatments, the nodules number increased from 50.13 $plant^{-1}$ with unfertilized plants to 92.19 $plant^{-1}$ with the treatment of 500 kg CTS fed^{-1}, recorded increase percent of 83.83 %. At the same application rate of S fertilizers and according to their effect on the formed nodulation, these fertilizers takes the order: CTS > CS > ES > control. For example, the nodules number was 69.80, 80.80 and 92.19 $plant^{-1}$ with 500 kg S fed^{-1} of ES, CS and CTS, respectively. This means that, S fertilization reduced the harmful effect of $CaCO_3$ on soil microbial activity (Desta et al., 2015; Elsaggan, 2020; Bezabeh et al., 2021).

3.4. Straw and seeds yields of faba bean plant

Response and specific effect of three S fertilizers forms on the yield (kg fed^{-1}) i.e. straw, seeds and biological was studied under calcareous soil conditions of Egypt and the obtained data are listed in Table 6. These data show that, there are a significant increase in both seeds, straw and biological yields (kg fed^{-1}) of faba bean plant with the increase rate of added S in the three forms, where these yields were increased from 1311, 1435 and 2746 kg fed^{-1} in the control treatment (without S application) to 1772, 1810 and 3582 kg fed^{-1} in the plots received 500 kg CTS fed^{-1}, recorded increase percent of 35.16, 24.40 and 29.30 %, respectively. These values means that, S applications resulted in a high increase of seeds yield compared with that recorded with straw yield. This findings are in similar with those found by El-Galad et al. (2013) and recently by El-Sharkawy et al. (2021). Regarding to the specific effect of the used S fertilizers forms under the experimental treatments the data in Table 6 show that, at the same rate of added S fertilizers forms, CTS application was associated by a high yields of faba bean (seeds and straw) plot followed by the plants grown on the soil treated by CS and ES. In this respect, Elgezery (2016) and Abou Hussien et al. (2017) found a superior increase of barley plants fertilized by CS than with those found with ES application under calcareous soil conditions. These variation attributed to the reaction and transformation of added S forms in the soil and its effect on the improve soil chemical properties (El-Gamal, 2015).

Also, data in Table 6 show biological or harvest index of faba bean plants affected by both forms and application rate of S fertilizers. These values were increased with the increase in added rate in the three forms, where these values varied from 47.74 % without S applications to 49.47 % in the plants fertilized by 500 kg fed^{-1} (CTS). Increasing rate of added S resulted in a very small increase in harvesting index. For example, increasing application of CTS from 250 to 500 kg fed^{-1} resulted in the increase of biological index from 48.57 to 49.47 %. Increasing biological index as a result of S applications reveals to enhance effect of S fertilization in calcareous soil on seeds productivity of faba bean plants.

In addition, data in Table 6 show the agronomical efficiency of the used S fertilizers in calcareous soil. These data clear that, for each S fertilizer, agronomical efficiency was decreased with the increase added rate. For example, agronomical efficiency of S added as CTS was 6.46 and 3.54 kg kg^{-1} with the application rates of 250 and 500 kg fed^{-1}, respectively. As well as, the values of agronomical efficiency values of faba bean plants varied from S sources to another, where the highest values were found with the application of CTS followed by those found with CS and ES applications. For example, these values with 500 kg fed^{-1} were 3.06, 3.33 and 3.54 kg kg^{-1} for ES, CS and CTS applications, respectively.

TABLE 6. Nodules number, seeds yield, straw yield, biological yield and harvest index of faba bean plant as well as the efficiency of S fertilizers in calcareous soil fertilized by sulphur-organo fertilizers.

SFR (kg fed^{-1})	**Nodules*** (number plant^{-1})	**Seed yield** (kgfed^{-1})	**Straw yield** (kgfed^{-1})	**Biological yield** (kgfed^{-1})	**Harvest index** (%)	**Sulphur efficiency** (kgkg^{-1})
S0	50.13^{f} ±2.02	1311.0^{g} ±11.30	1435.0^{f} ±15.12	2746.0^{g} ±26.42	47.74^{d} ±0.16	-
ES 250	57.44^{e} ±3.01	1380.0^{f} ±23.50	1510.0^{e} ±21.34	2890.0^{f} ±44.84	47.75^{d} ±0.28	5.52
ES 500	69.80^{c} ±2.11	1530.0^{d} ±32.55	1650.0^{c} ±31.15	3180.0^{d} ±63.70	48.11^{cd} ±0.34	3.06
CS 250	63.75^{d} ±3.04	1493.0^{e} ±21.41	1585.0^{d} ±18.56	3078.0^{e} ±39.97	48.51^{bc} ±0.49	5.98
CS 500	80.80^{b} ±2.03	1665.0^{b} ±29.25	1730.0^{b} ±25.50	3395.0^{b} ±54.75	49.04^{ab} ±0.52	3.33
CTS 250	70.23^{c} ±3.17	1615.0^{c} ±27.61	1710.0^{b} ±26.71	3325.0^{c} ±54.32	48.57^{bc} ±0.30	6.46
CTS 500	92.19^{a} ±2.42	1772.0^{a} ±31.72	1810.0^{a} ±30.65	3582.0^{a} ±62.37	49.47^{a} ±0.49	3.54
LSD 0.05	**3.153**	**27.994**	**28.790**	**37.537**	**0.658**	**-**

SFR= Sulphur fertilizers and rates**, S0=** Control without sulphur fertilizer**, ES =** Elemental sulphur**, CS =** sulphur compost, **CTS =** Compost tea riched by sulphur, *= Nodules number is the mean values of five plants**,**Means in a column with the same letter are not significantly different at the 5% level (mean values ± Stdev, n=3 with the exception of nodules number which equal 5 plants per each replicate).

3.5. Plant content of macronutrients

Seeds and straw of faba bean plants content (% and kg fed^{-1}) of some macronutrients (N, P, K, Ca and S) in calcareous soil fertilized by the three forms of S fertilizers were studied and the obtained data are recorded in Tables (7 and 8) and Figures (1 and 2). These data show that, the contents (% and kg fed^{-1}) of the determined nutrients were increased significantly at all application rates of S fertilizers in compared with the control treatment (S0). With the same treatment of S fertilization, seeds concentrations (%) of N, P, K, Ca and S were higher than those recorded with the straw. For example, with 500 kg S as CS fed^{-1}, the seeds content (%) of N, P, K, Ca and S were 1.92, 0.80, 1.22, 0.95 and 1.38 % and were 1.35, 0.56, 0.92, 0.84 and 0.96 % in the straw, respectively. Thus, the uptake (kg fed^{-1}) of these nutrients by seeds and straw takes the same trend of their nutrients content (Figures 1 and 2). The highest significant values (kgfed^{-1}) of N (37.21; 26.25), P (14.88; 11.95), K (22.15; 17.38), Ca (18.61; 16.11) and S (27.29; 20.27) for seeds and straw, respectively were recorded to CTS treatment. While the lowest one of seeds (20.45, 8.52, 12.19, 9.57, and 9.18 kgfed^{-1}) and straw (16.93, 5.45, 11.19, 9.47, and 9.18 kgfed^{-1}) for N, P, K, Ca and S, respectively accompanied the S0 plots.

These findings are similar with those obtained by El-Gamal (2015) and Abou Hussien et al. (2021) with wheat and faba bean plants, respectively. As well as, with the same rate of added S, the highest N, P, K, Ca and S concentrations were found in both seeds and straw of faba bean plants fertilized by CTS followed by these recorded in the plants received S as CS form. Before that, Elgezery (2016) and Abou Hussien et al. (2020) found a significant differences in barley plants response to S added in different forms.

TABLE 7. Seeds of faba bean plants content (%) of N, P, K, Ca and S affected by sulphur-organo fertilizers under calcareous soil conditions.

SFR (kg fed^{-1})	**N** (%)	**P** (%)	**K** (%)	**Ca** (%)	**S** (%)
S0	1.56e ±0.03	0.65g ±0.02	0.93g ±0.01	0.73g ±0.02	0.70g ±0.01
ES 250	1.60e ±0.04	0.70f ±0.02	0.98f ±0.03	0.80f ±0.03	0.82f ±0.02
ES 500	1.80c ±0.04	0.78c ±0.04	1.10d ±0.05	0.90d ±0.02	1.03d ±0.03
CS 250	1.67d ±0.02	0.73e ±0.01	1.03e ±0.02	0.87e ±0.05	0.93e ±0.01
CS 500	1.92b ±0.02	0.80b ±0.03	1.22b ±0.03	0.95b ±0.03	1.38b ±0.03
CTS 250	1.83c ±0.03	0.76d ±0.02	1.13c ±0.01	0.92c ±0.02	1.22c ±0.04
CTS 500	2.10a ±0.04	0.84a ±0.05	1.25a ±0.03	1.05a ±0.06	1.54a ±0.03
LSD 0.05	**0.045**	**0.008**	**0.008**	**0.008**	**0.040**

SFR= Sulphur fertilizers and rates**, S0=** Control without sulphur fertilizer**, ES =** Elemental sulphur**, CS =** sulphur compost, **CTS =** Compost tea riched by sulphur, Means in a column with the same letter are not significantly different at the 5% level (mean values ± Stdev, n=3)**.**

TABLE 8. Straw of faba bean plants content (%) of N, P, K, Ca and S affected by sulphur-organo fertilizers under calcareous soil conditions.

SFR (kg fed^{-1})	N (%)	P (%)	K (%)	Ca (%)	S (%)
S0	1.18f ±0.02	0.38e ±0.01	0.78d ±0.02	0.66g ±0.01	0.64g ±0.03
ES 250	1.22e ±0.04	0.42d ±0.02	0.80d ±0.03	0.70f ±0.02	0.71f ±0.03
ES 500	1.30c ±0.03	0.50c ±0.04	0.88c ±0.03	0.76d ±0.04	0.85d ±0.01
CS 250	1.25de ±0.02	0.43d ±0.03	0.85c ±0.01	0.74e ±0.01	0.80e ±0.02
CS 500	1.35b ±0.03	0.56b ±0.02	0.92b ±0.02	0.84b ±0.03	0.96b ±0.03
CTS 250	1.28cd ±0.03	0.51c ±0.02	0.88c ±0.02	0.80c ±0.01	0.93c ±0.01
CTS 500	1.45a ±0.03	0.66a ±0.03	0.96a ±0.03	0.89a ±0.04	1.12a ±0.03
LSD 0.05	**0.038**	**0.038**	**0.039**	**0.019**	**0.016**

SFR= Sulphur fertilizers and rates**, S0=** Control without sulphur fertilizer**, ES =** Elemental sulphur**, CS =** sulphur compost, **CTS =** Compost tea riched by sulphur, Means in a column with the same letter are not significantly different at the 5% level (mean values ± Stdev, n=3)**.**

4. Conclusion

All sulphur fertilizers examined for reclamation calcareous soil in this study, including elemental sulphur (ES), compost treated with sulphur (CS), and compost tea enriched with sulphur (CTS), were effective at ameliorating soil chemical (pH, EC, OM, CEC, and $CaCO_3$) and biological properties (dehydrogenase, phosphatase, and urease activities) and its content of available macronutrients (N, P, K, Ca, and S) which this positively affected the increase of the soil productivity (seeds and straw yields) of faba bean plants and its content of the examined nutrients.The best treatments affecting soil properties and plant traits were in favor of CTS and CS treatments.

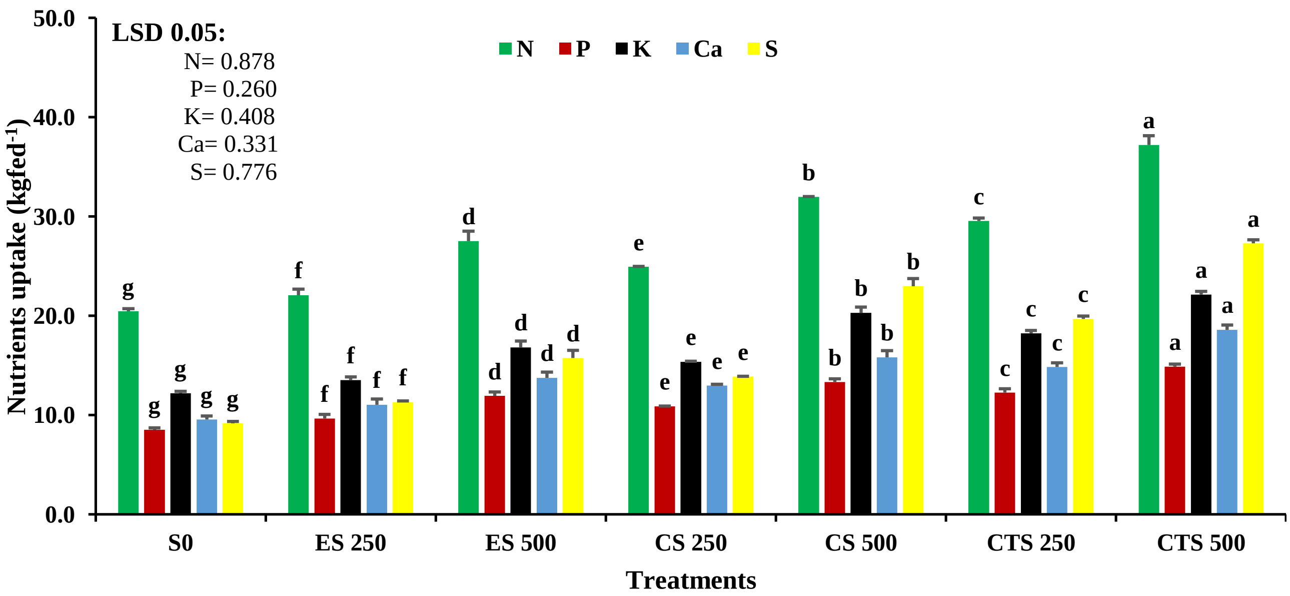

Fig. 1. Seeds of faba bean plants uptake for N, P, K, Ca and S as affected by sulphur-organo fertilizers under calcareous soil conditions. S0= Control without sulphur fertilizer, ES = Elemental sulphur, CS = sulphur compost, CTS = Compost tea riched, 250 and 500 are application rates (kg fed^{-1}), columns within the same nutrients labelled with different letter are significantly different at 5 % level of probability (error bars represented ± Stdev., n=3).

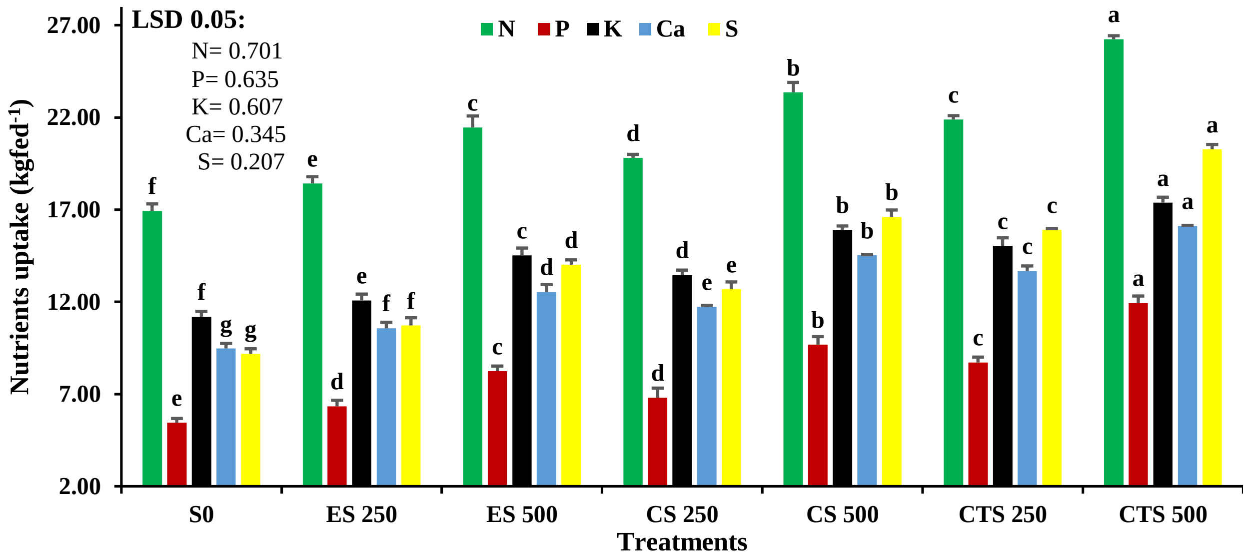

Fig. 2. Straw of faba bean plants uptake for N, P, K, Ca and S as affected by sulphur-organo fertilizers under calcareous soil conditions. S0= Control without sulphur fertilizer, ES = Elemental sulphur, CS = sulphur compost, CTS = Compost tea riched, 250 and 500 are application rates (kg fed^{-1}), columns within the same nutrients labelled with different letter are significantly different at 5 % level of probability (error bars represented ± Stdev., n=3).

Conflicts of interest

There is no conflict of interest between the authors or any donor or funding agency.

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