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EFFECT OF *THIOPAQ* ELEMENTAL SULFUR APPLICATION ON MANGANESE AVAILABILITY TO ZEA MAIZE GROWN ON CALCAREOUS SOILS

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ABSTRACT: *Micro-nutrient manganese (Mn) management in calcareous soils is greatly influenced by the problem of high content and reactivity of calcium carbonate as well as alkaline properties associated to calcareous environment. In an attempt to use THIOPAQ elemental sulfur (TES) – which is biologically produced from petroleum sour gas refinery processes - as a soil acidifier, incubation experiments of soils with sulfur were carried out for periods extended to 20 weeks to investigate the effect of applied sulfur rates on availability of soil Mn. In addition, greenhouse experiments were conducted to study the effects of applied sulfur on some agronomic parameters and Mn uptake by Zea maize. Amendment of soils with TES increased the concentration of DTPA-Mn in the three tested calcareous soils comparing to the control. Slightly more increments in DTPA-Mn concentration were also observed in the soils treated with sulfur in the presence of sulfur oxidizing bacteria (P. versutus) in all soils throughout the incubation times. TES applications to soils markedly increased SO_4^{2-} concentration in all soils at different incubation times under the conditions of absence and presence of P. versutus. The oxidation rate of TES was closely related to the initial concentration of SO_4^{2-} in soil solution; the higher initial SO_4^{2-} in soil solution the lower rate of S oxidation in both non-inoculated and inoculated soils. In greenhouse, the results indicated that main increases in the dry weight were attributed to the application of sulfur or sulfur with bacteria. Mn content in the plants grown on non-inoculated soils significantly increased as the rate of applied TES increased. Similar observations were found in the inoculated soils with P. versutus but at higher levels. The total Mn concentrations in maize grown in inoculated soils and treated with S2 and S3 of sulfur were equal. Soil inoculation by P. versutus enhanced the concentration of total Mn in all rates of S treatments and reflect the probable role of bacteria as a promoter of plant uptake of Mn. Application of S to soils greatly increased S content in the roots comparing with its contents in the shoots. S in both parts of corn plant increased as S application rate* *increased. The highest concentrations of S in plant roots were observed in the TES+P. versutus-treated soils particularly with S2 and S3 rates.*

Key Words: *Elemental Sulfur, DTPA-manganese, Zea maize, calcareous soils*

INTRODUCTION

In calcareous soils, calcium carbonate dominates the problems related to agricultural land use. The reactivity of calcium carbonate is considered very important property of soil carbonate that influence soil chemical and rhizosphere processes (Loeppert and Suarez, 1996). Calcium carbonate provides a reactive surface for adsorption and precipitation reactions, for example phosphate, micronutrients (Fe, Mn, Zn and Cu) and dissolved organic compounds (Saleh *et al.*, 1998, Amer *et al.*, 1991).

Availability of phosphorus and trace elements in calcareous soils is one of the major problems facing soil scientists and several studies have been done to enhance or elongate their availability to grown plants (Gholamabbas el al., 2010; Jalali and Moharrami, 2007, Carrillo-González el al., 2006).

Manganese (Mn) is an essential plant micronutrient acting as the key part of prosthetic groups in important processes including catalysis of the splitting of water in photosystem II (enzyme-S) and the scavenging of reactive oxygen species in the mitochondria by a Mn-containing superoxide dismutase (Mn-SOD). Moreover, Mn is an activator in several important enzymes including phenylalanine ammonia lyase (PAL), enzymes of the tri-carboxylic acid cycle and the chloroplast RNA polymerase (Marschner, 1995). Solubility of manganese in calcareous soils is less than the limiting factor of plant requirements and its solubility is controlled by $MnCO_3$ (Saleh, 1989 and Schwab and Lindsay, 1983). Sinha *et al.* (1978) reportted that, in calcareous and alkaline soils, soil pH and organic matter content were found to significantly affect the solubility of manganese. The solubility relationship of manganese has been expressed as a function of soil solution pH and the application of soil acidifiers such as sulfuric acid (Ryan *et al*, 1974) or elemental sulfur (Saleh, 2001) increasing Mn solubility and availability in calcareous soils.

Beside its essentiality to plant nutrition, elemental sulfur (ES) is considered as one of the major soil amendments used for reclaiming alkaline and calcareous soils (Marschner, 1995). ES was used as an soil acidifier and its effectiveness is governed by its oxidation rate, which is primarily a microbiological function. Thus physical factors such as soil temperature and moisture play an important role in regulating S oxidation (Janzen and Bettany, 1987). In a study on application of ES to calcareous soils used in growing mustard plants (*Brassica juncea*) under the growth chamber conditions, Kayser *et al.* (2001) found that ES addition increased the Zn and Cd solubilization in soil and increased their uptake by plants. On the other hand, Chouliaras and Tsadilas (1996) studied soil acidification by ES and its effect on the availability of K, P, Fe, Zn, Mn, and Cu to kiwifruit grown in pot experiment. They showed that organic P was significantly reduced while inorganic P increased. The increase in Fe concentration was insufficient for crop requirements whereas Cu and Mn increased to above the recommended level. In contrast, Falatah (1998) found that ES application to calcareous soil of the Kingdom of Saudi Arabia did not increase the available concentrations of Cu and P.

Zea maize as oilseed crop is one of S high responded crops, this response is ideal in the cases of S application in the forms of elemental sulfur and ammonium sulfate specially in alkaline and calcareous soils (Ghosh *et al.*, 2000). Using nitrilotriacetate (NTA) and elemental sulfur amendments in calcareous soils increased the solubility of Zn, Cd and Cu in soils and uptake by Zea maize plants (Kayser *et al.*, 2000). Husted *et al.* (2005) found that fertilizers containing sulfur in the form of reduced S (thiosulfate) had a strong mobilizing effect on Mn, and enabled the plants to accumulate large amounts of Mn in the biomass compared with oxidized S (sulfate).

The objectives of this work are exploring the effects of applied THIOPAQ elemental sulfur (TES) - which produced from the refinery processes of petroleum sour gases - on the availability of soil Manganese in calcareous sandy soils as a function of incubation time after application at constant temperature in laboratory. On the other hand, the role of Sulfur as soil amendment and its role in manganese availability to zea maize were studied.

MATERIALS AND METHODS

Laboratory incubation

According to Arena *et al.*, (2000), THIOPAQ technology is a family of reaction processes that can be used to remove and recover sulfur from sour refinery gas; sulfidic spent caustic, liquefied petroleum gas, flue gas and sour water. In these applications, the process can convert (oxidize) the sulfide to elemental sulfur or to sulfate. The controlled oxidation of sulfide to S is catalyzed by naturally occurring bacteria of the genus *Thiobacillus* which are introduced to the bioreactor with the proper growth media. The conversion process is carried out under the near ambient conditions of temperature and pressure. The THIOPAQ unit which is licensed by Paques to Alexandria for Mineral Oils Company (AMOC) is designed to remove and recover H_2S from three streams simultaneously, the sour offgas, the acid gas and the spent caustic streams.

Three different soils were collected from the regions of Al Noubaria (Abu Bakr and Adam Villages) and Bangar Assokkar (Mostafa Ismail Village). Some physicochemical properties were determined such as electrical conductivity and water soluble cations and anions in saturated extracts of soil paste (Roades *et al.*, 1982), soil pH in 1: 2.5 soil : water suspension (Page *et al.*, 1986). Particle-size distribution was determined by hydrometer method (Pansu and Gautheyrou, 2006). Total carbonate was determined by calcimeter method and active carbonate was determined by ammonium oxalate method (Pansu and Gautheyrou, 2006). DTPA-exatractable micronutrient cations were determined according to Martins and Lindsay (1990) and Olsen P concentration in soil was determined according to Fixen and Grove (1990). Table (1) presents some physicochemical properties of studied soils.

Incubation experiments at constant temperature were conducted in laboratory to study the effect of THIOPAQ elemental sulfur (TES) on the availability of soil Mn. Three riplicates of 100-gm of 2-mm air dried soil samples were thoroughly mixed with 0.418g S (1000 kg S/hectar) TES particles (< 150 um) were transferred into 200-mL plastic gars. Then samples were saturated with distilled water in the presence or absence of 5 mL of bacterial inoculant *Thiobacillus versutus* (also is called *Paracoccus versutus*).

After saturation, all samples were incubated at 30 $\pm$ 2 $^{\circ}$C to dry for 4 days then re-saturated with water again and repeated every 4 days. After 5, 10, 15 and 20 weeks of incubation, three replicates of treatments were withdrawn from incubation for analysis. Dried soil samples were crushed and pH was measured in soil suspension. The concentration of available S, and DTPA-extracted Mn were determined (Page *el al.*, 1986).

In soil suspensions, pH was measured using combined pH meter Orion model 900A. Available SO_4-S (is an indicator of S oxidation) and DTPA-Mn were measured using inductive coupled plasma emission spectrophotometer, Thermo, ICP-OES, 6000 series.

Greenhouse Experiments

A pot experiment was conducted in greenhouse to study the effect of TES application to soil on the growth of Zea maize and its Mn and S uptake. The soil samples of Adam village were air-dried and sieved through 4-mm stainless steel sieve and transferred into 5 kg-capacity plastic pots. In a four replicates, 3.8 kg soil were weight and transferred into the pots (height = 30.0 cm and diameter = 25.0 cm and surface area = 0.049 m^2). Then the soil was saturated with water (1.34 L). Nitrogen, phosphorus, and potassium fertilizers were thoroughly mixed with 1.0 kg soil by the rates 1.73 g urea, 3.3 g mono-super phosphate and 1.08 g potassium sulfate then TES was added (particle size less than 150 micron) by the rates 0.238, 1.20 or 2.40 ton ha^{-1} and mixed with the soil. In 50% of the treatments, sulfur-oxidizing bacteria *Paracoccus versutus* was added to soil by the rate 5 mL pot^{-1} (each mL contains $1x10^7$ cfu) after carrying it on 40.0 g peat moss and is mixed with the soil mixture and were transferred on to the soil in pots.

Table (1): Selected physicochemical characteristics of studied soils.

Property	Abu Bakr	Adam	Mostafa Ismail
Texture:			
Sand (%)	95.73	86.62	75.00
Silt+Clay (%)	4.27	13.38	25.00
Total $CaCO_3$ (%)	28.17	23.65	38.98
Active $CaCO_3$ (%)	2.50	0.00	3.50
Organic Matter (%)	0.14	0.32	0.17
EC, dS/m	8.85	10.01	2.50
pH	8.48	8.22	8.60
Soluble cations (meq/L):			
Ca	28.60	32.40	9.20
Mg	15.80	32.60	5.40
Na	29.60	24.66	14.80
K	0.91	0.65	0.10
Soluble anions (meq/L):			
Cl	63.20	85.00	16.60
HCO_3	1.30	3.20	1.70
SO_4	46.04	28.96	5.67
Olsen P, mg/kg	0.363	1.305	0.200
DTPA–extractable Micronutrients (mg/kg soil):			
Fe	2.780	2.800	1.440
Mn	4.100	1.760	1.780
Zn	1.080	3.200	0.300
Cu	0.360	0.300	0.134

Ten seeds of Zea maize were sowed in each pot then 0.2 kg soil was spreaded on the seeds and the pots were saturated by amounts of water enough to saturate only 1.2 kg soil. Then, the pots were distributed in the greenhouse using the randomized complete block design (RCBD). All treatments were received water every 4 days to be at 60% of water-holding capacity. The minimum and maximum values of temperature and relative humidity in the greenhouse were daily recorded. After ten days of sowing, 5 seedlings were withdrawn from each pot and the best 5 ones were lift in the pots. The plants were fertilized by 0.625 g urea per pot (after solubilization in irrigation water) and received the same amounts after 14 and 17 days of sowing. The average of temperature throughout 40 days was 18.5 °C minimum and 29.8 °C maximum and the relative humidity were 75.3% minimum and 83.0% maximum.

After 40 days of sowing, plants were harvested, washed by water and the fresh weight of total plant, shoots and roots were recorded. Then plant materials were dried at 65 °C for 48 hours and the dry weight was recorded for the shoots and roots. Plants were crushed and sieved through 20-mesh stainless steel screen for determination of sulfur and manganese. Plant samples were dry-ashed according to Jones and Case (1990) and S and Mn were measured using ICP-OES Thermo, ICP-OES, 6000 series.

STATISTICAL ANALYSIS

Data were statistically analyzed using Costat statistical analysis software, Analysis of variance (ANOVA) at 0.05 significance level were applied to determine the significance of the obtained results.

Results and Discussion
Soil Incubation

The effects of TES addition to soils in absence and presence of sulfur oxidizing bacteria on soil available manganese (DTPA-Mn) are shown in Fig. (1). Amendment of soils with sulfur increased the concentration of DTPA-Mn in the three tested soils comparing to the control (incubated soil).

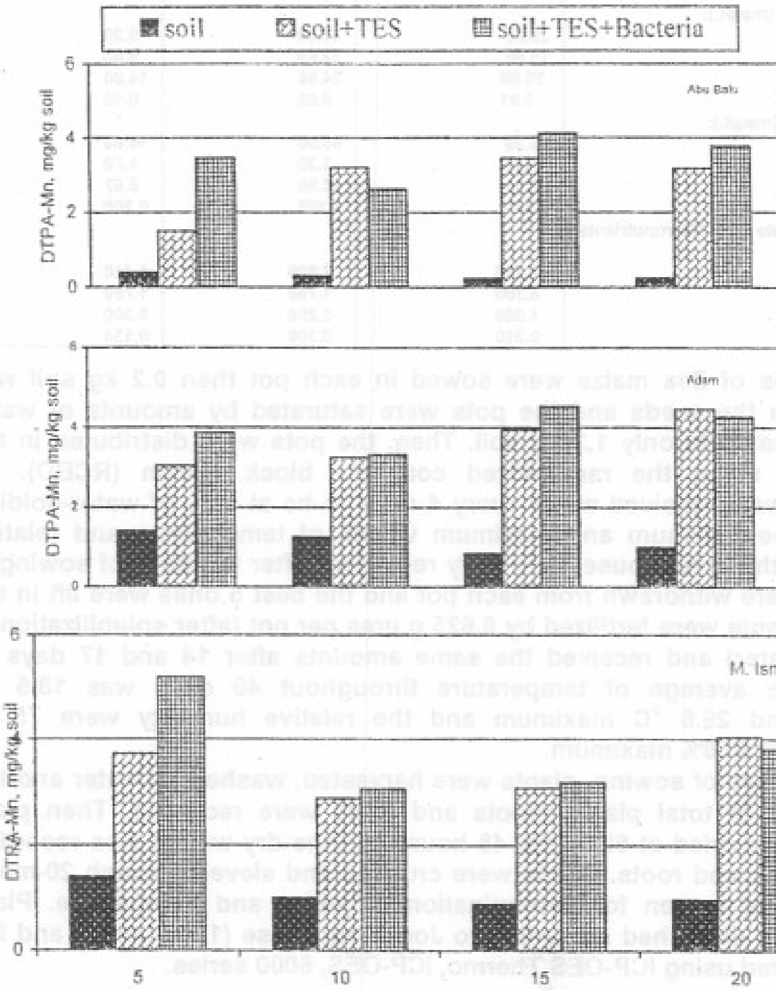

Fig. (1) DTPA-Mn concentration in the incubated calcareous soils till 20 weeks and treated with THIOPAQ elemental sulfur in presence and absence of sulfur oxidizing bacteria.

Slightly more increments in DTPA-Mn concentration were also observed in the soils treated with sulfur in the presence of *P. versutus* in all soils throughout the incubation times comparing to the soils treated only by S or bacteria. After 5 weeks of incubation and addition of TES, DTPA-Mn concentrations increased 3.81, 2.2, and 2.68 folds in Abu Bakr, Adam and M. Ismail soils, respectively (Fig. 1). These increments were related indirectly to sulfur oxidation where the oxidation process was accompanied with reduction in soil solution pH (0.29, 0.44, and 0.39 units, respectively). The extended periods of soil incubation (10, 15 and 20 weeks) with TES released more amounts of DTPA-Mn particularly in Abu Bakr and Adam soils (Fig. 1). The inoculation process of TES-treated soils increased the available Mn in soils particularly in the first 5 weeks of incubation in all soils. The higher concentrations of available soil Mn was also related to more reductions in soil pH (0.56, 0.73 and 0.54 units in Abu Bakr, Adam and M. Ismail, respectively). In a study of applied ES oxidation in calcareous soils, Cifuentes and Lindemann (1993) showed that enhanced elemental S oxidation consistently increased only Mn availability in the field and did not affect the other micronutrients. On the other hand, the current results were in agreement with the work of Modaihsh *et al.* (1989) where they studied, in a columns incubation experiment for periods extended to 18 weeks, the effect of elemental sulfur on nutrients availability in calcareous soils and found that the application of sulfur by rates 0.5, 1.5 and 3.0% (w/w) to soils increased the Olsen P and DTPA-Mn and slightly increased DTPA-Fe and Cu and had no effect on DTPA-Zn.

It is suggested that variations in Mn behavior might be related to the solid phase dominance in the tested soils where $CaCO_3$ is considered the major active solid phase in soil comparing to the other active phases such as organic matter in tested soils which ranged from 0.14 – 0.32% (see Table 1) and its influence on Mn availability was not dominated. The retention of Mn by $CaCO_3$ is higher than its affinity toward Fe and Zn whilst soil organic matter and Fe hydroxides preferred to adsorb and initiate complex formation with Fe and Zn than with Mn (Lindsay, 1979). On the other hand, Zn can be fixed or initiates complexes with clay minerals (Ford and Sparks, 2000). The closed complexation of Mn with carbonate in the tested soils may simply interpreting Mn release from soil as a result of TES application (as a soil acidifier).

Figure (2) shows that TES application to soils markedly increase SO_4^{2-} concentration in all soils at different incubation times in absence and presence of *P. versutus*. The oxidation rate of TES was related to the initial concentration of SO_4^{2-} in soil solution; the higher initial SO_4^{2-} in soil solution the lower rate of S oxidation in both non-inoculated and inoculated soils with *P. versutus* (Table 1 and Fig. 2). In Abu Bakr soil, where the initial concentration of water soluble SO_4^{2-} was 23.02 mmol/L, the oxidation process throughout the 20 weeks of incubation increased SO_4^{2-} concentration about

1.52 folds over the initial concentration whereas in M. Ismail soils where initial SO_4^{2-} is 2.84 mmol/L, the application of TES increased SO_4^{2-} about 10.13 times over initial concentration (Table 1 and Fig.2). These observations speculate that the high concentration of SO_4^{2-} in soil solution will inhibit the microbial oxidation process of elemental sulfur added to soils and the process will be achieved after long period depending on the dynamics of SO_4^{2-} in soil solution.

Table (2) summarizes the results of analysis of variance (ANOVA) to explore the main factors affecting Mn availability. The analysis showed that regardless the soil properties, the major factor affecting Mn availability was the TES application which also markedly decreased the pH of soil. Inoculation with sulfur-oxidizing bacteria had no significant effect on measured parameters. Lei *et al* (2007) showed that the biooxidation reaction of elemental sulfur by bacteria releasing 4 protons from each 2 oxidized atoms of S according to the following equation:

$$2S + 2H_2O + 3O_2 \xrightarrow{\textit{bacteria}} 2SO_4^{2-} + 4H^+$$

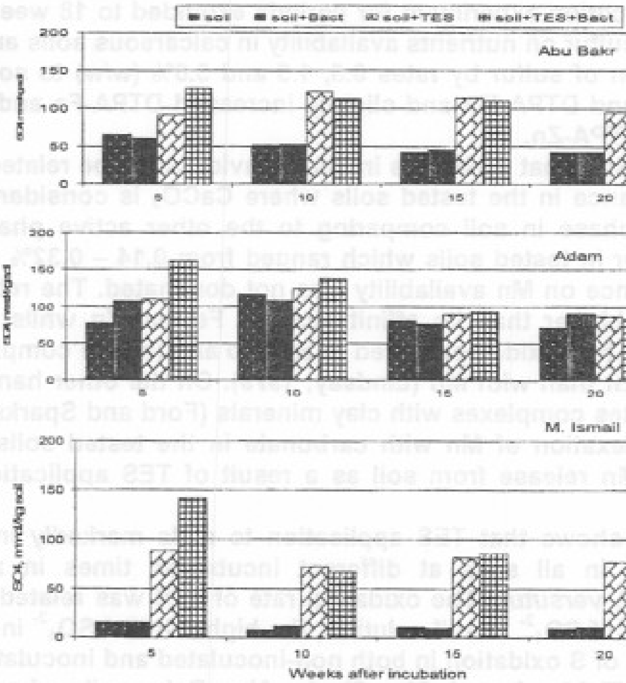

Fig (2). : Effect of applied TES to calcareous soils at different incubation periodswith S-oxidizing bacteria on concentration of soil solution sulfate.

Table (2): The effect of TES and S-oxidizing bacteria on th soil reaction (pH), DTPA-Mn and soil solution sulfur after 5, 10, 15 and 20 weeks of incubation

Factors	pH	Sulfur, mmol/kg soil	DTPA-Mn, mg/kg soil	pH	Sulfur, mmol/kg soil	DTPA-Mn, mg/kg soil
	5 weeks			10 weeks		
Soil (S)						
soil 1	7.72 c	113.87 a	14.25 b	7.93 a	121.26 a	14.86 b
soil 2	8.07 a	85.77 b	27.43 ab	8.03 a	39.81 c	21.34 a
soil 3	7.78 b	65.38 c	31.25 a	7.56 b	85.99 b	20.86 a
LSD0.05	0.027	12.505	13.82	0.154	8.245	4.003
Sulfur (Sul)						
without	8.12 a	56.80 b	17.06 b	8.03 a	58.58 b	7.63 b
with	7.60 b	119.88 a	31.55 a	7.65 b	106.12 a	30.11 a
LSD0.05	0.022	10.210	11.286	0.126	6.732	3.268
Bacteria (B)						
Without	7.90 a	74.73 b	22.97 a	7.87 a	82.15 a	19.76 a
With	7.82 b	101.95 a	25.64 a	7.81 a	85.55 a	18.28 a
LSD0.05	0.001	10.21	11.286	0.126	6.732	3.268
Main Effect						
S	***	***	*	***	***	**
Sul	***	***	*	***	***	***
B	***	***	ns	ns	ns	ns
Interactions						
SXSul	***	***	ns	**	***	ns
SXB	**	ns	ns	ns	ns	ns
SulXB	***	***	ns	ns	ns	ns
SXSulXB	***	ns	ns	ns	ns	ns
	15 weeks			20 weeks		
Soil (S)						
soil 1	8.20 a	84.88 a	19.12 b	8.27 a	83.10 a	24.63 a
soil 2	8.05 b	46.59 b	18.49 b	8.23 a	41.78 c	22.15 b
soil 3	7.69 c	78.97 a	23.99 a	8.05 b	67.91 b	17.36 c
LSD0.05	0.053	6.472	3.205	0.053	3.953	2.267
Sulfur (Sul)						
Without	8.15 a	44.77 b	33.79 a	8.36 a	44.05 b	7.10 b
with	7.81b	95.83 a	7.29 b	8.01 b	84.47 a	35.66 a
LSD0.05	0.043	5.284	2.617	0.044	3.228	1.851
Bacteria (B)						
Without	7.98 a	69.62 a	18.98 b	8.19 a	63.30 a	21.07 a
With	7.98 a	70.67 a	22.10 a	8.17a	65.23 a	21.70 a
LSD0.05	0.043	5.284	2.617	0.044	3.228	1.851
Main Effect						
S	***	***	**	***	***	***
Sul	***	***	***	***	***	***
B	ns	ns	*	ns	ns	ns
Interactions						
SXSul	***	***	**	***	***	ns
SXB	*	ns	ns	*	*	ns
SulXB	ns	ns	ns	*	**	ns
SXSulXB	ns	ns	ns	ns	ns	ns

Greenhouse Experiment

Growth parameters

Both the plant shoots and roots are highly affected by TES application where more plant height and more root volume and length were observed (Fig. 3).

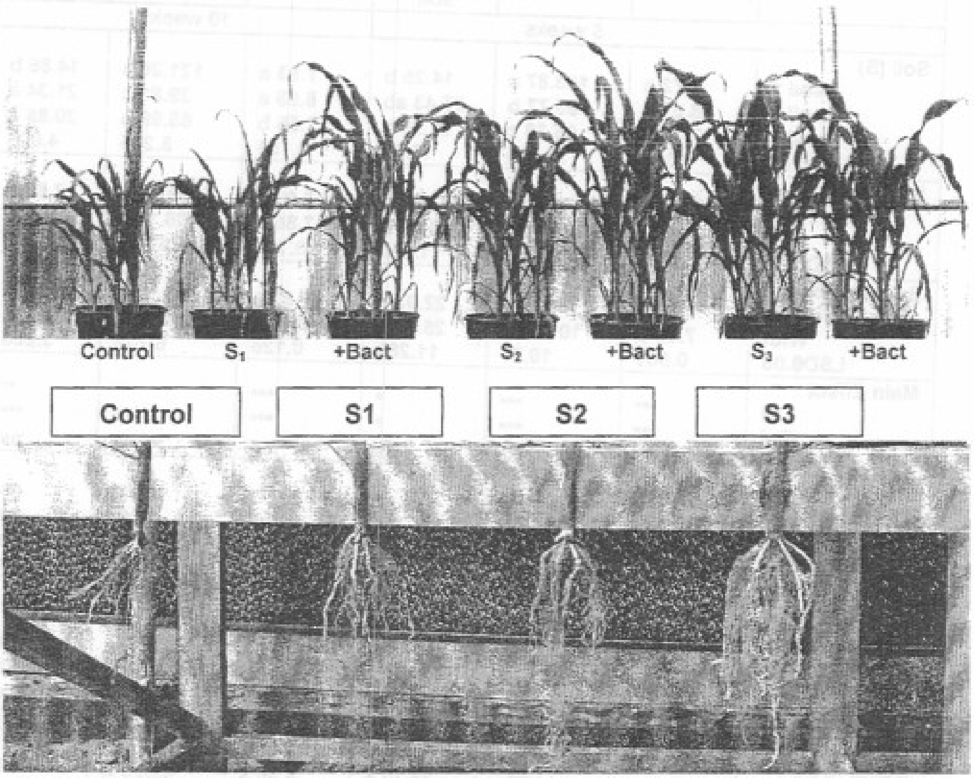

Figure (3): Effect of the applied rates of THIOPAQ elemental sulfur to Adam soil in the absence and presence of S-oxidizing bacteria (*Paracoccus versutus*)on the growth shoots and roots of Zea maize after 40 days of planting date.

Dry weight

Figure (4A) summarizes the dry weight plant shoots and roots as a results of applied sulfur rates. Application the different tested rates of TES to the soil increased the dry weight of both shoot and root of Zea maize plants. Addition of sulfur with *P. versutus* inoculants gave little increments in the shoot and root dry weight. Similar results were obtained by Besharati and Rastin (1999) where they found that S application (by 0.5%) with *Thiobacillus* inoculation had significant effects on dry matter roots and shoots of Zea maize grown in calcareous soils under greenhouse conditions. The inoculation of soil with *P. versutus* not significantly increased the dry weight of both shoots and roots of plant comparing with control and the main increases in the dry weight were attributed to the application of sulfur or sulfur with bacteria (Fig. 4A).

Effect of TES on Mn and S uptake

The total uptake of nutrients by the shoots and roots of corn plants were determined and calculated as mg nutrient per pot based on the dry weight. Results in Table 3 present the effect of S application in the absence and presence of *P. versutus* on the nutrients uptake in plant shoots and roots.

Manganese

The results of total uptake of Mn by plants was illustrated in Figure (4B). It was clear that Mn content in the plants grown on non-inoculated soils significantly increased as the rate of applied TES increased. Similar observations were found in the inoculated soils with *P. versutus* but by higher levels. The total Mn concentrations in maize grown on inoculated soils and treated with S2 and S3 of sulfur were equal (Fig. 4B). It is noteworthy to note from this figure that soil inoculation by *P. versutus* enhanced the concentration of total Mn in all rates of S treatments.

Sulfur

Sulfur contents in the roots of 40 day old maize plants are greater than its contents in the plant shoots and the differences between the roots and shoots S content changed according to the applied treatment (Fig. 4C). In the S non-treated soils, S content in roots increased about 1.64 and 2.8 mg/pot than the shoot-S in non-inoculated and inoculated soils, respectively. Application of S to soils greatly increased S content in the roots comparing with its contents in the shoots. S in both parts of corn plant increased as S application rate increased. Higher concentrations of S in plant roots were observed in the TES+*P. versutus*-treated soils particularly with S2 and S3 rates (Fig. 4C). Application of S increased the shoot S content by 74.84, 172.62 and 188.76% in the S1, S2, and S3-treated soils, respectively. On the other hand, further increments were observed in the S-treated soils in the presence of *P. versutus*. With respect to S content in the roots, inoculation of soils by *P. versutus* led to more plant uptake of S from the soils treated with all rates and forms of S.

Similar results were found in the previous studies, for example, Lefroy *et al.* (1997) found that S uptake by maize plants increased as applied S oxidation rate increased. Important results were obtained by these authors where they found that S uptake increased with application fine particles of S than with the coarse particles. It is clear that total S in plant increased with increasing the rate of applied sulfur and the maximum uptake was observed in the treatments of combination of applied S with bacteria.

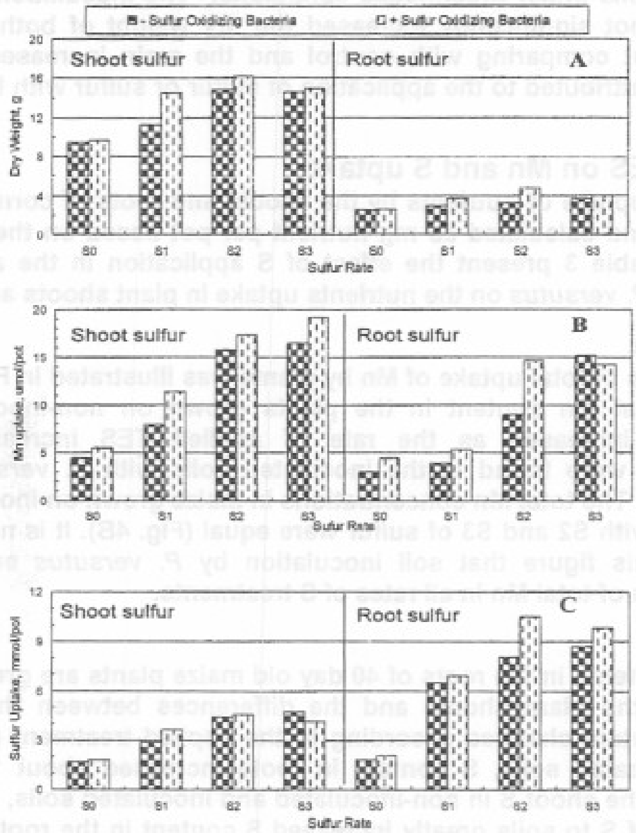

Fig. (4): Effect of TES application with or without sulfur-oxidizing bacteria on the dry weight of 40-day old Zea maize shoot and root (A) and its uptake of Mn (B) and S (C) under greenhouse conditions.

Table (3) shows the ANOVA of measured variables where both shoot and root dry weight as well as sulfur uptake increased with the rate of applied S increased to 1.2 ton/h whereas Mn uptake by shoot and root increased as the rate of applied S increased up to 2.4 t/h. Both of sulfur application and bacterial inoculation had significant influence on Mn uptake by shoot and roots of Zea maize.

Table (3): The effect of sulfur rate, sulfur-oxidizing bacteria and their combination effect on shoot and root dry weight, and Mn and S uptake by Zea maize plants.

Factors	Measured Variables					
	Shoot D.W., g/pot	Root D.W., g/pot	Shoot S, mmol/pot	Root S, mmol/pot	Shoot Mn, umol/pot	Root Mn, umol/pot
Sulfur						
S0	9.586 c	2.514 c	1.724 c	1.934 c	4.949 a	3.721 c
S1	12.841 b	3.290 b	3.263 b	6.693 b	9.658 b	4.666 c
S2	15.529 a	3.990 a	4.509 a	9.293 a	16.524 a	11.793 b
S3	14.768 ab	3.811 ab	4.423 a	9.275 a	17.778 a	14.644 a
LSD0.05	2.2315	0.585	0.6399	1.5065	2.1644	1.6087
Bacteria						
Without	12.527 a	3.059 b	3.424 a	6.027 a	11.113 b	7.781 b
with	13.835 a	3.744 a	3.535 a	7.326 a	13.346 a	9.651 a
LSD0.05	1.578	0.4134	0.453	1.0653	1.5305	1.1375
Main Effects						
Sulfur (S)	***	***	***	***	***	***
Bacteria (B)	ns	**	ns	ns	**	**
Interactions						
SxB	ns	ns	ns	ns	ns	**

In Conclusion, The results of laboratory incubation experiments showed that It is important to note that application of TES to soils significantly increased the availability of Mn in first few weeks of S application and the availability is related to the carbonate content in soils. The greenhouse experiment on the effect of sulfur application with or without soil inoculation with S-oxidizing bacteria (P. Versutus) explored the role of both sulfur and bacteria on the plant growth and nutrients use efficiency by plant in the earlier stages of growth. Applied TES with or without *P. Versutus* inoculation had a positive effects on the plant growth either for shoot or root. Inoculating of soils by *P. Versutus* without application of TES increased the uptake of Mn. This result reflects a growth promotion action for *P. Versutus* toward the plant use efficiency for Mn.

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تأثير إضافة كبريت الثيوباك علي تيسر المنجنيز لنباتات الذرة النامية في الأراضي الجيرية

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الملخص العربي

يعتبر عنصر المنجنيز أحد العناصر الغذائية الضرورية الصغرى التى تحتاج الي إدارة جيدة بالأراضي الجيرية حيث تتأثر درجة تيسره للنباتات النامية بمشكلة المحتوى المرتفع لكربونات الكالسيوم ودرجة الحموضة والقلوية (pH) المرتفعة للأراضي الجيرية. فى محاولة لاستخدام الكبريت المستخرج من عمليات تكرير المواد البترولية والمسمى بكبريت الثيوباك كمحسن للتربة وخافض للـ pH، تم تنفيذ تجارب معملية لتحضين الأرض مع الكبريت لفترات زمنية امتدت حتى ٢٠ أسبوع ودراسة تأثير ذلك على تركيز المنجنيز الأرضي الميسر وعلى الـ pH. كما تم تنفيذ تجربة بالصوبة لبيان تأثير إضافة كبرت الثيوباك بمعدلات ٠٫٢٣٨، ١٫٢، و٢٫٤ طن/هكتارعلى نمو الذرة لعمر ٤٠ يوم ومقدار كل من المنجنيز والكبريت الممتصين نتيجة المعدلات المضافة منه وذلك مع دراسة تأثير التلقيح بالبكتريا المؤكسدة للكبريت من عدمه. أدت إضافة الكبريت الى الأرض الى زيادة تركيز المنجنيز الميسر في كل عينات الأراضي المختبرة بالمقارنة بتركيزه فى الأراضي غير المعاملة بالكبريت. كما أن التلقيح بالبكتريا عمل على تحرير المزيد من المنجنيز الميسر وذلك بعد فترات التحضين المختبرة والتى وصلت الى ٢٠ أسبوع. وهذه الزيادة المعنوية للمنجنيز راجعة الى التأثير غير المباشر لأكسدة الكبريت التى صاحبها انخفاض ملحوظ في الـpH بالمحلول الأرضي. بينت النتائج حدوث زيادة كبيرة في تركيز أنيون الكبريتات فى المحلول الأرضي نتيجة التحضين مع الكبريت مما يؤكد حدوث الأكسدة سواء فى غياب أو وجود البكتريا خاصة فى الأراضى التى احتوت على تركيز كبريتات

منخفض قبل التحضين. وهذا يجعلنا نعتقد أن معدل أكسدة الكبريت المضاف للأرض يتأثر بهذا المحتوى حيث يقل معدل الأكسدة (أو تثبط عملية الأكسدة) بزيادة محتوى المحلول الأرضى من أنيون الكبريتات والعكس صحيح وهذا ماتؤكده النتائج. نتائج الزراعة فى الصوبة أكدت أن إضافة الكبريت أدى الى زيادة معنوية فى الوزن الجاف لكل من المجموع الخضرى والجذور. كما أن معدل امتصاص المنجنيز بواسطة نبات الذرة ازداد بزيادة معدل الكبريت المضاف فى كل من الأراضي غير الملقحة وتلك الملقحة بالبكتريا وكانت الزيادة أكبر فى الأراضى الملقحة. من ناحية أخرى أشارت نتائج امتصاص المنجنيز فى الأراض غير المعاملة بالكبريت أن الكمية الممتصة من المنجنيز كانت أكبر فى الأراضي الملقحة مقارنة بغير الملقحة مما يشير الى دور تحفيزى للبكتريا فى امتصاص المنجنيز. أشارت النتائج أيضا الى إرتفاع محتوى النبات من الكبريت نتيجة إضافة كبريت الثيوباك وكانت الزيادة كبيرة بدرجة معنوية فى الجذور عنها فى المجموع الخضرى. وتخلص هذه الدراسة الى التأكيد على أهمية إضافة الكبريت الزراعى الى الأراضي الجيرية ودوره الفعال فى زيادة تيسر المنجنيز للمحاصيل النامية بتلك الأراضي.