Influence of Superphosphate and Elemental Sulfur on Soil Physical Properties, Growth, Yield and Nutrients Status of Sunflower

I. Soil Physical and Chemical Characteristics and Fertility Status

Abdel-Nasser, G. and A.H.A. Hussein
Soil & Agricultural Chemistry Dept., Faculty of Agriculture (Saba Bacha), Alexandria University

ABSTRACT

A field experiment was conducted in the experimental station of the Faculty of Agriculture (Saba Basha), Alexandria university at EL-Nozha during 1998 growing season of sunflower (*Helianthus annuus* L). The objective of this work was to investigate the combined effect of superphosphate and elemental sulfur on soil physical and chemical characteristics. The experimental soil has a clayey texture. All plots (10 m^2) cultivated with sunflower received 60 kg N/fed in the form of ammonium nitrate (33.5 % N) and 30 kg K_2O/fed in the form of potassium sulfate (48% K_2O) as recommended. Soil application of superphosphate, SP (15 % P_2O_5) at rates of 0, 15, 30 and 45 kg of P_2O_5/ feddan and elemental sulfur (S) at rates of 0, 150, 300 and 600 kg/feddan were used in the present study. The superphosphate and elemental sulfur were mixed with 30 cm top layer of the soil before planting. The obtained results revealed that application of both superphosphate and elemental sulfur significantly altered the physical properties of soil. It decreased the soil bulk density and medium (meso-) pores, but increased the total porosity, large and fine pores. Also, mean weight diameter (MWD) and optimum size of soil particles (OP) were significantly increased. Also, application of both SP and S significantly improved the soil moisture retention and available water. Basic infiltration rate was significantly increased through increasing the macro pores . The results indicated that both SP and S were more effective in improving the soil physical characteristics. A positive correlation relationship was found between soil physical properties and the rates of SP and S. The electrical conductivity (EC) was significantly increased, while the soil pH and exchangeable sodium percentage (ESP) were decreased as a result of SP and S applications. Results showed also a significant effect of SP and S in improving the available soil nutrients i.e. N, P, K, Fe, Mn, Cu and Zn, in which it increased significantly with SP and S application at all rates. Generally, application of SP and S by mixing them with top 30-cm soil layer, was found to be more effective in improving the soil physical and chemical properties and decreasing the ESP. The most important result from the present paper is clarifying the important role of SP and S application in modifying soil physical and chemical properties of sodic soil that enhance the plant production (growth and yield) and more utilization of soil nutrients by plant that will be illustrated in the part II of the present study.

INTRODUCTION

Sulfur (S), like nitrogen, phosphorus, potassium and calcium could be regarded as a major nutrient, which is needed in relatively large amounts for optimal plant growth. Sulfur has important metabolic functions for plant; it is a component of amino acids and proteins and the SH (sulphydryl or thiol) group plays an important role in many physiological reactions, also S is a constituent of CoA and of the vitamins biotin and thiamine (Mengel and Kirkby, 1987).

Acid forming sulfur compounds such as elemental sulfur and gypsum ($CaSO_4$) has been used for many years in the reclamation and improvement of alkaline soils. In this process, sulfur oxidized by soil microorganisms to sulfuric acid, which in turn lowers soil pH, improves soil structure and increases the availability of certain plant nutrients notably P, K and several of micro-nutrients (Hassan and Olson, 1966). Also, Stromberg and Tisdale (1979) stated that the undesirable properties of sodic soils can be corrected by the use of several acid-forming sulfur compounds, which increase water penetration, lower soil pH and consequently increase nutrients availability (Abdel-Nasser and EL-Shazly, 2000 and Abdel-Nasser and Harhash, 2000).

As the S is oxidized to SO_4^{-2} and sulfuric acid, $CaCO_3$ undergoes dissolution and Ca^{+2} ions are released to the soil solution which can replace exchangeable Na, thereby lowering the exchangeable sodium percentage (ESP), (Anter *et al.*, 1972; Ayers and Westcat, 1985; Abdel-Nasser and Harhash, 2000 and Abdel-Nasser and EL-Shazly, 2000). Also, Electrical conductivity (EC) was affected by elemental S applications (Yousry *et al.*, 1984 and Abdel-Nasser and EL-Shazly, 2000).

Several investigators reported the importance of S in increasing growth and yield of fruit trees; Abo-Rady *et al.* (1988) on date palm, Kassem *et al.* (1995) on gauva, Cummings *et al.* (1981), Peterson *et al.* (1987) on blueberries; Hening *et al.* (1991) on pecan; EL-Shazly and Abdel-Nasser (1999) on Balady Mandarin and Abdel-Nasser and EL-Shazly (2000) on Balady orange .

Therefore, the present study was carried out to clarify the combined effects of superphosphate and elemental sulfur rates on soil physical and chemical properties cultivated with sunflower plants.

MATERIALS AND METHODS

A field experiment was conducted in the Experimental Station of the Faculty of Agriculture (Saba Basha), Alexandria University at EL-Nozha during 1998 growing season of sunflower.

The experimental site has a clayey texture; some physical and chemical characteristics were determined at the beginning of the growing season before application of superphosphate and elemental sulfur. The analysis of soil samples collected from the plough layer (30 cm depth) was done according to the methods outlined in Carter (1993) and the data are shown in Table (1).

Soil application of superphosphate, SP (15 % P_2O_5) at rates of 0, 15, 30 and 45 kg of P_2O_5/feddan and elemental sulfur (S) at rates of 0, 150, 300 and

Table 1. Some physical and chemical characteristics of the experimental soil.

Parameters	Soil depth, cm		
	0 – 30	30 - 60	60 - 90
Particle –size distribution, %			
Sand	27.0	26.5	26.2
Silt	31.8	33.0	31.9
Clay	41.1	40.5	41.9
Texture class	Clay	Clay	Clay
Bulk density , Mg/m^3	1.33	1.31	1.31
Saturation water content ,m^3/m^3	0.498	0.505	0.506
Field capacity , m^3/m^3	0.343	0.347	0.350
Permanent wilting point ,m^3/m^3	0.216	0.218	0.220
Saturated hydraulic conductivity ,cm/hr	0.22	0.22	0.21
Organic matter content, %	1.75	1.78	1.77
$CaCO_3$, %	8.61	9.84	9.64
Cation exchange capacity, cmol (+)/kg	42.4	41.6	42.1
Exchangeable cations, %			
Ca	29.8	32.2	34.2
Mg	37.8	34.9	32.1
Na	26.9	27.4	28.1
K	5.5	5.3	5.6
pH (1: 1 water suspension)	8.4	8.5	8.5
Electrical conductivity, dS/m	3.12	3.25	3.30
Soluble Cations, meq/l			
Ca^{2+}	0.75	0.81	0.79
Mg^{2+}	0.62	0.70	0.72
Na^{+}	1.64	1.60	1.64
K^{+}	0.07	0.10	0.09
Soluble Anions, meq/l			
$CO_3^{=}$ + HCO_3^{-}	0.71	0.80	0.75
Cl^{-}	1.87	1.79	1.96
$SO_4^{=}$	0.45	0.55	0.51
Available soil nutrients, mg/kg			
N	356	379	372
P	19.1	18.3	18.0
K	425	432	436
Fe	3.9	3.8	3.7
Mn	2.8	2.9	2.7
Cu	1.0	1.1	1.0
Zn	1.5	1.6	1.4

600 kg/feddan were used in the present study. The superphosphate and elemental sulfur were mixed with 30 cm top layer of the soil before planting.

Sunflower (*Helianthus annuus* L.) variety was planted at 30 cm apart between hills in the prepared plots on May 21, 1998. Each plot has an area of 10 m^2 (65 cm between rows that have a 5 m long). The experiment was conducted in a Split Plot Design with 3 replications. The main plots contain the superphosphate treatments, while the subplot were devoted to the elemental sulfur treatments. All plots were received the 60 kg N/fed in the form of ammonium nitrate (33.5 % N) and 30 kg K_2O/fed. as recommended. The N- and K-fertilizers were added in two equal doses during the growing period. The first dose was applied with the first irrigation (21 days after planting) and the second one, 4 weeks later. Sunflower was harvested at maturity stage (October 28, 1998).

At harvest time, undisturbed and disturbed soil samples to a depth of 30-cm were collected for physical and chemical analysis. Soil bulk density (BD), field capacity (FC) and permanent wilting point (PWP) were determined according to the standard methods outlined in Klute (1986). The pore-size distribution (PSD) as percentage of total porosity was calculated by the capillary theory (Jury *et al.*, 1991) using water retention data from the formula:

$$\mathbf{d\ (\mu m) = 300/h}$$

Where **h** is the tension applied in kPa and **d** is the diameter of pores in µm.

The pore–size distribution was differentiated to large (> 30 µm), medium (30-9 µm), fine (9-0.2 µm) and very fine (< 0.2 µm) pores as recommended by Richards (1972), Kohnke (1982) and Klute (1986). Mean weight diameter (MWD) was determined according to the method described in Carter (1993). Optimum size of soil particles (OP) was determined according to Kohnke (1982).The basic infiltration rate was determined with single-ring infiltrometer according to Elrick *et al.*(1995).

Soil samples were mixed thoroughly and sieved through a 2-mm mesh screen and air-dried prior to soil chemical analysis. Soil organic carbon was determined according to the modified Walkley-Black method described in Nelson and Sommers (1982). The soil organic matter content (OM) was calculated using the correction factor 1.724. Electrical conductivity (EC) was measured in 1: 1 soil: water extract using a conductivity meter (Rhoades, 1982). Soil pH was measured in 1:1 soil: water suspension using pH meter (Rhoades, 1982). Exchangeable sodium percentage (ESP) was determined according to the method described in Richards (1972). Soil available nutrients: N, P and K were extracted using a 0.5 M $NaHCO_3^-$ extraction method (Schoenau and Karamanos, 1993), then determined spectrophotometrically (Carter, 1993). The Fe, Mn, Cu and Zn were extracted using DTPA–extraction method (Lindsay and

Norvell, 1978), then determined photometrically by Atomic Absorption Spectrophotometer (Carter, 1993).

The collected data throughout the course of the present study were subjected to statistical analysis of variance according to Steel and Torrie (1982). Correlation coefficient and linear regression were done using the methods outlined in Draper and Smith (1981) .

RESULTS AND DISCUSSION

I. Soil physical characteristics:

Bulk density (BD)

Data in Table (2) present the values of soil bulk density (BD) as related to the rate of superphosphate (SP) and sulfur (S) under. The data clearly indicate that addition of SP or S significantly decreased the soil bulk density. The reduction in BD was more pronounced with S. This effect may be due to the exchangeable Ca^{+2} produced from the solubility of $CaCO_3$ in soil (McLean, 1971). These results suggested that the addition of SP or S enhanced the formation of large soil aggregates and increased the solid volume (Abo-Soliman *et al.*, 1992). In contrast, El-Sersawy (1998) stated that S material caused 3% increase in bulk density comparing with control. The effect of SP in reducing the soil BD may be attributed to Ca^{+2} ion released from SP that contain $CaSO_4$ in its composition.

The interaction effect clearly indicate that high rates of both SP and S resulted in more reduction in soil BD (Table, 2).

Total porosity (TP)

Total porosity (TP) as illustrated in the same Table (2) showed the importance of SP and S materials in increasing total pore spaces (TP) as compared with check treatment. The highest pore spaces were correlated with high level of SP and S materials.

The superiority of S than SP in increasing soil porosity is rendered mainly to the exchangeable Ca^{+2} resulted from solubility of soil $CaCO_3$ or Ca^{+2} ions released from SP. The Ca^{+2} enhance the formation of soil aggregates and increasing the pore spaces due to the reduction in soil BD. It is means that sulfur materials were able to modify soil porosity (Pagliai *et al.*, 1981).

Pore-size distribution (PSD).

Regarding the effect of S materials on pore-size distribution, the data in Table (5) showed different trends.

Table 2. Bulk density, total porosity and pore size distribution of soil as affected by superphosphate and sulfur applications.

Treatments: P rate kg P_2O_5/fed	Treatments: S rate kg/fed	Bulk density Mg/m^3	Total porosity	Pore-size distribution, %: Large	Medium	Fine	Very fine
0	0	1.31	0.505	5.4	24.0	30.5	40.1
	150	1.29	0.513	5.6	23.2	30.9	40.3
	300	1.25	0.528	5.9	21.5	31.7	40.9
	600	1.20	0.547	6.1	19.8	32.8	41.3
15	0	1.30	0.509	5.7	22.0	31.8	40.5
	150	1.27	0.521	5.9	20.8	32.4	40.9
	300	1.24	0.532	6.2	19.6	32.9	41.3
	600	1.18	0.555	6.5	17.9	33.7	41.9
30	0	1.28	0.517	6.9	18.8	33.2	41.1
	150	1.25	0.528	7.6	17.2	33.8	41.4
	300	1.21	0.543	8.1	15.5	34.6	41.8
	600	1.16	0.562	8.7	13.7	35.3	42.3
45	0	1.27	0.521	7.9	16.0	34.2	41.9
	150	1.23	0.536	8.3	14.4	34.9	42.4
	300	1.20	0.547	8.7	13.1	35.5	42.7
	600	1.15	0.566	9.4	10.7	36.8	43.1
Mean effect of superphosphate, kg P_2O_5/fed							
0		1.262	0.523	5.75	22.13	31.48	40.65
15		1.250	0.529	6.08	20.08	32.70	41.15
30		1.230	0.538	7.83	16.30	34.23	41.65
45		1.210	0.543	8.58	13.05	35.35	42.53
$LSD_{0.05}$		0.027**	0.025**	0.34**	0.69**	0.25**	0.16**
Mean effect of Sulfur, kg/fed							
0		1.290	0.513	6.48	20.20	32.43	40.90
150		1.260	0.525	6.85	18.90	33.00	41.25
300		1.230	0.537	7.23	17.43	33.68	41.68
600		1.170	0.558	7.68	15.53	34.65	42.15
$LSD_{0.05}$		.019**	0.022**	0.18**	0.32**	0.20**	0.39**
Interaction P X S							
$LSD_{0.05}$		.039^{NS}	0.043^{NS}	0.36**	0.64^{NS}	0.39**	0.78^{NS}

** significant at 1% probability level

The large pores > 30µm (aeration drainable porosity) took the priority of increase compared with the other pore fractions, as a result of SP and S materials application. The increasing percent in such macro- pores relative to the control reached to 49.22 and 18.52% associated with elemental SP and S, respectively. The improvement in large pores, particularly under alkali clay soil condition is considered of great importance for air exchange, water movement and reducing soil evaporation rate and its reflection on plant growth (Kohnke, 1982 and Russell, 1989).

The second group of pores is the medium pores (30-9 µm diameter). It seemed to be decreased with the addition of SP and S materials. The effect might be more pronounced with SP than elemental S. Increasing the S rate reduced the presence of such size of pores. The decreases present in such meso-pores relative to the control reached to 31.99 and 23.12 % related to SP and S, respectively.

Regarding the fine pores (9-0.2µm), which is very important for soil moisture retention (storing available water), the data showed an increase in this group with addition of SP or S materials. The increasing percent relative to the control treatment were 12.29 and 6.85% related to SP and S, respectively.

In respect with very fine pores (< 0.2 µm), the results indicated the increase of very fine pores as a result of SP or S applications. The increase in such pores, has a same magnitude for SP and S (4.62 and 3.06 %, respectively).

Generally, taking the all pore size divisions into consideration, the data showed that S took the priority of increasing soil pore space followed by SP (8.77 and 3.82%,respectively). The alteration of pore-size distribution as a result of S materials addition, is considered of good changes because of many factors related to plant growth, such as root penetration, aeration, water and solute movement and water retention of soil, depending mainly on pore-size distribution (Hill and Cruse, 1985; Russell, 1989 and Tester, 1990).

Mean Weight Diameter (MWD) :

Application of SP and S significantly increased MWD as compared with control treatment (Table, 4). Such effects were more pronounced at higher rates of both SP or S materials., (Abdel-Nasser and EL-Shazly, 2000 and Abdel-Nasser and Harhash, 2000). This effect may be due to the exchangeable Ca^{+2} produced from the solubility of $CaCO_3$ in soil (McLean, 1971) or applied through SP. This led to formation of large soil aggregates and increased the MWD (Marshall and Holmes, 1979, Abdel-Nasser and EL-Shazly, 2000 and Abdel-Nasser and Harhash, 2000).

Optimum Size of soil particles (OP):

The optimum size of soil particles (OP) as affected by SP and S application is presented in Table (4). The data clearly indicate a significant effect of both SP and S, especially at highest rates. The OP percent increased by about 16.50 and 14.64%, respectively over the control treatment. Such results were in agreement of Abdel-Nasser and EL-Shazly (2000). As reported by Kohnke (1982), the optimum size of peds for good plant growth lies between 0.5 and 2.0 mm, the present study confirmed this concept.

Soil moisture retention.

Table (4) showed the soil moisture content at different tension 33 kPa (FC) and 1500 kPa (PWP) as a result of SP and S materials, as well as soil available water (AW). The SP and S materials increased the soil retainability as compared with control treatment but the S was better than SP. The increase was mostly associated with field capacity and permanent wilting point (33 and 1500 kPa). The addition of SP or S introduced higher values of moisture retention compared with control. The increasing soil water retention related to SP and S materials may be attributed to increasing of fine pores as mentioned before and increasing the aggregation effect (Hill and Cruse, 1985 , Russell, 1989 and Abdel-Nasser and EL-Shazly, 2000).

The increasing percent in field capacity (33 kPa) were 3.52 and 3.80% relative to SP and S, respectively at high rate of application. While, the increases in PWP were 3.30 and 5.21%, respectively.

Regarding to soil available water, the effect of SP and S materials has a slight effect on increasing water retention of soil.

Basic infiltration rate.

Values of basic infiltration rate (cm/hr) as affected by the SP and S materials are presented in Table (3).

As a general trend, values of basic infiltration rate significantly increased as a result of increasing SP or S application rate.

The infiltration rate is a good tool for expressing the factors affecting water movement through soil pores and the conductive capacity of such soil, but the infiltration rate of the surface soil layer can be improved and controlled by soil management (Ghazy *et al.*, 1984 and Talha *et al.*, 1979). The present results showed a superiority effect of SP in improving the basic infiltration rate. The addition of S materials especially SP as well as increasing, its mixing depth resulted in enhancing the macro-pores formation and consequently increasing the basic infiltration rate (Abo-Soliman, 1984).

Table 3. Mean weight diameter, optimum particle size, water retention and saturated hydraulic conductivity of soil as affected by super- phosphate and sulfur applications

Treatments		Mean weight diamete, mm	Optimum size %	Water retention, m^3m^{-3}			Basic infiltration rate cm/hr
P rate kg P_2O_5/fed	S rate kg/fed			Field capacity	Permanent wilting point	Available water	
0	0	0.451	48.5	0.362	0.208	0.154	0.165
	150	0.498	49.2	0.366	0.211	0.155	0.171
	300	0.532	51.6	0.371	0.214	0.157	0.178
	600	0.569	52.4	0.377	0.219	0.158	0.182
15	0	0.462	49.4	0.365	0.209	0.156	0.172
	150	0.492	51.6	0.370	0.213	0.157	0.178
	300	0.557	53.8	0.376	0.217	0.159	0.183
	600	0.614	56.2	0.382	0.220	0.162	0.195
30	0	0.493	51.6	0.370	0.212	0.158	0.181
	150	0.562	53.2	0.374	0.214	0.160	0.187
	300	0.617	56.4	0.380	0.218	0.162	0.196
	600	0.662	59.3	0.386	0.225	0.166	0.211
45	0	0.524	53.2	0.376	0.215	0.161	0.195
	150	0.573	56.7	0.382	0.219	0.163	0.212
	300	0.645	60.6	0.386	0.221	0.165	0.232
	600	0.721	64.5	0.393	0.222	0.171	0.245
Mean effect of superphosphate, kg P_2O_5/fed							
	0	0.513	50.43	0.369	0.212	0.156	0.174
	15	0.531	52.75	0.373	0.215	0.159	0.182
	30	0.583	55.13	0.377	0.217	0.162	0.194
	45	0.616	58.75	0.382	0.219	0.165	0.221
$LSD_{0.05}$		0.025**	0.62**	0.004	0.003**	0.004**	0.004**
Mean effect of Sulfur, kg/fed							
	0	0.483	50.68	0.368	0.211	0.157	0.178
	150	0.531	52.68	0.372	0.214	0.159	0.187
	300	0.588	55.60	0.378	0.218	0.161	0.197
	600	0.642	58.10	0.382	0.222	0.164	0.208
$LSD_{0.05}$		0.012**	0.35**	0.002	0.002**	0.003**	0.046**
Interaction P X S							
$LSD_{0.05}$		0.025**	0.70**	0.004	0.004NS	0.007NS	0.009**

** significant at 1% probability level

The application of SP combined with S led to decrease the values of ESP (Exchangeable Sodium Percentage) in soil due to the exchange reaction between Ca^{+2} ion (from the solubility of $CaCO_3$) and Na adsorbed on soil matrix, accordingly enhanced the downward movement of water, consequently increased the basic infiltration rate (Abo-Soliman, 1984 and Abo-Soliman *et al.*, 1992, Abdel-Nasser and Harhash, 2000 and Abdel-Nasser and Hussein, 2001).

II. Soil chemical properties.

Soil pH

Data presented in Table (4) show the effects of SP and S materials application on soil chemical properties.

The data clearly show that pH values significantly decreased as a result of increasing SP or S materials. The reduction in pH was more pronounced at high S rate (600 kg/feddan). The reduction in soil pH may be attributed to acidification resulted from S oxidation (Starkey, 1966 and El-Shazly and Abdel-Nasser, 1999, Abdel-Nasser and EL-Shazly, 2000). Similar trend was obtained with S sources but the elemental sulfur was relatively more effective than gypsum (Hassan and Olson, 1966).

Soluble salts

Soluble salts in soil solution as expressed by electrical conductivity (EC) were significantly increased as SP or S rate increased. The higher values of EC were related with higher rates of SP or S materials..

The relative higher values of EC for soil receiving sulfur application could be attributed to acidity produced through oxidation of S by microorganisms, this acidity was an efficient solvent (Kriem and Zaid, 1992, El-Shazly and Abdel-Nasser, 1999 and Abdel-Nasser and EL-Shazly, 2000).

Exchangeable Sodium Percentage (ESP)

With regard to Exchangeable Sodium Percentage (ESP), it is noticed that both SP or S materials significantly decreased the ESP, but S was more effective than SP. Such result can be explained on the basis that S when applied to soil exposed to oxidation through the activity of microorganisms. It produces free Ca^{+2} ions which replace the Na adsorbed on soil complex, thus reduced the ESP by about 26.06 and 58.33% relative to SP and S, respectively (Richards, 1972).

Increasing S rate significantly decreased the ESP to the critical limit of sodicity (15%). The higher reduction in ESP was correlated with high S rate i.e. 600 kg/feddan. Decreasing Na adsorbed as a result of exchangeable Ca^{+2} can increases water holding pores and improves the water movement in soil profile.

able 4. Some chemical properties of soil as affected by super-phosphate and sulfur applications

Treatments		pH	EC dS/m	ESP %	Macronutrients, %			Micronutrients, mg/kg			
P rate g P_2O_5/fed	S rate kg/fed				N	P	K	Fe	Mn	Cu	Zn
0	0	8.62	3.21	34.2	130.0	14.1	430.1	4.0	3.0	0.8	1.7
	150	8.53	3.24	30.1	134.5	15.8	441.2	4.2	3.3	0.9	1.9
	300	8.34	3.28	25.3	140.5	17.1	462.1	4.7	3.7	1.3	2.1
	600	8.05	3.30	17.4	149.5	19.9	483.1	5.1	4.3	1.7	2.4
15	0	8.53	3.25	33.6	134.0	14.8	438.2	4.2	3.2	0.9	1.9
	150	8.43	3.27	27.2	139.0	16.1	449.3	4.6	3.7	1.2	2.2
	300	8.25	3.28	22.1	146.0	18.3	478.1	5.2	4.2	1.6	2.4
	600	7.88	3.31	14.8	156.0	21.2	499.4	5.5	4.9	1.9	2.8
30	0	8.35	3.28	32.8	137.5	15.7	446.4	4.4	3.5	1.1	2.0
	150	8.14	3.30	24.3	145.5	17.3	458.2	4.9	4.0	1.4	2.3
	300	8.06	3.32	18.7	157.5	19.4	491.5	5.4	4.7	1.9	2.7
	600	7.61	3.31	12.5	161.5	23.2	516.8	5.8	5.6	2.2	3.1
45	0	8.24	3.30	31.2	140.5	16.9	452.3	4.5	3.8	1.3	2.2
	150	8.04	3.32	21.5	153.0	18.2	469.4	5.3	4.3	1.7	2.5
	300	7.92	3.32	16.2	160.5	20.8	503.6	5.7	4.9	2.2	2.9
	600	7.44	3.35	10.2	169.0	24.5	536.8	6.4	6.1	2.4	3.3
an effect of superphosphate, kg P_2O_5/fed											
0		8.39	3.29	26.75	138.6	16.7	454.1	4.5	3.6	1.2	2.0
15		8.25	3.28	24.43	143.8	17.6	466.3	4.9	4.0	1.4	2.3
30		8.04	3.28	22.08	150.5	18.9	478.2	5.1	4.5	1.7	2.5
45		7.91	3.32	19.78	155.8	20.1	490.5	5.5	4.8	1.9	2.7
D $_{0.05}$		0.03^{**}	0.1^{NS}	1.37^{**}	1.75^{**}	0.46^{**}	20.7^{*}	0.07^{**}	0.09^{**}	0.05^{**}	0.08^{**}
ean effect of Sulfur, kg/fed											
0		8.44	3.26	32.95	135.5	15.4	441.8	4.3	3.4	1.0	2.0
150		8.29	3.28	25.78	143.0	16.9	454.5	4.8	3.8	1.3	2.2
300		8.44	3.28	20.58	151.1	18.9	483.8	5.3	4.4	1.8	2.5
600		7.75	3.32	13.73	159.0	22.2	509.0	5.7	5.2	2.1	2.9
D $_{0.05}$		0.03^{**}	0.09^{NS}	0.74^{**}	2.8^{**}	0.53^{**}	18.18^{**}	0.08^{**}	0.1^{**}	0.06^{**}	0.08^{**}
teraction P X S											
D $_{0.05}$		0.06^{**}	0.18^{NS}	1.48^{**}	5.6^{NS}	1.05^{NS}	36.37^{NS}	0.16^{**}	0.2^{**}	0.11^{**}	0.16^{*}

** significant at 1% probability level

Available soil nutrients:

As regard to available soil nutrients, the data in Table (4) revealed that both SP and S have a significant effect on soil available nutrients i.e. N, P, K, Fe, Mn, Cu and Zn, but S is more effictive than SP.

Increasing S rate significantly increased the available nutrient contents. The high values were attained at higher S rate. The obtained results can be explained on the basis that the oxidation of sulfur applied to soil by microorganisms to $SO^{=}_4$ ions. The $SO^{=}_4$ ions can dissolve some clay minerals and release these nutrients or due to the reduction in the soil pH, which affect the solubility, and availability of soil nutrients (Yousry *et al.*, 1984 and Mengel and Kirkby, 1987).

By acidification resulted from sulfur application, the extractable soil N was significantly increased. The increases in extractable soil N were 17.34 % as increasing S rate from zero to 600 kg/feddan. This result may be explained on the fact that $SO^{=}_4$ formed due to S oxidation can markedly reduce the NO_3^- losses from soil and simulated the reduction of NO_3^- to NH_4^+ (Kowalenko, 1979), decreasing N losses in soil led to increase N availability and plant uptake, Table (4).

Increasing S rate substantially increased extractable soil P. Such result may be due to that, increasing S rates resulted in an increase of soluble $SO^{=}_4$, which lowered the soil pH, and consequently increased the extractable P. In addition, in soil containing $CaCO_3$, the H^+ ions increased as a result of S application, the unavailable P react with H^+ and become more extractable and available to plant uptake (Yousry *et al.*, 1984). Moreover, the lower extractable P in S- untreated soil could be attributed to that, when P fertilizers are applied to soil containing high $CaCO_3$ content, PO_4^{3-} ions can be adsorb to $CaCO_3$ granules and precipitate to a form of unavailable P (Mattingly, 1975).

The amount of extractable K was increased significantly as the rate of S application increased. The increase in extractable K in soil was about 15.21% over the control treatment. Such results may be attributed to the fact that S application can broke down the K-bearing minerals in soil, consequently release more available K (Ali, 1974).

Also, extractable soil micronutrients, i.e. Fe, Mn, Cu, and Zn were increased due to S applications, (Table 4). Such results could be attributed to that, when soil treated with S, the soil pH is lowered which permits the increase of micronutrients availability, thus, raising the plant tissue contents of these elements. These results are in accordance with Spires (1984) and Wainwright (1984). Regarding the effect of SP on the extractable soil nutrients, the data indicated that SP has a significant effect on changing the extractability of soil nutrients.

Generally, SP and S rates have a marked effect on increasing the extractability of soil nutrient in which the higher values were obtained with higher rates.

Multiple linear regression of both SP and S application against some soil physical and chemical properties were performed according to the following formula:

$$Y = b_0 + b_1 * SP + b_2 * S$$

Where : Y is any soil properties,

SP is the rate of superphosphate application, kg P_2O_5/fed,

S is the rate of sulfur application rate, kg/fed, and b_0, b_1 and b_2 are the regression coefficients. The regression coefficients and determination coefficient are illustrated in Table (5). The effects of SP and S on some soil physical and chemical properties are shown in Figs (1 to 12) .

Generally, the most important outcome of this study is to clarify the important role of combined application of superphosphate and elemental sulfur in improving the soil physical properties and chemical properties of sodic soil. It can be recommended that in case of sodic soils, the addition of S with phosphoric fertilizers is advisable to improve soil properties that reflected in improving the growth, yield and more utilization of soil nutrients by plants as shown in the part II of this study (Hussein and Abdel-Nasser, 2002).

Table 5. Multiple linear regression of SP and S application rates against som soil physical and chemical properties.

Parameters	Regression coefficients			R^2
	b_0	b_1	b_2	
BD	1.314375	- 0.001150	-0.0002	0.995**
TP	0.503700	0.000440	7.44E-05	0.996**
Large pores	5.001250	0.068167	0.001986	0.963**
Medium pores	24.485000	-0.196670	-0.0078	0.993**
Fine pores	30.487500	0.087667	0.003724	0.996**
Very fine pores	40.026250	0.040833	0.00209	0.987**
MWD	0.436950	0.002413	0.000265	0.970**
OP	47.397500	0.172333	0.009952	0.889**
FC	0.361400	0.000333	2.7E-05	0.991**
PWP	0.208750	0.000133	1.5E-05	0.957**
AW	0.152650	0.000200	1.18E-05	0.978**
Ks	0.156638	0.001018	5.0E-05	0.942**
EC	3.232500	0.001467	9.33E-05	0.943**
ESP	34.941250	-0.155170	-0.03121	0.978**
N	128.20630	0.387500	0.038976	0.976**
P	13.591250	0.076167	0.011529	0.972**
K	423.64380	0.807833	0.116043	0.977**

** significant at 1% probability level

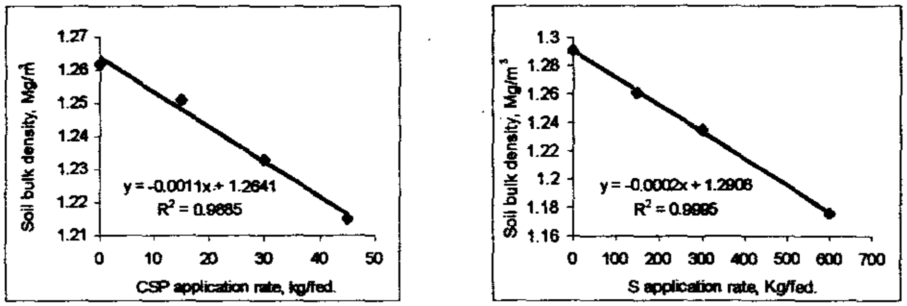

Fig. (1). Effect of SP (left) and S (right) on soil bulk density.

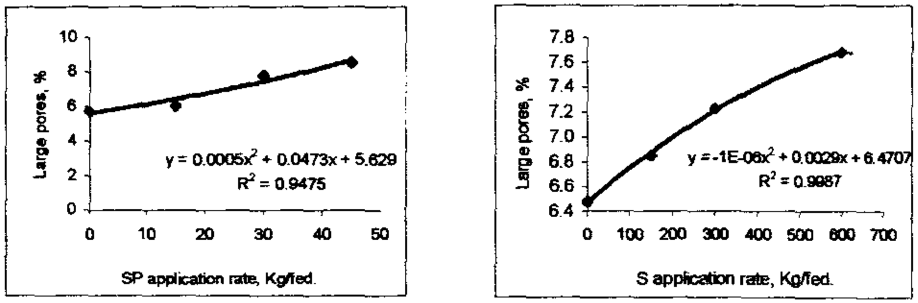

Fig.(2). Effect of SP (left) and S (right) on soil latge pores.

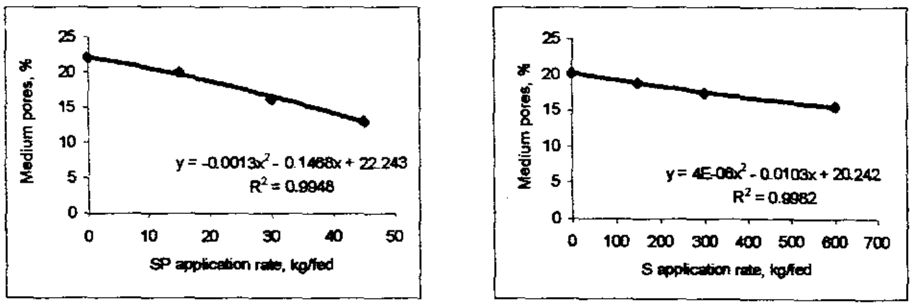

Fig.(3) Effect of SP(left) and S(right) on soil medium pores

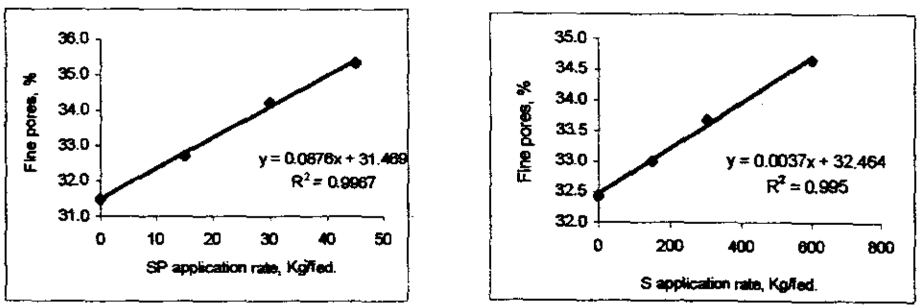

Fig. (4). Effect of SP (left) and S (right) on soil fine pores.

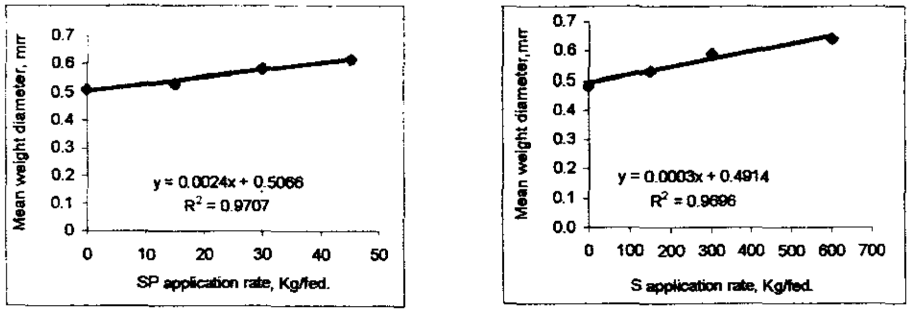

Fig.(5). Effect of SP (left) and S (right) on mean weight diameter of soil aggregates.

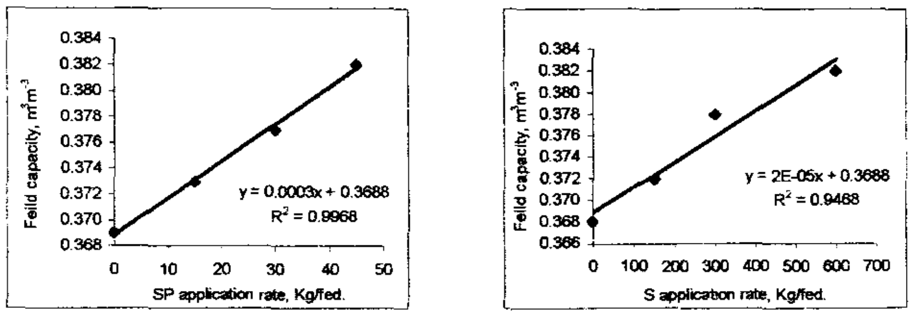

Fig. (6). Effect of SP (left) and S (right) on field capacity of soil.

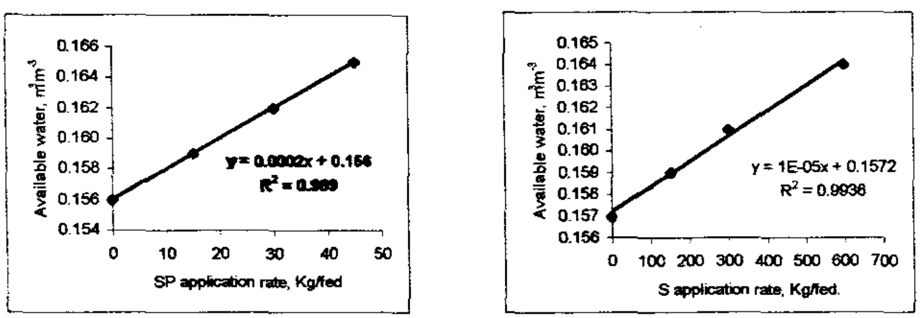

Fig. (7). Effect of SP (left) and S (right) on soil available water.

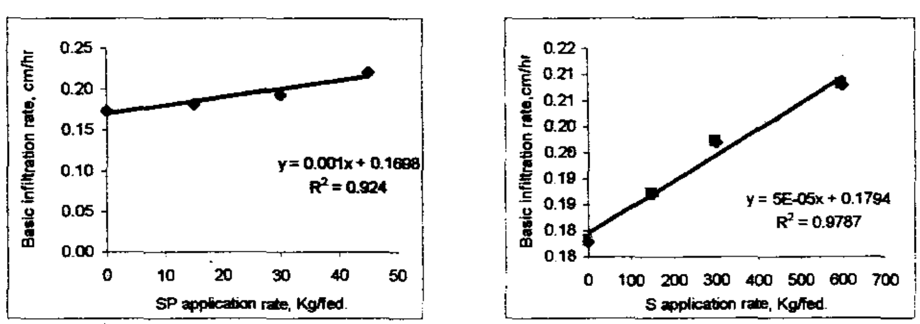

Fig. (8). Effect of SP (left) and S(right) on basic infiltration rate of soil

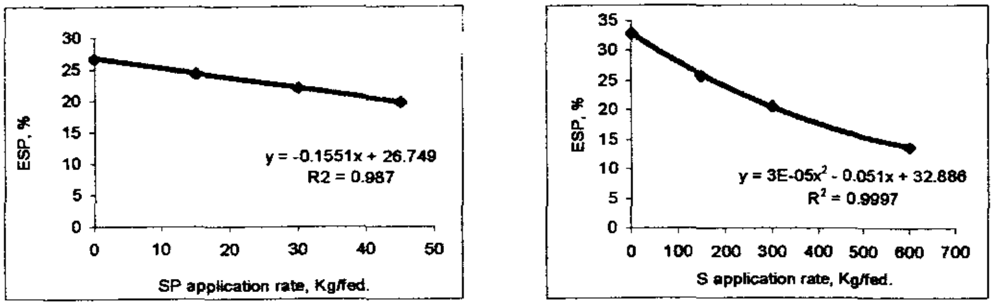

Fig. (9). Effect of SP (left) and S (right) on Exchangeable Sodium Percentage.

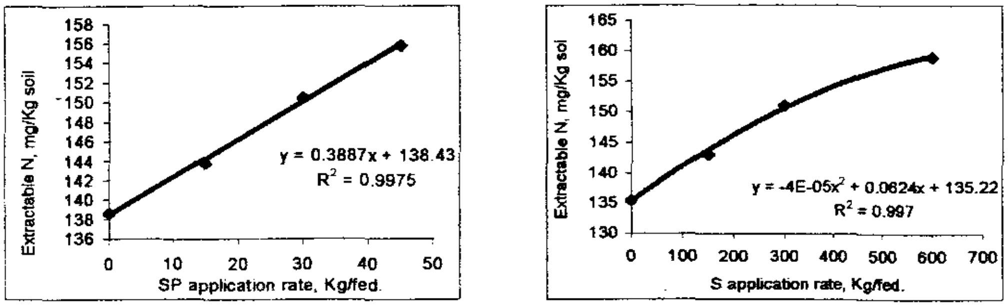

Fig. (10). Effect of SP (left) and S (right) on extractable soil N.

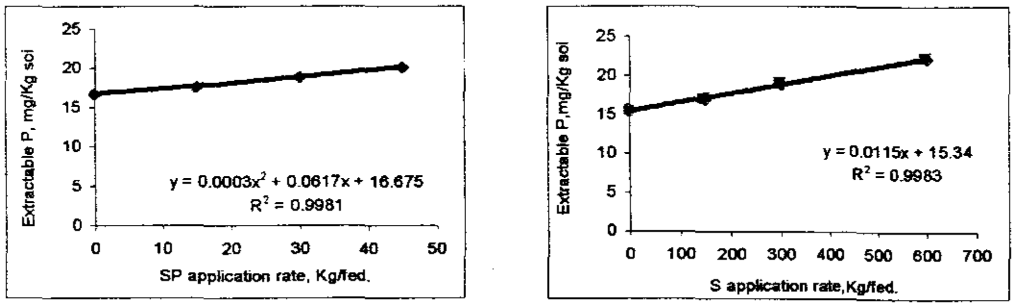

Fig. (11). Effect of SP (left) and S (right) on extractable soil P.

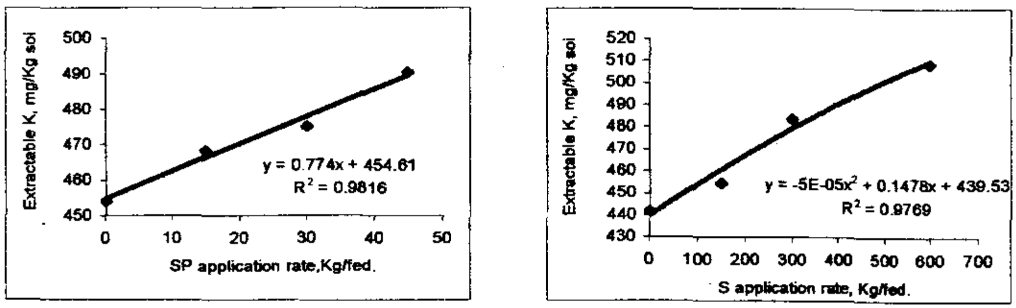

Fig. (12). Effect of SP (left) and S (right) on extractable soil K.

REFERENCES

Abdel-Nasser, G. and S. M. EL-Shazly. 2000. Effect of sulphur application on soil physical and chemical characteristics, nutrient status, yield and fruit quality of Balady orange trees J. Agric. Res., Tanta Univ., 26 (1): 72 - 92.

Abdel-Nasser, G. and M.M. Harhash. 2000. Effect of organic manures in combination with elemental sulfur on soil physical and chemical characteristics, yield, fruit quality, leaf water contents and nutritional status of Flame seedless grapevines. Part I. Soil physical and chemical characteristics. J. Agric. Sci. , Mansoura Univ., 25 (6) : 3541-3558 .

Abdel-Nasser, G. and A. H. A. Hussein. 2001. Effect of different manure sources on some soil properties and sunflower plant growth. Part I. Soil physical and chemical properties. Alex. J. Agric. Res. , 46(1): 227-251.

Abo-Rady, M.D.K.; O. Duheash; M. Khalil, and M.A. Turjoman 1988. Effect of elemental sulphur on some properties of calcareous soil and growth of date palm seedlings. Arid Soil Research and Rehabilitation, 2 (2): 121-130.

Abo-Soliman, M.S.M., M.A. Abou El-Soud, A.A. Amer, and W.S. El-Sabry 1992. Effect of some reclamation and improvement processes on some physical properties of saline sodic soils in North Delta, Egypt. J. Agric. Sci., Mansoura Univ., 17 (1): 158-169.

Abo-Soliman, M.S. 1984. Studies on physical and chemical properties of some soils of Middle Delta in Egypt. Ph.D. Thesis, Fac. Agric., Mansoura Univ.

Ali, O. M. 1974. Potassium supplying power of the soils in Egypt Ph. D. Thesis. Fac. of Agric., Al. Azhar Univ. Cairo. Egypt.

Anter, F., S.A..Z. Mahmoud, A. Metwally, and A.H. El-Damaty 1972. Microbiological and chemical changes during reclamation of alkali soils, P. 953-963. In Proc. Inter. Symp. On new Developments in the field of salt Affected Soils. December 4-9, Cairo, Egypt.

Ayers, R. S. and D.W. Westcat. 1985. Water quality for Agriculture. FAO Irrigation and Drainage paper No. 29., FAO, Rome Italy.

Carter, M.R. (ed.) 1993. Soil sampling and Methods of Analysis. Canadian Society of Soil Science, Lewis Publisher, London, Tokyo.

Cummings, C.M., I.P. Mainland, and J.P.Lilly 1981. Influence of soil pH, S and sawdusts on Blueberry survival, growth and yield. J. Amer. Soc. Hort. Sci., 106 (6): 783-785.

Draper, N.R. and H. Smith. 1981. "Applied regression analysis". 2nd ed. John Wiley, New York.

Elrick, D.E., G.W. Parkin, W.D. Reynolds, and D.J. Fallow 1995. Analysis of early-time and Steady State Single-ring infiltration under falling head conditions. Water Resour. Res., 31: 1883-1895.

El-Sersawy, M.M. 1998. Hydrophysical and impedance properties of cultivated calcareous soils as affected by some tillage practices. Egypt. J. Appl. Sci., 13 (1): 284-299.

EL-Shazly, M. and G. Abdel-Nasser 1999. Efficiency of phosphorus fertilizers as affected by soil sulphur application in Balady Mandarin plants. J. Agric. Sci. Mansoura Univ., 24(12) :.7623 - 7638 .

Ghazy, A.M., M.A. Wahab, and S. Abd El-Razek. 1984. Hydraulic conductivity relations in soils of Fayum drpression, Egypt. J. Soil Sci., 24 (1): 47-53.

Hassan, N and R.A. Olson 1966. Influence of applied sulfur on availability of soil nutrients for corn (*Zea mays* L) nutrition. Soil Sci. Soc. Amer. Proc. Vol. 30: 284-286.

Hening, H., D. Sparks, and J. J. Evans. 1991. Sulphur deficiency influence vegetative growth, chlorophyll and element concentrations and amino acids of pecan. J. Amer. Soc. Hort. Sci., 116 (6): 974-980.

Hill, R.L. and R.M. Cruse. 1985. Tillage effects on bulk density and soil strength of two Mollisols. Soil Sci. Soc. Am. J., 49: 1270-1273.

Hussein, A.H.A. and G. Abdel-Nasser. 2002. Influence of super- phosphate and elemental sulfur on soil physical properties, growth, yield and nutrients status of sunflower. II. Growth, yield, leaf water contents and nutrients status. Adv. Agr. Res. , 6(2): -

Jury, W.A., W.R. Gardner, and W.H. Gardner. 1991. " Soil Physics". Fifth edition. John Wiley & Sons, Inc. New York.

Kassem, A.A., H.A. Kassem, and H.M. Kamal. 1995. The influence of sources, level of nitrogen fertilizers and/or sulphur application on guava trees grown in alkaline sandy soil. Menofiya J. Agric. Res., 20 (3): 1223-1235.

Klute, A. (ed.) 1986. Methods of Soil Analysis. Part 1, 2nd edition. Soil Science Society of America, Madison, WI.

Kohnke, H. 1982. "Soil Physics", Reprinted in India by Arrangement with McGraw-Hill, Inc., New York TMH Edition.

Kowalenko, C.G. 1979. Rapid analysis of soil nitrate with sulphur. Can. J. Soil Sci., 59: 221-223.

Kriem, H.M. and M.S. Zaid. 1992. An experimental evaluation of the effect of sugar cane waste and sulphur addition on some soil properties and plant growth in calcareous soil. J. Agric. Sci., Mansoura Univ., 17 (1): 189-196.

Lindsay, W.L. and W.A. Norvell. 1978. Development of DTPA soil test for zinc, iron, manganese and copper. Soil Sci. Soc. Amer. J. 42: 421-428.

Marshall, T.J. and J.W. Holmes. 1979." Soil Physics ". Cambridge University press, Cambridge London, New York.

Mattingly, C. 1975. Labile phosphate in soil. Soil Sci., 119: 369 – 375.

McLean, E.O. 1971. Potentially beneficial effects from liming : Chemical and physical. Soil Crop Sci. Soc. Fla. Proc., 31: 189-196.

Mengel, K. and A. Kirkby. 1987. Principles of plant Nutrition 4th Ed. International Potash Institute, Norblafen–Bern/ Switzerland.

Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. P. 539-579. In A.L. Page et al. (ed.) Methods of soil analysis. Part 2. Chemical and microbiological properties. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Pagliai, M., G. Guidi, M. La Marca, M. Giachetti, and G. Lucamante. 1981. Effect of sewage sludge and composts on soil porosity and aggregation. J. Environ. Qual., 10: 556-561.

Peterson, P.V., C.A. Mullins, D.A. Lietzke and D.E. Deyton. 1987. Effect of soil applied elemental sulphur, aluminum sulfate and sawdust on growth of rabbitege blueberries. J. Amer. Soc. Hort. Sci. 112: 612-616.

Rhoades, J.D. 1982. Soluble salts P. 167-180. In A.L. Page et al. (ed.) Methods of soil analysis Part 2. Chemical and microbial methods. 2nd ed. Agron. Monogr 9. ASA and SSA. Madison, WI.

Richards, L.A. (ed.) 1972. "Diagnosis and Improvement of Saline and Alkaline soils". U.S. Dept. of Agric., Agric. Handbook No. 60.

Russell, E.W. 1989. Soil conditions and plant growth. ELBS edition of eleventh edition.

Schoenau, J.J. and R.E. Karamanos. 1993. Sodium Bicarbonate-Extractable P, K and N. Chapter 7 in M.R. Carter, Soil sampling and Methods of Analysis, Lewis Publishers, 823 pp.

Spiers, G. M. 1984. Influence of lime and Sulphur addition on growth, yield and leaf nutrient content of rabbiteye blue berry. J. Amer. Soc. Hort. Sci., 109: 559 – 562.

Starkey, R.L. 1966. Oxidation and Reduction of Sulfur Compounds. Soil Sci. 101 (4): 297-306.

Steel, R.G. and J.H. Torrie. 1982. Principles and Procedures of Statistics. 2nd Ed., McGraw Hill Book Company, New York, USA.

Stromberg, L.K. and S.L. Tisdale. 1979. Treating irrigated arid-land soils with acid-forming sulphur compounds. The sulphur Institute Technical Bulletin, 24.

Talha, M., A.G. Abd El-Samie, and M.S. Omar. 1979. Factors affecting water movement in alluvial Soil. Egypt. J. Soil Sci., 19 (1): 55-72.

Tester, C.F. 1990. Organic amendment effects on physical and chemical properties of a sandy soil. Soil Sci. Soc. Amer., J. 54: 827-831.

Wainwright, M. 1984. Sulphur oxidation in soils. Adv. Agron., 37: 349 – 396.

Yousry, M., A. El-Leboudi, and A. Khater. 1984. Effect of Sulphur and petroleum by-products on soil characteristics. I. Availability of certain nutrients in a calcareous soil under intermittent leaching. Egypt. J. Soil Sci., 24 (3): 185-194.

الملخص العربي

تأثير سوبر فوسفات الكالسيوم والكبريت على الخواص الفيزيائية للتربة ، النمو، المحصول والحالة الغذائية لعباد الشمس

١ – الخواص الفيزيائية والكيميائية وحالة الخصوبة للتربة

جمال عبد الناصر محمد و عادل حسين أحمد حسين
قسم الأراضي والكيمياء الزراعية – كلية الزراعة (سابا باشا) – جامعة الإسكندرية

أجريت تجربة حقلية في محطة التجارب الزراعية التابعة بكلية الزراعة (سابا باشا) – جامعة الإسكندرية بمنطقة أبيس خلال موسم النمو ١٩٩٨ لنبات عباد الشمس . الغرض من هذه الدراسة هو بحث التأثير المشترك لكلا من سوبرفوسفات الكالسيوم والكبريت الزراعي على الخواص الفيزيائية والكيميائية وحالة الخصوبة للتربة . أرض التجربة ذات قوام طيني – كل القطع التجريبية (١٠ م٢) تم زراعتها بنبات عباد الشمس وتم إضافة ٦٠ كجم نيتروجين/فدان في صورة نترات أمونيوم (33.5% ن) و ٣٠ كجم بو٢أ/فدان في صورة سلفات بوتاسيوم (٤٨% بو٢أ) وتم إضافة سوبر فوسفات الكالسيوم (١٥% فو ٢أ٥) للقطع التجريبية بمعدلات صفر ، ١٥ ، ٣٠ ، ٤٥ كجم فو٢ أ٥/فدان والكبريت بمعدلات صفر ، ١٥٠ ، ٣٠٠ ، ٦٠٠ كجم/ فدان . سوبر فوسفات الكالسيوم والكبريت العنصري تم خلطها مع الطبقة السطحية للتربة (٣٠ سم) قبل الزراعة أوضحت النتائج المتحصل عليها أن إضافة كلا من سوبر فوسفات الكالسيوم والكبريت قد أدت إلى إحداث تغيير جوهري في الصفات الفيزيائية للتربة فقد أدى ذلك إلى خفض قيمة الكثافة الظاهرية للتربة والمسام المتوسطة وكلنها أدت إلى زيادة المسامية الكلية والسعة الكبيرة والدقيقة – أيضا فقد لوحظ زيادة معنوية في قيمة نصف القطر الموزون للحبيبات ونسبة حبيبات التربة المثلي . أيضا فإن إضافة كلا من سوبر فوسفات الكالسيوم والكبريت الزراعي قد أدت إلى تحسن واضح في الخواص المائية للتربة والماء الميسر للنبات كذلك فإن معدل التسرب الأساسي للتربة قد زاد معنويا من خلال زيادة المسامية الكبيرة . وتشير النتائج إلى أن كلا من سوبر فوسفات الكالسيوم والكبريت الزراعي كانت مؤثرة جدا في تحسين الخواص الفيزيائية للتربة . هذا وقد وجدت علاقة معنوية موجبة بين الخواص الفيزيائية للتربة ومعدلات إضافة كلا من سوبر فوسفات الكالسيوم والكبريت الصغرى والأملاح الكلية الذائبة زادت معنويا بينما يتم تفاعل التربة ونسبة الصوديوم المتبادل نقصت معنويا نتيجة إضافة كلا من سوبر فوسفات الكالسيوم والكبريت المعدني . وأوضحت النتائج تأثير معنوي لكلا من سوبر فوسفات الكالسيوم والكبريت المعدني في تحسين العناصر الغذائية الميسرة بالتربة مثل نيتروجين – فوسفور – بوتاسيوم – حديد – منجنيز – نحاس وزنك حيث أنها زادت معنويا . وبصفة عامة فإن إضافة كلا من سوبر فوسفات الكالسيوم والكبريت العنصري بخلطها مع الطبقة السطحية للتربة (٣٠ سم) كان لها تأثير واضح في تحسين الخواص الفيزيائية والكيميائية للتربة وخفض نسبة الصوديوم المتبادل . وأهم النتائج المستخلصة من هذه الدراسة هو توضيح الدور الهام لسوبر فوسفات الكالسيوم والكبريت الزراعي في تحسين الخواص الفيزيائية والكيميائية للتربة الصودية . والتي تؤدي إلى تحسين إنتاجية النبات (النمو والمحصول) واستفادة أكثر من العناصر الغذائية بواسطة النبات والتي سوف يتم توضيحها في الجزء الثاني من هذه الدراسة .