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Phosphorus Availability as Influenced by Different Application Rates of Elemental Sulphur to Soils

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PHOSPHORUS is one of the three nutrients generally added to soils. However, the amount of available P in alkaline and calcareous soils is limited to be sufficient for normal plant growth. Therefore, the first part of this study was devoted to evaluate the effect of different application rates of sulphur (0.0; 0.5;1.0;2.0 and 3.0 Tons/acre) at various inoculated periods (1; 2; 3 and 4 weeks) with or without sulphur-oxidizing bacteria on the availability of P for sandy; clay loam; and calcareous soils. The second part, was designed as field experiments for garlic to compare the effect of different rates of P (0, 100; 200; 300 Kg of super phosphate /acre)with and without different rates of elemental sulphur (0.0; 0.5; 1.0 and 2.0 Tons/acre) on garlic yield and bulb weight.

The availability of P increased with increasing both sulphur application rates and inoculated period of soils with sulphur-oxidizing bacteria. The magnitude of increasing phosphorus availability was dependent upon soil type at the following order: calcareous soil > sandy soil > clay loam soil. It was concluded that application of one or two tons sulphur per acre (depending upon soil type) resulted in supplying a suitable amounts of available phosphorus. Available phosphorus increased from 2.2 to 51; 0.9 to 25 and 9.5 to 19 ppm for calcareous; sandy and clay loam soil, respectively.

The results of field experiments indicated the drop in soil pH as a function of applied sulphur which, influenced the availability of phosphorus. The yield of garlic increased from 4 to 5.2 Tons/acre by increasing application rate of P from 0 to 400 Kg per acre super phosphates alone. Also garlic yield increased from 4 to 5.7 Tons by application of 2 Tons per acre of sulphur alone. This means that application of sulphur alone has contributed to convert the phosphorus present in soil from insoluble to soluble forms for garlic plant and to be more productive than that treated with 400Kg per acre super phosphate alone. However, the combination between the application of high rate of P and S resulted in increasing the garlic yield from 4 to 7.1 Tons/acre.

Keywords: Sulphur, Phosphorus, Garlic, Fertilizers and Inoculation with sulphur-oxidizing bacteria.

In agricultural systems P inputs in the form of mineral and/or organic fertilizers are necessary to increase the production and replace P removed in plant and/or

animal products (Haygarth *et al.*, 1998). The presence of P in different forms or association with different soil colloids influences availability of P.

Phosphorus is most common nutrient limiting crops production (Gibson, 1997). P adsorption to soils may be the dominant P removal pathway (Lockaby & Walbridge, 1998). When applied sulphur to a well-drained soil ends up in the sulfate form according to the following oxidation reactions: $2S + 3O_2 + H_2O \rightarrow 2H_2SO_4$. The oxidation of sulphur compounds, such as sulfites (SO_3^{-2}) and sulfides (S^{-2}), can occur by strict chemical reactions. Whereas, most of the sulfur oxidation occurring in soils is thought to be biochemical in nature (Brady, 1974).The availability of phosphorus is controlled by soil characteristics and environmental condition (Ae N. *et al.*, 1991 and Ae N. *et al.*,1990).

One of the unique characteristics of phosphorus is its immobility in soil. Practically all soluble phosphorus from fertilizer or manure is converted in the soil to water-insoluble phosphorus within a few hours after application (Barber & Chen, 1990; Sah *et al.*, 1989; Lockaby & Walbridge, 1998 and Axt & Walbridge, 1999). Phosphorus occurs in the soil solution as the negatively charged phosphate ion $H_2PO_4^-$ in acid soils or $HPO_4^=$ in alkaline soils. These ions react readily with iron, aluminum, and manganese compounds in acid soils and with calcium compounds in neutral and alkaline soils. These reactions remove immediately available phosphorus ions from the soil solution. Therefore, the availability of phosphorus in alkali and calcareous soil is considered one of limiting factor of production. Thus, the object of this study was to evaluate the function of elemental sulphur to increment the availability of phosphorus to meet daily requirement for proper production of garlic and to compare this response with that for phosphorus fertilizers.

Material and Methods

Pots Experiment

Three surface-horizon-soil- samples, (a sandy; a clay loam and a calcacareous soil) were selected to represent a wide range of Egyptian Soils. The soil samples were air-dried and sieved through a 2-mm screen. Some properties of these samples presented in Table 1. Polyethylene pots containing 500 g soil-sulphur mixture were prepared in triplicates. The elemental sulphur was applied to each soil by the rates of : 0; 0.5; 1; 2 and 3%. One set of each soil samples representing all sulphur treatments was inoculated with sulphur-oxidizing bacteria and the other set without bacterial inoculation. The soil moisture for both sets was maintained at 50% of the field capacity for four weeks by daily irrigation .Soil samples were collected weekly from all treatments, for measurements of soil pH; EC and available phosphorus

TABLE 1. Some properties of the selected soil samples.

Soil type	EC (m.moh.)	PH	$CaCO_3$ (%)
	1: 2.5		
Sandy	1.16	8.4	0.5
Calcareous	0.38	8.6	37.0
Clay-Loam	3.26	9.1	5.4

Field Experiments

A field experiment was carried at National Research Center Experimental station. The soil is sandy clay loam with EC of 4 m.moh/cm. The Egyptian cv. of garlic was planted. The experiment included 16 treatments, which were resulted from the combinations of 4 levels of each sulphur (O; 0.5; 1 and 2 tons/acre) and/or phosphorus (0; 100; 200 and 400 Kg/ acre). The split plot design with 4 replicates was followed. The sub-plot area was 5.4 m^2 and included 3 rows (3m X 60 cm). Before planting calcium super phosphate at experimental rate was added to all treatments. Nitrogen fertilizer at a rate of 300 Kg/acre as ammonium sulphate (20.5 %N) and 200 kg/acre potassium sulphate were added to plant. At harvesting time the bulbs from four replicates of each treatment were collected and left for 7 days to dry . Then the total weight of bulbs was recorded.

Results and Discussion

Changes in soil pH due to sulphur application

The oxidation reaction of applied sulphur in soil was evidenced from the change in soil pH. The data in Table 2 illustrated the drop in soil pH due to sulphur application. The inoculation of soil with sulphur-oxidizing bacteria enhanced the oxidation rate of sulphur which resulted in increment the drop in soil pH than that without bacteria (Fig. 1) Generally, the effect of applied sulphur on soil pH depended on the sulphur application rate; on soil type; and on the incubation period. The effect of application rate was more emphasize in sandy soil. The drop in soil pH increase with increasing application rate of elemental sulphur.

The incubation period has significant effect on the magnitude of the drop in soil pH (Fig. 1) As incubation period increased the drop in soil pH increased. Soil type showed different responses to the oxidation of sulphur for different application rates and the periods of incubation. Because, the buffering capacity of each soil played an important role in controlling the change in soil pH against the acidifying products which resulted from the oxidation of applied sulphur. The data in Fig. 2 showed that the effect of applied sulphur on soil pH was remarkable in sandy soil as compared with other soils inoculated and uninculated with bacteria. The magnitude of the drop in soil pH was related to soil type and decreased in the following order: sandy soil > calcareous soil > alkali clay loam soil. However, the measurement of the oxidation rate of sulphur as a function of the drop in soil pH was some what masked by the effect of released base constituents in calcareous and clay loam soils.

TABLE 2. Effect of applied sulphur on the pH (1:2.5 extract).

Soil type	S rates ton/acre	Incubation period per week							
		uninoculated				Inoculated			
		1	2	3	4	1	2	3	4
Sandy	0	8.53	8.45	9.00	9.01	8.30	8.60	8.80	9.00
	½	8.20	6.40	6.60	5.35	7.30	6.29	5.84	4.57
	1	7.94	6.10	6.53	5.09	6.76	6.10	5.67	4.64
	2	7.03	5.95	5.76	5.39	6.55	5.88	5.58	4.59
	3	6.93	5.89	5.63	4.40	6.46	5.89	5.57	4.53
Calcareous	0	8.50	8.5	8.63	8.67	8.50	8.60	8.80	8.80
	½	7.60	8.98	8.50	7.80	7.60	7.92	8.57	7.77
	1	7.70	8.33	8.46	7.65	7.66	8.19	6.47	7.74
	2	7.77	8.26	8.57	7.61	7.71	7.57	8.49	7.72
	3	7.69	8.12	8.48	7.57	7.68	7.85	8.39	7.64
Clay loam	0	8.40	8.44	8.50	8.39	8.32	8.26	8.48	8.27
	½	7.90	7.72	7.94	7.73	7.85	7.81	7.99	7.66
	1	7.86	7.70	7.95	7.52	7.66	7.71	7.95	7.48
	2	7.85	7.69	7.97	7.55	7.69	7.68	7.96	7.51
	3	7.55	7.63	7.93	7.38	7.63	7.66	7.96	7.43

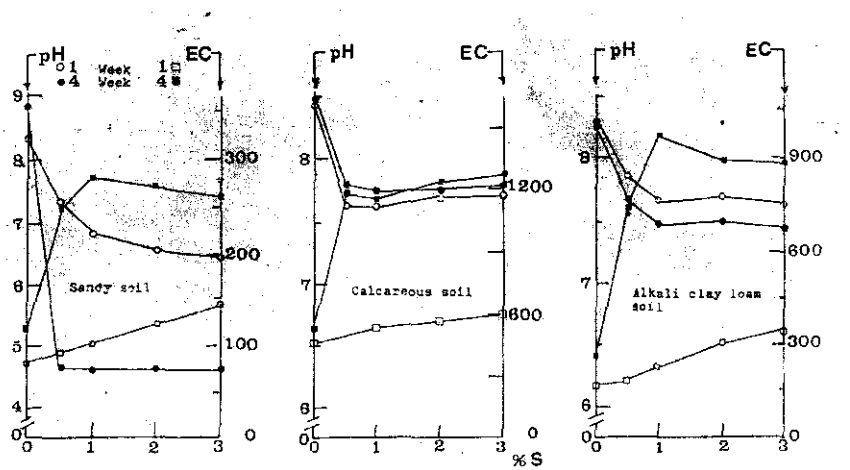

Fig.1. Effects of applied sulphur on soil pH and EC for soils at first and fourth week.

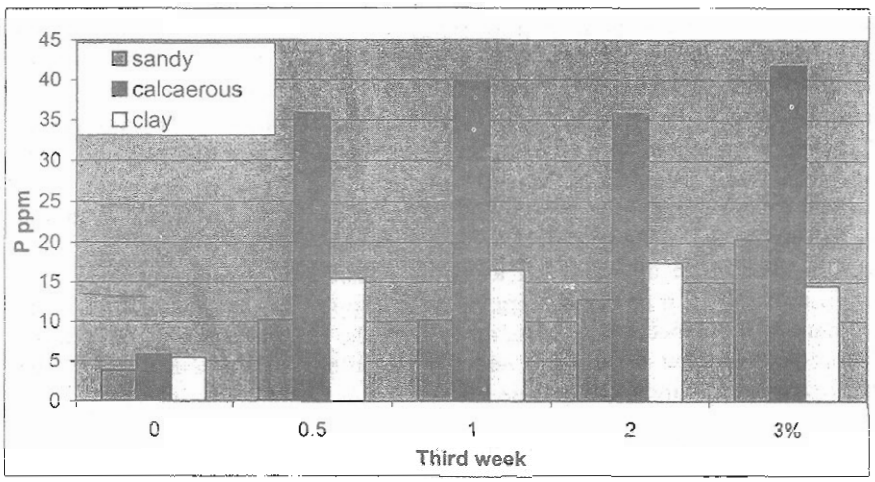

Fig. 2. Effect of different levels of sulphur on the availability of phosphorus in soils.

Variation in soluble salts due to sulphur application

The use of soil pH as a parameter for sulphur oxidation reaction in the soil was inadequate, due to the inverse effects of released base. Thus, it seems to be difficult to follow-up the oxidation of sulphur through the measurement of soil pH. The alternative approach was the measuring of the EC of 1 : 5 soil extract (Table 3) . The data presented in Fig. 1 showed the effects of applied sulphur on soil pH and EC at first and fourth weeks of the incubation period for the three soils. Although, the soil pH of calcareous and alkali clay loam soils had slightly dropping in soil pH with increasing applied sulphur, the EC data for these soils exhibited continuous release of soluble salt with increasing the applied sulphur. This indicated that the oxidation of sulphur in soil was a continuous

The increase in availability of phosphorus due to sulphur application, inoculation periods and soil type

Many factors are involved in controlling the availability and solubility of phosphorus in soil. However, the solubility and availability of phosphorus is largely dependent upon soil pH. Therefore, the application of sulphur to alkali and calcareous soils is expected to increase phosphorus availability through lowering the soil pH. Therefore, the application of sulphur to alkali and calcareous soils is expected to increase phosphorus availability through lowering the soil pH. The results presented in Table 4, indicated that the soluble phosphorus of all soils treated with sulphur was greatly affected by sulphur application. The amount of increasing in phosphorus availability was dependent upon soil type, application rate, inoculation with sulphur-oxidizing bacteria and incubation periods. The availability of phosphorus increasd with increasing application rates of sulphur. Also the availability of phosphorus increased with increasing incubation period for with and without inoculated soils up to the third

week for all sulphur levels and start to decline at the forth week, but still higher than that of initial of each soil (Fig.2). The maximum increase of available phosphorus was at 3% sulphur level for sandy soil and at 1% S for calcareous and alkali soils (Fig.3). Inoculation with sulphur-oxidizing bacteria with sulphur treatments resulted in increasing bioavailability of phosphorus than that without inoculation (Table 4) . The effect of inoculation on availability of phosphorus was different from soil to another . The influence of inoculation on the availability of phosphorus was greater in calcareous soil than that in other two soils. The magnitude of the increase in the availability of phosphorus differed due to soil type and decreased in the following order: calcareous soil > sandy soil > clay loam soil. The range of increasing available phosphorus was from 0.9 to 25.0 ppm; from 2.2 to 42.6 ppm and from 9.5 to 22.1 ppm for sandy; calcareous and clay loam soil, respectively. This mean that the availability of phosphorus influenced by sulphur application and the magnitude of influence follow the order: calcareous > sandy > clay loam soil.

TABLE 3. Effect of applied sulphur on the EC μ moh. (1:5).

Soil type	S rates ton/acre	Incubation period per week							
		uninoculated				Inoculated			
		1	2	3	4	1	2	3	4
Sandy	0	60	65	80	110	80	90	95	120
	½	65	180	240	250	90	208	220	250
	1	70	190	265	260	100	184	255	280
	2	77	225	270	240	120	149	250	270
	3	80	210	230	260	140	179	240	260
Calcareous	0	450	520	660	660	500	650	660	680
	½	500	850	890	970	540	770	1000	1200
	1	520	980	1000	1100	600	900	1050	1150
	2	570	860	1050	1200	640	660	1050	1230
	3	600	780	1100	1100	650	680	1050	1270
Clay loam	0	90	138	160	170	160	220	230	250
	½	120	415	450	570	180	570	600	740
	1	140	590	640	910	210	530	740	980
	2	260	555	790	860	300	600	740	890
	3	300	680	730	790	340	610	740	880

TABLE 4. Effect of applied sulphur on the availability of phosphorus (μg/g soil).

Soil type	S rates ton/acre	Incubation period per week							
		uninoculated				Inoculated			
		1	2	3	4	1	2	3	4
Sandy	0	0.9	3.5	3.8	2.4	1.7	2.5	4.9	3.1
	½	3.0	4.0	10.2	15.2	5.9	15.2	18.5	24.1
	1	6.7	9.5	10.2	14.1	5.2	18.8	17.6	25.5
	2	6.7	9.2	12.8	13.1	9.6	13.1	20.4	25.5
	3	6.7	7.5	20.4	14.5	8.2	16.3	25.0	25.1
Calcareous	0	2.2	3.6	5.8	6.7	2.2	5.6	8.5	11.4
	½	2.9	4.2	35.8	29.1	8.0	12.5	45.9	21.7
	1	2.8	9.4	39.7	29.3	14.8	15.6	51.1	21.7
	2	3.0	6.3	35.8	22.1	12.9	19.4	39.8	23.8
	3	2.7	8.1	41.7	21..6	10.8	13.1	42.6	21.7
Clay loam	0	9.5	11.3	5.5	1.7	12.2	9.6	8.8	4.8
	½	13.8	13.1	15.5	23.1	14.0	13.5	16.3	14.1
	1	15.3	18.8	16.5	23.1	14.8	16.9	18.8	14.1
	2	13.1	13.8	17.4	23.5	8.9	18.1	18.6	15.2
	3	12.4	13.1	14.5	22.8	9.8	22.1	16.5	16.9

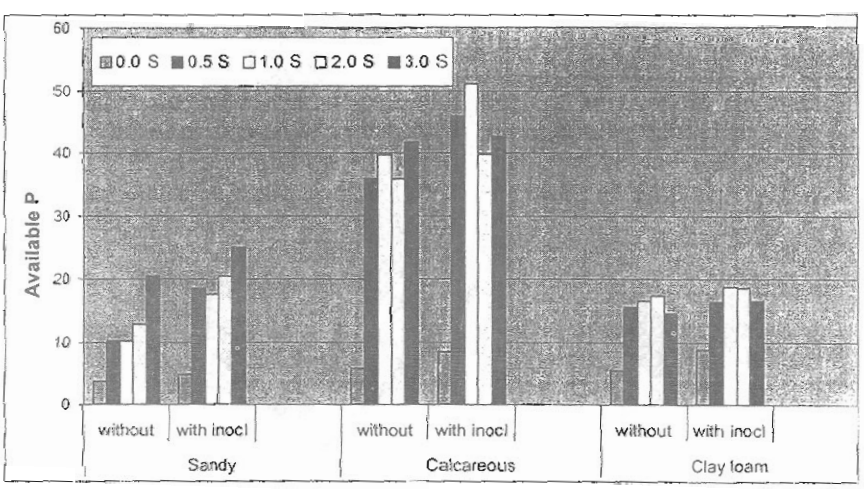

Fig .3. Effect of applied sulphur and on P availability in different soils.

Field experiment

The effect of applied sulphur to improve the chemical properties of soil was reflected on the yield of garlic. The yield of garlic, which grown in clay loam soil under furrow irrigation responded to different rates of elemental sulphur and phosphorus applications (Fig. 4) . The yield of garlic increased by 2.5%; 22.5% and 30% with increasing the sole phosphorus application of 100; 200 and 400 Kg super-phosphate /acre respectively.

The yield of garlic increased by 7.5%; 35.0% and 42.5% as compared with control due to the sole sulphur application of 0.5; 1.0 and 2.0 ton /acre. This may be related to the biologically activity which produced sulphoric acid lowers the soil pH and increases the availability of certain nutrients. Therefore, 1 ton /acre of sulphur mixed with surface soil resulted in produce yield of garlic more than that produced from soil treated with 400 Kg sole super-phosphate /acre.

Yield of garlic dramatic response to combined sulphur and phosphorus application. The combined effect resulted on marked increase in garlic yield by 27.5%; 55.0 % and 77.5% as compared with control for first (S_1P_1); second (S_2P_2) and third (S_3P_3) level of both S and P respectively. The maximum increase for the yield of garlic was 30 %; 42.5% and 77.5% due to the application of sole phosphorus; sole sulphur and combined S and P respectively.

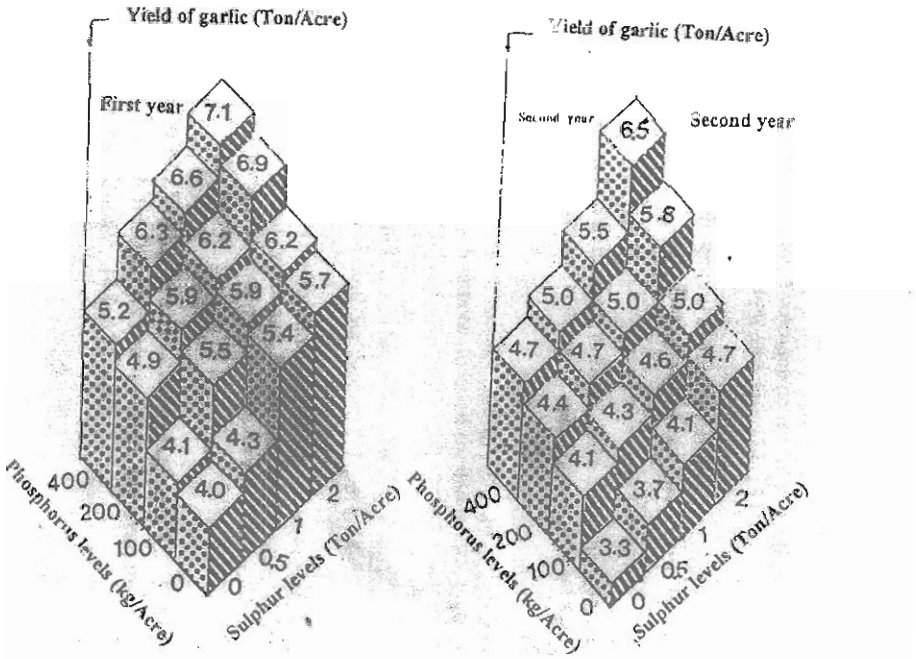

Fig.4. The response of total yield as a function of different rates of sulphur and/or phosphorus for two successive seasons.

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تأثير إضافة معدلات مختلفة من الكبريت علي تيسر الفوسفور في التربة وكذلك علي محصول الثوم

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يعتبر الفوسفور أحد العناصر السمادية الثلاثة التي تضاف إلي التربة و كمية الفوسفور الميسر في الأراضي الجيرية والقلوية محدودة ولاتكفي حاجة النبات. ولهذا صمم الجزء الأول من هذه الدراسة لتقييم تأثير إضافة الكبريت العنصري بمعدلات مختلفة (صفر – ٠,٥ – ١,٠ – ٢,٠ – ٣,٠ طن/إيكر) مع التحضين لفترات مختلفة (١- ٢-٣-٤ أسبوع) مع أو بدون البكتيريا المؤكسدة للكبريت علي تيسر الفوسفور في ٣ أنواع من الأراضي (رملية وجيرية وسلتية). أما الجزء الثاني من الدراسة فهو عبارة عن تجربة حقلية للمقارنة بين تأثير إضافة معدلات مختلفة من الفوسفور علي صورة سوبر فوسفات (صفر – ١٠٠ – ٢٠٠ – ٣٠٠ كجم/إيكر) مع أو بدون كبريت بمعدلات (صفر – ٠,٥ – ١,٠ – ٢,٠ طن/إيكر) علي تيسر الفوسفور في التربة وكذلك علي وحصول الثوم .

أظهرت النتائج زيادة الفوسفور الميسر مع زيادة معدل الكبريت وكذلك مع طول فترة التحضين سواء مع إضافة أو عدم إضافة البكتيريا المؤكسدة للكبريت وإختلفت هذه الزيادة تبعا لنوع التربة حيث كانت في التربة الجيرية > الرملية > الطميية.

تبين أن إضافة ١ أو ٢ طن كبريت/إيكر (تبعا لنوع التربة) أدي إلي تيسر كميات من الفوسفور تفي بحاجة المحصول حيث زاد الفوسفور الميسر من ٢و٢ إلي ٥١,٠ ومن ٠,٩ إلي ٢٥,٠ ومن ٥,٩ إلي ١٩,٠ جزء في المليون في التربة الجيرية والرملية والطميية علي التوالي.

أظهرت نتائج التجربة الحقلية إنخفاض رقم حموضة التربة نتيجة إضافة الكبريت مما أدي إلي زيادة تيسر الفوسفور. وزاد محصول الثوم من ٤,٠ إلي ٥,٢ طن/إيكر عند إضافة ٤٠٠كجم/إيكر من السوبرفوسفات منفردا بينما زاد المحصول من ٤,٠ إلي ٥,٧ طن/ إيكر عند إضافة ٢,٠ طن/إيكر من الكبريت منفردا وهذا يعني أن إضافة الكبريت يؤدي إلي تحول الفوسفور من الصورة الغير ذائبة إلي الصورة الميسرة للنبات ويعطي محصول أعلي من إضافة السوبرفوسفات منفردا حتي معدل ٤٠٠ كجم/إيكر. بينما أدت إضافة المعدل المرتفع من الكبريت مع السوبرفوسفات إلي زيادة المحصول من ٤,٠ إلي ٧,١ طن/إيكر .