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Impact of Phosphorus and Sulfur Fertilizers Levels on Soybean Productivity

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ABSTRACT

This study was carried out at the Village of Algraydh, Kafrelshiekh Governorate, Egypt, during the summer seasons 2016 and 2017 to conclude whether, and if so how, soybean growth, yield and seed oil percentage are affected by phosphorus and sulfur mineral fertilizers levels. The experiment was laid-out in strip-plot design with four replications. The vertical-plots included five levels of phosphorous (P) fertilizer (0 without as control, 10, 20, 30 and 40 kg P_2O_5 fed^{-1}). While, the horizontal-plots assigned with five levels of sulfur (S) fertilizer (0 without as a control, 20, 40, 60 and 80 kg S fed^{-1}). Application of 40 kg P_2O_5 fed^{-1} produced the maximum averages of growth characters, yield and yield components as well as seed oil percentage. Furthermore, using 30 kg P_2O_5 fed^{-1} came after the previously mentioned level and without significant differences between them in both seasons. Adding 80 kg S fed^{-1} produced the highest averages of all studied traits, followed by 60 kg S fed^{-1} and without significant differences between them in both seasons. It could be concluded that combined application of 30 kg P_2O_5 fed^{-1} plus 60 kg S fed^{-1} is recommend for improving the productivity and seed oil percentage of soybean under the ecological conditions of Kafrelsheikh Governorate, Egypt.

Keywords: Soybean, Phosphorus fertilizer, Sulphur fertilizer Growth, Yield, Oil percentage.

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is consider as one of the vital and important leguminous crops for food and feed in Egypt and worldwide. It is containing about 20-22% of vegetable oil, 42-45% of protein, 30-35% of carbohydrates and 10-12% of total sugar as well as high amount of the amino acid, thiamin, vitamins, niacin, riboflavin, phosphorus, calcium and iron (Wahhab *et al.,* 2001). In addition, soybean seed oil is free of cholesterol and rich in the essential and unsaturated fatty acids. Moreover, the oil of soybean is important for dieting, diabetic and protects against some types of cancer diseases (Fabiyi, 2006 and Agwu *et al.,* 2009). Beside the importance of soybean as important oil crop (20-30% of the world's processed vegetable oil), it has been employed as a source of bio-diesel fuels (Graham and Vance, 2003 and Acikgoz *et al.,* 2009). There is a big gap between consumption and production of oil for this reason, the cultivated area of soybean plant increased to minimizing the deficit in oil crops production. According to FAO (2018) the total cultivated area in Egypt reached about 23800 fed with total seed production of about 35000 ton. On the other hand, the worldwide cultivation of soybean reached about 121.5 million ha with approximate productivity of about 334.9 million ton. Recently, attention has been directed toward improving soybean growth, seed yield and quality. The nutritional requirements of soybean are among the most important limitations for optimizing quantitative and qualitative yield characters. Phosphorous (P), plays a pivotal role in improving growth, development and reproduction, flowering, pod setting, seed formation, protein synthesis, sugars translocation, plant resistance to several diseases and seed quality (Brady, 2002). Phosphorus is considering as a major and essential macronutrient required by all plants for contributes in many metabolic processes *i.e* cell division, building new tissues, photosynthesis, respiration, nucleic acids, glucose synthesis, N fixation and synthesis of phospholipids (Thavarajah *et al.,* 2010). In addition, during the process of symbiotic N_2 fixation, the rhizobium bacteria needs high quantity of phosphorous as a source of energy for bacterial growth, increasing root growth and the density of rhizobia bacteria in the soil and to transform atmospheric N_2 into available ammonium (NH_4) form available for plant nutrition (Schulze *et al.,* 2006) and the energy transfer adenosine triphosphate (ATP) metabolism mainly depending on the availability of P in soils (Plaxton, 2004). Sinclair and Vadez (2002) indicated that N fixation required a high amount of P and this process was very sensitive to P shortage due to the reduction in nodule numbers, fresh and dry mass as well as declined ureide production. Servani *et al.* (2014) revealed that phosphorus fertilization plays an important role in the life cycle of legume plants and can change the rates of plant growth, leaf area, yield and its attributes as well as seed oil content of soybean plants. In addition, phosphorus shortage can limit nodulation by soybean plants and application of P fertilizer maybe overcomes the deficit. Kumar *et al.* (2017) reported that application P at the rate of 90 kg P_2O_5 ha^{-1} caused significant increases in plant growth, seed yield, biological yield and harvest index of soybean plants. Moreover, application of 46 kg P_2O_5 ha^{-1} increased significantly nodules numbers $plant^{-1}$, nodules fresh and dry weights, growth characters, yield and yield attributes of soybean plants (Kuntyastuti and Suryantini, 2015; Soares *et al.,* 2016 and Tarekegn and Kibret, 2018).

Sulfur (S) plays a vital role as macronutrient, using sulfur as a soil amendment for lowering soil pH value is more convenient in field application due to its low-cost and long-lasting effect given its slow oxidation processing (Neilsen *et al.,* 1993). Moreover, sulphur acting a vital role in various metabolic processes of plant and came in the fourth ranked as a major plant nutrient after nitrogen, phosphorus and potassium. It is a component of amino acids such as cysteine and methionine needed for the synthesis of protein (Jan *et al.,* 2002), a basic part of the ferredoxin and an iron-sulphur protein happening in the chloroplasts. Ferredoxin has a significant role in nitrogen dioxide and sulphate reduction, nitrogenase activity, nitrogen fixation by root nodule bacteria (Scherer *et al.,* 2008). In addition, sulfur application in a narrow band to lower root zone pH and increase phosphorus availability to the crop is a possible economically feasible solution. Many researchers showed that number of nodules $plant^{-1}$, plant height, chlorophyll content, leaf area index, seed yield $plant^{-1}$, 1000-seed yield, seed and biological yields ha^{-1} as well as seed oil content of soybean seeds significantly affected due to sulphur application, the highest averages of these characters were produced with 20 kg S ha^{-1} (Jamal *et al.,* 2005; Morshed *et al.,* 2009; Farhad *et al.,* 2010; Hussain *et al.,* 2011; Hosmath *et al.,* 2014; Anil *et al.,* 2017 and Getachew *et al.,* 2017). Moreover, adding 40 kg S ha^{-1} caused increase in seed yield and oil percentage of soybean (Mamatha *et al.,* 2018).

Regarding to the interaction effect, there are numerous investigations suggested the beneficial effect of sulfur on reducing the pH value of calcareous soil by about 1-2 units; thus increasing the availability of plant nutrients, particularly phosphorus and the microbial oxidation of elemental S to SO_4^{-2} generates acidity, which in turn releases P bound to Ca and Fe minerals into soil solution (Gabriel *et al.,* 2008; Ye *et al.,* 2010 and Wiedenfeld*,* 2011). Legume growth characters, yield and its components as well as nitrogen fixation rates could be significantly increased by apply of suitable amount of phosphorus and sulfur as essential nutrients (Olivera *et al.,* 2004 and Scherer *et al.,* 2008). Highest number of nodules $plant^{-1}$, fresh and dry weights of nodules $plant^{-1}$, plant height, leaf area index, number of pods $plant^{-1}$, seed and biological yields ha^{-1} were produced with application of 90 kg P_2O_5 plus 60 kg S ha^{-1}, followed by added 90 kg P_2O_5 plus 40 kg S ha^{-1} (Dhage *et al.,* 2014 and Kumar *et al.,* 2017).

In this context, the present study was assumed to understand the role of phosphorous and sulphur fertilizers levels on growth characters, seed yield and its components as well as seed oil percentage of soybean under the ecological conditions of Kafrelshiekh Governorate, Egypt.

MATERIALS AND METHODS

Experimental site and objective:

A two season-field experiment was conducted at Village of Algraydah, Kafrelshiekh Governorate during the two successive summer seasons of 2016 and 2017 in order to study the effect of phosphorus and sulfur fertilizers levels on productivity and oil percentage of soybean seeds.

Treatments and experimental design:

The experimental treatments comprising four replicates were arranged in a strip-plot design. Vertical plots included five levels of phosphorous (P) fertilizer (P_1: without as a control, P_2: 10, P_3: 20, P_4: 30 and P_5: 40 kg P_2O_5 fed^{-1}). Phosphorus fertilizer in the form of calcium superphosphate (15.5 % P_2O_5) was carefully mixed with the surface soil layer (0-20 cm) directly after dividing and before planting. The horizontal-plots were assigned to five levels of sulphur (S) fertilizes (S_1: without as a control, S_2: 20, S_3: 40, S_4: 60 and S_5: 80 kg S fed^{-1}). Sulphur fertilizer in the form of agriculture gypsum (18% S) was applied to the soil using the same methods of phosphorous.

Sowing and soil fertilization:

The experimental field included 100 units (10.5 m^2 for each). The experimental unit included 5 ridges (60 cm width × 3.5 m length). Egyptian clover was the previous winter crop during both growing seasons. Before planting soil samples were taken random at depths of 0-15 cm and 15-30 cm and analyzed to obtain the physical and chemical properties. The soil was clayey with pH of 7.83, electrical conductivity (EC) of 1.56 dSm^{-1}, organic matter (OM %) of 1.56%, available N of 26.50 ppm, available P of 9.50 ppm, exchangeable K of 265.00 ppm and available S of 35.50 ppm, as an average over both growing seasons. Soybean seeds (Giza 22 cultivar, maturity group (IV)) was obtained from Oil Research Section, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt. Before sowing, the seeds of soybean were inoculated with 10 g of bacteria (*Bradyrhizobium japonicum*) per kg of seed as described by Rice *et al.* (2001). After that, the seeds were directly sown on two sides of ridges in hills 15.0 cm apart on the 5^{th} of May in both seasons. After three weeks, only two healthy plants remained in each hill. Nitrogen fertilizer in the forms of urea (46.5% N) at the rate of 45 kg N fed^{-1} and potassium fertilizer potassium in the form of potassium sulphate (48% K_2O) at the rate of 48 kg K_2O fed^{-1} were applied twice at equal portions, the first after thinning and the second after three weeks later. All common agriculture practices for growing soybean were followed according to the Ministry of Agriculture recommendation, except the factors under study.

Studied characters:

After 70 days from sowing (DFS), five guarded plants were randomly chosen from the outer ridges of each plot to determine the following characters: Total number of nodules $plant^{-1}$, nodules fresh weight $plant^{-1}$, nodules dry weight $plant^{-1}$ (oven-dried at 70 °C), total chlorophyll (SPAD) measurement using SPAD-502, Minolta Co. Ltd., Osaka, Japan and leaf area index (LAI) measurements according to Watson (1958) using the following equation:

$$LAI = \frac{\text{Leaf area per plant (cm}^2\text{)}}{\text{Plant ground area (cm}^2\text{)}}$$

At the harvest date *i.e.* 125 DFS at reproductive stage R_8, five randomly guarded plants were taken from the outer ridges of each experimental unit to determine the following characters: Plant height (cm), stem diameter (cm), number of pods $plant^{-1}$, pod length (cm), number of seeds pod^{-1}, number of seeds $plant^{-1}$ and 100-seed weight (g). Seeds and biological yields fed^{-1} were determined by harvested all plants in the three inner ridges of each experimental unit. Thereafter, seed yield was corrected for 10-12% moisture content then weighted and converted to tons fed^{-1}. Harvest index (HI): It was estimated as a ratio among seed yield fed^{-1} to biological yield fed^{-1}. Seed oil percentage (%), it was estimated by using the method as described by AOAC (1990).

Data analysis:

Analysis of variance was carried out using ANOVA for a strip-plot design as cited by Gomez and Gomez (1984), using MSTAT computer program. Least Significant Difference (LSD) at 5 % probability as stated by Snedcor and Cochran (1980) was used to compare the differences among the significant treatments means.

RESULTS AND DISCUSSION

Effect of phosphorous fertilizer levels:

Plant growth characters:

Data presented in Tables 1 and 2 clearly reveal that phosphorous fertilizer levels *i.e* without (control), 10, 20, 30 and 40 kg P_2O_5 fed^{-1} showed a significant effect on plant growth characters (nodules numbers $plant^{-1}$, nodules fresh and dry weights, chlorophyll content, leaf area index, plant height and stem diameter) in both growing seasons. The highest averages of these characters were resulted from using the highest levels of P fertilizer (40 kg P_2O_5 fed^{-1}). Whereas, the differences between application 40 and 30 kg P_2O_5 fed^{-1} were insignificant on all plant growth characters in both seasons. On the other hand, the lowest averages of these characters were recorded with control treatment (without) in both seasons. It could be noticed that application of 40 kg P_2O_5 fed^{-1} exceeded other treatment (without, 10, 20 and 30 kg P_2O_5 fed^{-1}) by 56.30, 40.06, 15.67 and 0.21% in number of nodules $plant^{-1}$, 44.92, 39.63, 29.25 and 0.86% in fresh weight of nodules $plant^{-1}$, 40.30, 26.04, 18.15 and 1.49% in nodules dry weight $plant^{-1}$, 27.23, 19.06, 15.48 and 0.80% in total chlorophyll content, 26.34, 24.48, 19.97 and 1.33% in LAI, 31.65, 18.85, 13.74 and 0.36% in plant height and 26.80, 20.17, 12.91 and 1.66% in stem diameter, respectively as an average over both growing seasons.

Table 1. Means of nodules numbers $plant^{-1}$, nodules fresh weight $plant^{-1}$(g), nodules dry weight $plant^{-1}$ (g) and total chlorophyll (SPAD) as affected by phosphorous and sulfure fertilizers levels and their interaction during 2016 and 2017 seasons.

Characters / Seasons	Nodules numbers $plant^{-1}$		Nodules fresh weight $plant^{-1}$ (g)		Nodules dry weight $plant^{-1}$ (g)		Total chlorophyll (SPAD)	
Treatments	2016	2017	2016	2017	2016	2017	2016	2017
A- Phosphorous fertilizer levels (kg P_2O_5 fed^{-1}):								
Without (control)	18.75	22.11	1.82	2.01	0.47	0.56	35.28	39.98
10	27.57	28.45	1.95	2.25	0.59	0.69	40.30	43.38
20	39.08	39.74	2.34	2.58	0.67	0.75	43.02	44.34
30	46.39	46.88	3.36	3.53	0.82	0.89	50.66	51.87
40	46.50	46.97	3.40	3.55	0.83	0.90	51.04	52.32
LSD at 5 %	0.90	0.97	0.11	0.07	0.06	0.02	1.62	0.89
B- Sulphur fertilizer levels (kg S fed^{-1}):								
Without (control)	30.41	31.42	2.09	2.26	0.55	0.60	38.58	40.99
20	35.04	36.15	2.33	2.54	0.63	0.72	41.96	44.26
40	36.54	37.89	2.69	2.97	0.70	0.80	44.60	47.70
60	38.07	39.30	2.88	3.08	0.74	0.83	47.43	49.31
80	38.24	39.39	2.89	3.09	0.75	0.84	47.74	49.64
LSD at 5 %	0.58	0.63	0.17	0.16	0.02	0.01	0.71	0.56
C- Interaction (F. test):	*	*	NS	NS	NS	NS	NS	NS

*; significant at 0.05 level of probability and NS; non-significant at 0.05 level of probability.

Table 2. Means of leaf area index (LAI), plant height (cm), stem diameter (cm) and number of pods $plant^{-1}$ as affected by phosphorous and sulfure fertilizers levels and their interaction during 2016 and 2017 seasons.

Characters / Seasons	Leaf area index (LAI)		Plant height (cm)		Stem diameter (cm)		Number of pods $plant^{-1}$	
Treatments	2016	2017	2016	2017	2016	2017	2016	2017
A- Phosphorous fertilizer levels (kg P_2O_5 fed^{-1}):								
Without (control)	2.71	2.79	74.61	78.68	0.62	0.65	48.40	54.66
10	2.76	2.88	90.01	91.96	0.66	0.72	53.53	60.00
20	2.87	3.11	95.84	97.58	0.71	0.80	66.00	72.33
30	3.58	3.79	110.56	112.86	0.84	0.87	75.06	80.53
40	3.63	3.84	111.02	113.22	0.86	0.88	76.13	81.40
LSD at 5 %	0.06	0.05	1.47	1.61	0.01	0.01	1.15	0.94
B- Sulphur fertilizer levels (kg S fed^{-1}):								
Without (control)	2.82	2.97	90.38	92.74	0.62	0.67	57.93	61.73
20	2.95	3.09	92.93	95.28	0.70	0.75	60.13	66.00
40	3.11	3.27	96.58	99.06	0.76	0.80	63.53	70.06
60	3.31	3.52	100.72	103.47	0.80	0.84	68.46	75.00
80	3.36	3.56	101.42	103.73	0.82	0.85	69.06	76.13
LSD at 5 %	0.06	0.05	1.08	0.95	0.01	0.01	0.83	1.15
C- Interaction (F. test):	*	*	NS	NS	NS	NS	*	*

*; significant at 0.05 level of probability and NS; non-significant at 0.05 level of probability.

The increases in plant growth characters due to application high levels of phosphorus fertilizer might be related to phosphorus is an essential macronutrient required by all soybean plants in many metabolic processes *i.e* cell division, building new tissues, photosynthesis, respiration, nucleic acids and glucose synthesis, N fixation, synthesis of phospholipids (Thavarajah *et al.,* 2010). Also, during the process of symbiotic N_2 fixation, the rhizobium bacteria need high quantity of phosphorous as a source of energy for bacterial growth, increasing root growth and the density of rhizobia bacteria in the soil and to transform atmospheric N_2 into an ammonium (NH_4) form useable by plants (Schulze *et al.,* 2006). Moreover, phosphorus plays an important role in the life cycle of legume plants and can change the rates of plant growth, leaf area, yield and its attributes of soybean plants (Servani *et al.,* 2014). The obtained results are in agreement with those recorded and discussed by (Kuntyastuti and Suryantini, 2015; Soares *et al.,* 2016; Kumar *et al.,* 2017 and Tarekegn and Kibret, 2018).

Yield and yield components:

Phosphorus fertilizer levels had a significant effect on yield and its components in both seasons. As presented in Tables 2, 3 and 4, it is obviously noticed that application of P at the high level (40 kg P_2O_5 fed^{-1}) resulted in the highest averages of number of pods plant^{-1} 76.13 and 81.40, pod length 6.47 and 6.96 cm, number of seeds pod^{-1} 3.87 and 4.37, number of seeds plant^{-1} 187.93 and 200.46, 100-seed weight 21.30 and 22.56 g, seed yield fed^{-1} 1.850 and 1.950 ton fed^{-1}, biological yield fed^{-1} 3.823 and 3.931 ton fed^{-1} and harvest index 0.48 and 0.49, respectively in both growing seasons. Furthermore, application of 30 kg P_2O_5 fed^{-1} followed the previously mentioned treatment (40 kg P_2O_5 fed^{-1}) and without significant differences between them over both seasons. On the other hand, the lowest mean averages of yield and its attributes were recorded with control treatment in both seasons. In conclusion, applying the level of 40 kg P_2O_5 fed^{-1} caused increases in seed yield fed^{-1} by 42.44, 37.58, 10.40 and 0.15% and biological yield fed^{-1} by 14.68, 10.14, 1.94 and 0.22% as compared with the control treatment, 10, 20 and 30, P_2O_5 fed^{-1}, respectively as an average over both growing seasons. Also, using 30 P_2O_5 fed^{-1} treatment exceeded without, 10 and 20 P_2O_5 fed^{-1} levels in seed yield fed^{-1} by 42.36, 37.50 and 10.27% and biological yield fed^{-1} by 14.48, 9.92 and 1.72%, respectively as an average over both growing seasons.

Table 3. Means of pod length (cm), number of seeds pod^{-1}, number of seeds plant^{-1} and 100-seed weight (g) as affected by phosphorous and sulfure fertilizers levels and their interaction during 2016 and 2017 seasons.

Characters Seasons	Pod length (cm)		Number of seeds pod^{-1}		Number of seeds plant^{-1}		100-seed weight (g)	
Treatments	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
A- Phosphorous fertilizer levels (kg P_2O_5 fed^{-1}):								
Without (control)	4.83	5.53	2.71	3.20	149.46	162.20	17.57	18.32
10	5.46	6.02	2.93	3.49	165.00	171.20	18.63	19.48
20	5.62	6.59	3.11	3.68	182.26	188.86	19.28	21.32
30	6.43	6.92	3.78	4.29	186.60	199.40	21.18	22.40
40	6.47	6.96	3.87	4.37	187.93	200.46	21.30	22.56
LSD at 5 %	0.21	0.22	0.10	0.17	3.01	2.47	0.44	0.29
B- Sulphur fertilizer levels (kg S fed^{-1}):								
Without (control)	5.21	5.53	2.80	3.37	154.73	161.00	17.43	18.28
20	5.52	5.81	3.08	3.68	169.53	177.06	18.82	20.17
40	5.75	6.22	3.30	3.84	175.53	185.66	20.03	21.38
60	6.15	7.20	3.57	4.02	185.13	198.73	20.78	22.06
80	6.18	7.28	3.66	4.10	186.33	199.66	20.90	22.19
LSD at 5 %	0.11	0.12	0.10	0.09	2.38	1.81	0.19	0.23
C- Interaction (F. test):	NS	NS	NS	NS	*	*	*	*

***; significant at 0.05 level of probability and NS; non-significant at 0.05 level of probability.**

Table 4. Means of seed yield (ton fed^{-1}), biological yield (ton fed^{-1}), harvest index (HI) and oil % as affected by phosphorous and sulfure fertilizers levels and their interaction during 2016 and 2017 seasons.

Characters Seasons	Seed yield (ton fed^{-1})		Biological yield (ton fed^{-1})		Harvest index (HI)		Oil (%)	
Treatments	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
A- Phosphorous fertilizer levels (kg P_2O_5 fed^{-1}):								
Without (control)	1.068	1.118	3.344	3.269	0.32	0.34	19.14	19.62
10	1.085	1.290	3.356	3.614	0.32	0.35	19.87	20.64
20	1.631	1.775	3.777	3.825	0.43	0.46	20.08	21.43
30	1.846	1.948	3.821	3.915	0.48	0.49	21.31	22.06
40	1.850	1.950	3.823	3.931	0.48	0.49	21.33	22.09
LSD at 5 %	0.014	0.024	0.049	0.099	0.01	0.01	0.13	0.15
B- Sulphur fertilizer levels (kg S fed^{-1}):								
Without (control)	1.306	1.407	3.501	3.562	0.37	0.39	19.26	20.13
20	1.455	1.586	3.567	3.671	0.40	0.42	19.93	20.78
40	1.549	1.648	3.650	3.726	0.41	0.43	20.59	21.41
60	1.583	1.718	3.698	3.797	0.42	0.44	20.97	21.75
80	1.587	1.721	3.703	3.799	0.42	0.44	20.99	21.76
LSD at 5 %	0.015	0.021	0.027	0.022	0.01	0.01	0.13	0.13
C- Interaction (F. test):	*	*	*	*	NS	NS	*	*

***; significant at 0.05 level of probability and NS; non-significant at 0.05 level of probability.**

The increases in seed yield of soybean plants due to using the high levels of phosphorus fertilizer (40 and 30 P_2O_5 fed^{-1}) might be attributed to the fact that phosphorus plays essential roles in the metabolic processes *i.e* cell division, photosynthesis, respiration, nucleic acids and glucose synthesis, N fixation, synthesis of phospholipids (Thavarajah *et al.,* 2010 and Servani *et al.,* 2014). Results on yield and its components with high levels of phosphorus fertilizer were in compliance with those indicated by (Soares *et al.,* 2016; Kumar *et al.,* 2017 and Tarekegn and Kibret, 2018).

Seed oil percentage:

In both growing seasons, data presented in Table 4 clearly show that phosphorus fertilizer levels had a significant effect on seed oil percentage of soybean. Highest averages of oil% were resulted with the high levels of 40 and 30 kg P_2O_5 fed^{-1} and without significant differences between them in both seasons. The corresponding data were (21.33 and 22.09%) for 40 kg P_2O_5 fed^{-1} and (21.31 and 22.06%) for 30 kg P_2O_5 fed^{-1}, respectively in first and second growing seasons. These results are in good harmony with those obtained by (Servani *et al.,* 2014).

Effect of sulphur fertilizer levels:

Plant growth characters:

Data presented in Tables 1 and 2 clearly show that sulphur fertilizer levels *i.e* without as control, 20, 40, 60 and 80 kg S fed^{-1} showed a significant effect on all studied plant growth characters *i.e.* nodules numbers plant^{-1}, nodules fresh and dry weights, chlorophyll content, LAI, plant height and stem diameter in both seasons. The maximum mean averages of these characters were resulted from using the highest level of S fertilizer (80 kg S fed^{-1}) in both seasons. Whereas, the differences between application 80 and 60 kg S fed^{-1} were insignificant on all plant growth characters in both seasons. On the other hand, the lowest averages of these characters were recorded with control treatment in both seasons. It could be noticed that application of 80 kg S fed^{-1} exceeded other levels (without, 20, 40 and 60 kg S fed^{-1}) by 20.35, 8.29, 4.12 and 0.33% in number of nodules plant^{-1}, by 27.27, 18.58, 5.40 and 0.33% in fresh weight of nodules plant^{-1}, by 27.54, 15.31, 5.92 and 1.18% in nodules dry weight plant^{-1}, by 18.30, 11.47. 5.24 and 0.65% in total chlorophyll content, by 16.32, 12.70, 7.79 and 1.30% in LAI, by (10.74, 9.25, 4.63 and 0.47%) in plant height and by (22.29, 13.56, 6.56 and 1.49%) in stem diameter, respectively as an average over both growing seasons.

The increases in plant growth characters due to application high levels of suphure fertilizer levels might be attributed to sulphur is consider one of the macronutrients and plays a vital role in various metabolic processes of plant *i.e.* synthesis of protein (Jan *et al.,* 2002), a basic part of the ferredoxin and an iron-sulphur protein happening in the chloroplasts. Ferredoxin has a significant role in nitrogen dioxide and sulphate reduction, nitrogenase activity, nitrogen fixation by root nodule bacteria (Scherer *et al.,* 2008). These results are in consistency with those reported by (Jamal *et al.,* 2005; Morshed *et al.,* 2009; Farhad *et al.,* 2010 and Anil *et al.,* 2017).

Yield and yield components:

Sulphur fertilizer levels had a significant effect on yield and its components in both seasons (Tables 2, 3 and 4). It is clearly noticed that sulphur application at the high level (80 kg S fed^{-1}) resulted increases in number of pods plant^{-1} by 17.51, 13.11, 7.99 and 1.17%, pod length by 19.79, 15.36, 10.72 and 0.75%, number of seeds pod^{-1} by 20.65, 13.04, 8.08 and 2.20%, number of seeds plant^{-1} by 18.16, 10.16, 6.40 and 0.55%, 100-seed weight by 17.11, 9.52, 3.90 and 0.58%, seed yield fed^{-1} by 17.97, 8.08, 3.31 and 0.21, biological yield fed^{-1} by 5.83, 3.52, 1.67 and 0.09 and harvest index by 11.63, 4.65, 2.32 and 0%, respectively as compared with using (without, 20, 40 and 60 kg S fed^{-1}), calculated as an average over both growing seasons. Furthermore, application of 60 kg S fed^{-1} came in the second rank after the previously mentioned treatment (80 kg S fed^{-1}) and without significant differences between them over both growing seasons. On the other hand, the lowest averages of yield and its components were recorded with control treatment in both seasons.

The increases in yield and its attributes of soybean plants due to using the high levels of sulphur fertilizer levels (80 and 60 S fed^{-1}) might be due to sulphur play an important role in improve vegetative growth of soybean plants, which it is consider a component of ferredoxin in chloroplast and is involved in photosynthetic process (Scherer *et al.,* 2008). Sulfur application in a narrow band to lower root zone pH and increase phosphorus availability to the crop is a possible economically feasible solution. Furthermore, the high levels of S caused increased in yield components *i.e.* number of pods plant^{-1}, number of seed plant^{-1}, number of seeds pods^{-1}, 100-seed weight, which resulted in increased of seed and biological yields as well as harvest index. These findings are in good conformity with the previous findings by (Jamal *et al.,* 2005; Morshed *et al.,* 2009; Farhad *et al.,* 2010; Hussain *et al.,* 2011, Hosmath *et al.,* 2014 and Mamatha *et al.,* 2018).

Seed oil percentage:

Concerning oil%, data presented in Table 4 clearly showed that sulphur fertilizer levels had a significant effect on oil% in soybean seeds. Maximum averages of oil% were resulted with the high levels of 80 and 60 kg S fed^{-1} and without significant difference between. The corresponding data were (20.99 and 21.76%) for 80 kg S fed^{-1} and (20.97 and 21.75%) for 60 kg S fed^{-1}, respectively in the first and second seasons. These results are in agreement with those indicated by (Jamal *et al.,* 2005; Farhad *et al.,* 2010 and Mamatha *et al.,* 2018).

Interaction effect:

As presented in Tables 1, 2, 3 and 4 nodules number plant^{-1}, LAI, number of pods plant^{-1}, number of seeds plant^{-1}, 100-seed weight, seed yield fed^{-1}, biological yield fed^{-1}, HI and oil % significantly affected due to the interaction between phosphorous and sulphur fertilizer levels in both seasons.

As seems to appear the maximum averages of nodules number plant^{-1} (Fig. 1), LAI (Fig. 2), number of pods plant^{-1} (Fig. 3), number of seeds plant^{-1} (Fig. 4), 100-seed weight (Fig. 5), seed yield fed^{-1} (Fig. 6), biological yield fed^{-1} (Fig. 7) and oil % (Fig. 8) were resulted from application 40 kg P_2O_5 fed^{-1} in combined with 80 kg S fed^{-1} followed by using 30 kg P_2O_5 fed^{-1} plus 60 kg S fed^{-1} and without significant differences between them in both seasons. The increases in these characters due to the combined application of phosphorus and sulphur fertilizers at the levels of 40 kg P_2O_5 plus 80 kg S fed^{-1} and 30 kg P_2O_5 fed^{-1} plus 60 kg S fed^{-1} as compared other treatments may be due to P and S plays essential role in plant metabolism. In addition sulfur application in a narrow band to lower root zone pH and increase phosphorus availability to the crop, help in absorption of large quantities of nutrients through their well developed root system and nodules formation, nodules number, which might have increased plant growth and ultimate the yield as well as oil% of soybean plants. Furthermore, legume growth characters, yield and its components as well as nitrogen fixation rates could be significantly increased by apply of suitable amount of phosphorus and sulfur as essential nutrients (Scherer *et al.,* 2008; Olivera *et al.,* 2004; Dhage *et al.,* 2014 and Kumar *et al.,* 2017).

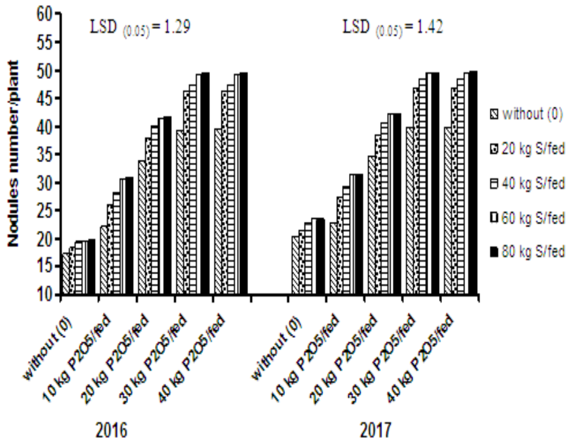

Fig. 1. Means of nodules number plant^{-1} as affected by the interaction between phosphorous and sulfure fertilizers levels during 2016 and 2017 seasons.

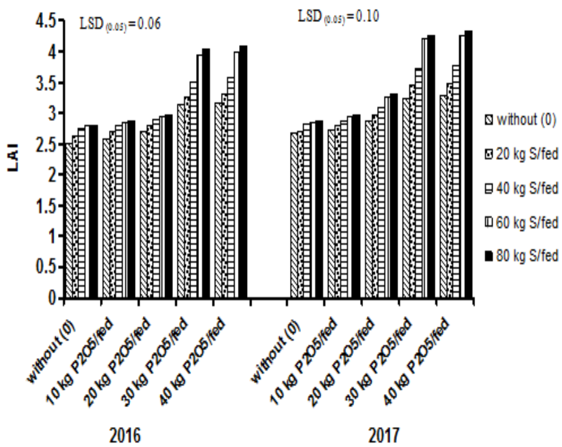

Fig. 2. Means of LAI as affected by the interaction between phosphorous and sulfure fertilizers levels during 2016 and 2017 seasons.

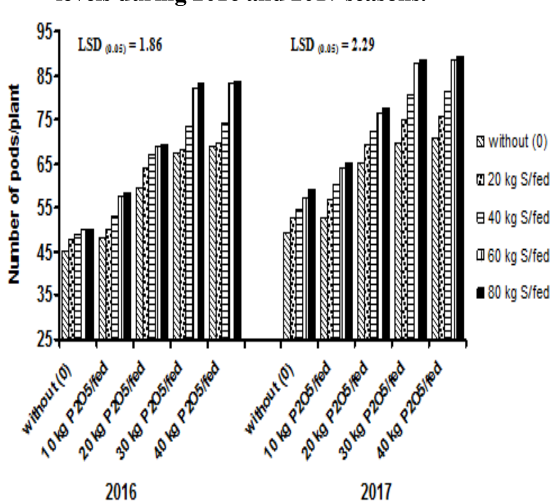

Fig. 3. Means of number of pods plant^{-1} as affected by the interaction between phosphorous and sulfure fertilizers levels during 2016 and 2017 seasons.

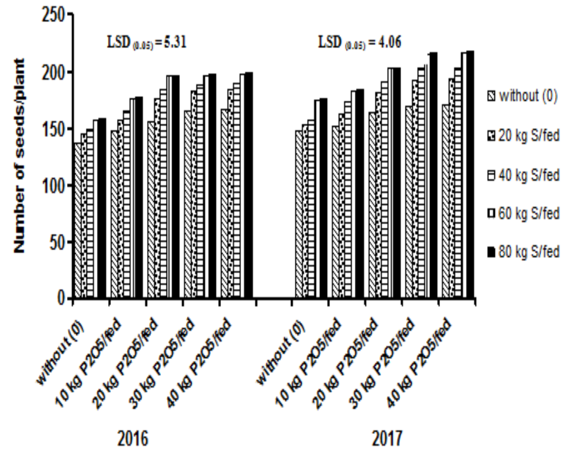

Fig. 4. Means of number of seeds plant^{-1} as affected by the interaction between phosphorous and sulfure fertilizers levels during 2016 and 2017 seasons.

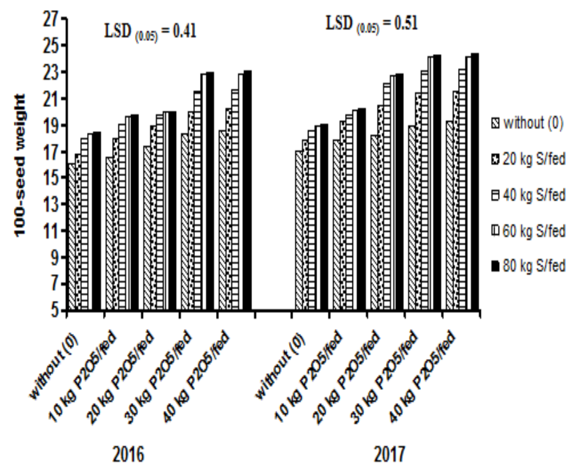

Fig. 5. Means of 100-seed weight as affected by the interaction between phosphorous and sulfure fertilizers levels during 2016 and 2017 seasons.

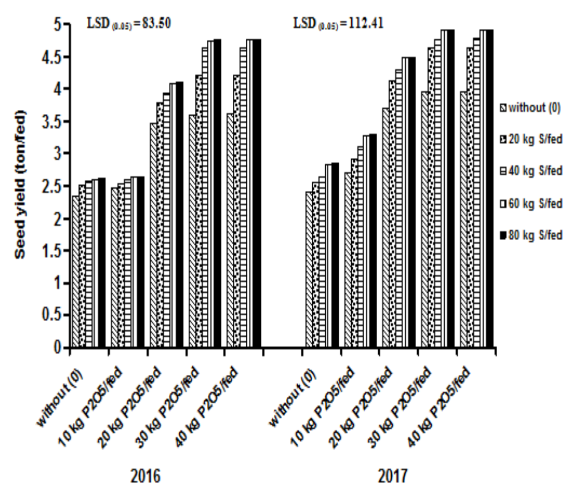

Fig. 6. Means of seed yield (ton fed^{-1}) as affected by the interaction between phosphorous and sulfure fertilizers levels during 2016 and 2017 seasons.

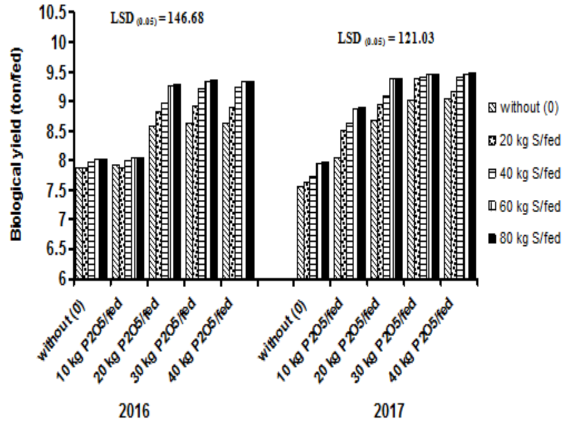

Fig. 7. Means of biological yield (ton fed^{-1}) as affected by the interaction between phosphorous and sulfure fertilizers levels during 2016 and 2017 seasons.

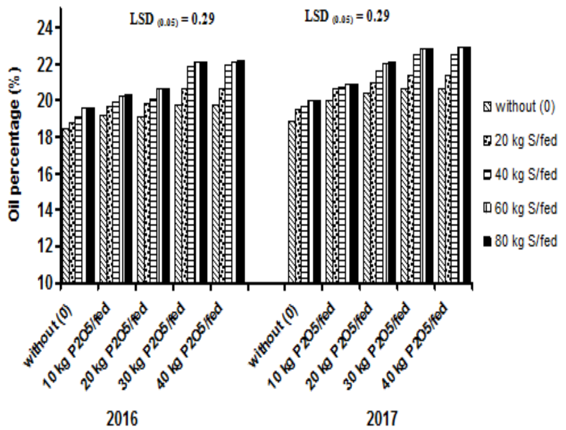

Fig. 8. Means of oil percentage (%) as affected by the interaction between phosphorous and sulfure fertilizers levels during 2016 and 2017 seasons.

CONCLUSION

It could be detected that combined application of 30 kg P_2O_5 fed^{-1} plus 60 kg S fed^{-1} is recommend for improving the growth characters and maximizing yield as well as seed oil percentage of soybean cultivar Giza 22 under the ecological conditions of Kafrelsheikh Governorate, Egypt.

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تأثير مستويات التسميد الفوسفاتى والكبريتى على إنتاجية فول الصويا

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تم اجراء تجربتين حقليتين بحقل إرشادى بقرية الجرايدة - مركز بيلا – محافظة كفر الشيخ خلال الموسمين الصيفين 2016 و 2017 بغرض دراسة تأثير مستويات التسميد الفوسفاتى والكبريتى على صفات النمو ؛ المحصول ومكوناته وكذلك نسبة الزيت لمحصول فول الصويا. تم تنفيذ التجربة فى تصميم الشرائح المتعامدة فى أربعة مكررات ، حيث إشتملت الشرائح الرأسية على مستويات التسميد الفوسفاتى وهى معاملة الكنترول "بدون" ، 10 ، 20 ، 30 ، 40 كجم فوسفور/فدان ، بينما شغلت الشرائح الأفقية بمستويات التسميد الكبريتى وهى معاملة الكنترول "بدون" ، 20 ، 40 ، 60 و 80 كجم كبريت/فدان. أظهرت النتائج المتحصل عليها من خلال هذه الدراسة أن إضافة 40 كجم فوسفور/فدان سجلت أعلى القيم لصفات النمو والمحصول ومكوناته وكذلك نسبة الزيت خلال موسمى الزراعة ، كما حققت معاملة التسميد الفوسفاتى بمعدل 30 كجم فوسفور/فدان المرتبة الثانية بعد المعاملة السابقة مباشرة وبدون فروق معنوية بينهما فى كلا موسمى الزراعة. أشارت النتائج المتحصل عليها تفوق معاملة نباتات فول الصويا بالمعدل الأعلى للكبريت 80 كجم كبريت/فدان حيث أنتجت أعلى القيم لصفات النمو والمحصول ومكوناته وكذلك نسبة الزيت فى كلا موسمى الزراعة. فى حين جاء إستخدام معدل 60 كجم كبريت/فدان فى المرتبة الثانية وبدون فروق معنوية بينهما خلال موسمى النمو. لتحسين صفات النمو والمحصول ومكوناته وكذلك نسبة الزيت وتقليل تكاليف الإنتاج والحد من التلوث البيئى نتيجة الإسراف فى إستخدام الأسمدة المعدنية لمحصول فول الصويا فإنه يوصى بتسميد نباتات فول الصويا صنف جيزة 22 بمعدل 30 كجم فوسفور/فدان مع إضافة 60 كجم كبريت/فدان مع تحسين صفات التربة وذلك تحت الظروف البيئة لمحافظة كفر الشيخ.