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Study the efficiency of using phosphogypsum with organic and biological fertilization on cotton yield

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ABSTRACT

Phosphogypsum (PG) is considered a by-product from the degeneration of phosphate rock (PR) in sulfuric acid. PG is widely used to improve the physico-chemical properties of soil and increase the amount of soluble nutrients in the soil. The experiment was carried out during the 2021–2022 seasons at Sids Research Station, Agricultural Research Center, Bani Sweif, Egypt, using the Giza 95 cultivar to evaluate the effect of PG (1.5 and 2.5 tons/fed) alone or with natural stimulants of farmyard manure (FYM) and phosphate solubilizing bacteria (PSB) on leaves' chemical constituents, growth and yield characteristics, fiber properties, and soil properties after cotton harvesting. The experiment design was a split-plot with three replicates. The main plots included calcium superphosphate and PG applications, and the sub-plots included control, FYM, and PSB applications. The results illustrated that PG application (2.5 tons/fed) recorded the significantly highest values of all studied parameters. Adding FYM achieved the significantly highest results, followed by PSB application compared to control. The interaction between PG application (2.5 ton/fed) and FYM (5 ton/fed) gave the best means on all studied parameters during the two seasons. The positive effect of PG application individually or with FYM and PSB might be related to enhancing soil properties, reducing soil pH, and producing organic and growth hormones, causing an increase in macro- and micro-nutrient uptake by plants and improving cotton plants' growth and development.

Keywords: Cotton, Phosphogypsum, Farmyard manure, phosphate solubilizing bacteria.

INTRODUCTION

Cotton is the most widely grown and profitable non-food crop on the globe. Egyptian cotton (*Gossypium barbadense* L.) has acquired a global reputation for having the highest lint quality when compared to other foreign cotton species grown around the world (Mahdy *et al.,* 2017). Cotton is an important cash crop that is cultivated for oil, animal feed, and fiber in the textile industry. Good nutrition is essential for increasing cotton production. Plant growth and development are hampered by macro- and micronutrient deficiencies, which lower seed cotton yield.(Ahmed *et al.,* 2020).

Phosphorus (P) inavailability is a widespread problem, especially in alkaline and acidic soils (Lenka and Lal, 2012). Generally, plants absorb P as HPO4-2 or H2PO4-1, whereas most soils have a low concentration of soluble ortho-phosphates and should be replenished from other resources of P in the soil to meet plants' requirements. Phosphorus is a necessary nutrient element in cotton production after nitrogen (N) and non-renewable natural resources. It is a crucial element of adenosine triphosphate (ATP) formation that is used in plant metabolism (Arif *et al.*, 2018). Phosphorus is important in the structure of nucleic acid (DNA and RNA), proteins, amino acids and fatty acids. It enters phospholipids structure in bio-membrane of plant cells and is required for metabolic processes (Ali and Ahmed, 2021). Furthermore, Phosphorus participates in different biological functions such as photosynthetic pigments biosynthesis, nitrogen fixation, respiration, enzymes regulation, leaf expansion and nutrient movement within the plant. Also, it is essential for cell division and new tissue development (Ibrahim, 2016; Samet *et al.,* 2018). Moreover, some growth factors that have been related to phosphorus have increased stalk as well as, stem strength, improved root development, stimulated flower formation, and ameliorations in crop quality, and enhanced resistance to diseases of plants (Singh *et al.,* 2022).

Indeed, the P fertilizer price has increased, reflecting its declining application to cotton crops by farmers and resulting in a cotton yield reduction. To address this issue, environmentally friendly, cost-effective, and productive farming technologies should be improved. Some research has been conducted on how to raise soil phosphorus levels using mineral fertilizer, phosphogypsum, and organic or bio-fertilization to enhance significant agronomic yield responses (Mesic *et al.,* 2016; El-Ghamry *et al.,* 2017; Hasana *et al.,* 2022; Jamal *et al.,* 2023).

Phosphate rock (PR), also known as fluorapatite, mainly contains calcium phosphate minerals and is extracted from geologic and marine deposits. The PR dissolves slowly when added to soil, which allows nutrients in the soil solution to be uptaken by plants. P fertilizers are made from PR, such as mono-amonium phosphate (MAP), di-amonium phosphate (DAP), single super phosphate (SSP), and triple super phosphate (TSP). The application of PR has become as effective as superphosphate, yet PR reduces the cost of chemical fertilizer and environmental pollution (Nayak *et al.,* 2013; El-Ghamry *et al.,* 2017; Hellal *et al.,* 2019).

Phosphogypsum (PG) is produced as a by-product of the phosphoric fertilizer industry that is generated through the phosphoric acid production method. The PR is decomposed with concentrated sulphuric acid at 70-80 °c as according to the following formula (Hasana *et al.*, 2022; Pliaka and Gaidajis, 2022).

$$\underset{\text{Fluorapatite}}{Ca_{10}(PO_4)f_2} + \underset{\text{sulphuric acid}}{10\,H_2SO_4} + \underset{\text{Water}}{20\,H_2O} \longleftrightarrow \underset{\text{Phosphoric acid}}{6\,H_3PO_4} + \underset{\text{calcium sulphate}}{10\,CaSO_4} + \underset{\text{Hydrogen Fluoride di-hydrate}}{2\,HF}$$

Annual global PG production is about 160 million tons, of which only 15% of that is used while, the remnant is either stockpiled (58%) or discarded in water bodies (27%) (Hasana *et al.,* 2022). PG contains calcium (Ca), sulphate (S) and phosphorus (P), thus PG application to soil improves nutrient availability in the soil for plants growth (Saadaoui *et al.,* 2017; Bouray *et al.,* 2020; Pliaka and Gaidajis, 2022). PG is utilized in agriculture all over the world either as fertilizer or as soil modification under calcium phosphate (Hasana *et al.,* 2022). PG application had positive effects on cotton growth with low input and a sustainable cropping system (Ibrahim, 2016).

Organic manures, known as farmyard manure (FYM), that may be partially or totally replace chemical P fertilizers for reducing the dependency on including P-ones. (Khan *et al.,* 2022; Jamal *et al.,* 2023). FYM increases soil organic carbon and lower concentrations of P, which is bound with different molecules that should be decomposed to modify it to inorganic phosphates and allow plant absorption from the soil (Hopkins and Hansen, 2019). Also, FYM contains all valuable nutrient source for plant such as nutrients (N, P and S), micro-nutrient and organic acids that could enhance P motion and bio-availability through the soil. Organic manures improved soil physical, chemical and biological properties by increasing soil organic matter (SOM), soil aggregation, bulk density, penetration resistance and water hold capacity. That caused to enhance soil nutrient cycling and offers a good environment for plants growth and development (Singh *et al.,* 2022).

Phosphorus bio-fertilizer, as phosphate solubilizing bacteria (PSB) provide plants with soluble P, increases the nutrient uptake from the soil, and improves plants' growth and development through their activities in the soil or rhizosphere. Application of PSB enhanced P uptake by plants, as they were able to dissolve P and mobilize phosphorus in plants.(El-Shamy *et al.,* 2022). Also, PSB could increase the efficiency of biological nitrogen fixation, improve trace-elements availability and produce plant growth promoting compounds and thus improve plant development (Timofeeva *et al.,* 2022). Moreover, PSB (Bacillus polymyxa) could produce organic acids that reduced the soil pH and enhanced the release of bound P in the soil. Many PSB have been isolated from soil, including PSB from the genera Pseudomonas, Bacillus, Rhizobium, Agrobacterium, Achromobactin, Micrococcus, Aerobacter, Enterobacter, Flavobacterium, and Erwinia (Rodriguez and Fraga, 1999). Accordingly, bio-fertilization technology is considered an eco-friendly approach to enhancing crop efficiency (El-Ghamry *et al.,* 2017).

The main objective of the current study was to evaluate the effect of PG application either alone or with some activators such as FYM and PSB on cotton leaves constituents, growth characteristics, yield components, fiber properties and soil properties.

MATERIAL AND METHODS

Materials of study:

To attain the aim of the study, an experiment was carried out in two seasons, 2021 and 2022, at the experimental farm of Sids Research Station, Agricultural Research Center, Bani Sweif, Egypt. This experiment followed a split plot design with three replications in which the main plots were randomly assigned to phosphorus applications including 22.5 kg calcium superphosphate/fed., 1.5 tan PG/fed., and 2.5 tan PG/fed. The sub-plots were randomly assigned for three treatments as follows: control, bio-fertilizer (PSB), and organic manures (FYM) to evaluate the effect of PG application with some activators such as FYM and PSB on cotton leaf constituents, yield components, fiber properties, and soil properties. Seeds of the Giza 95 cotton cultivar (Gossypium barbadense L.) from the Cotton Research Institute were sown in the clayey loam soil of the study on April 6th, 2021, and April 8th, 2022. The experimental plot consisted of 7 rows, 3.5 m long and 0.6 m wide (plot area = 14.70 m2). All experimental plots received irrigation, fertilizer (N and K), and pesticide as recommended by the Egyptian Ministry of Agriculture for cotton cultivation.

The soil physical and chemical characteristics of the experimental field are shown in Table (1) which was done according to the methods described by Page (1982).

Table 1. Some physic-chemical properties of the experimental site in 2021 and 2022 seasons.

Soil properties	2021	2022
Soil particle distribution:		
Particle size distribution:		
Clay (%)	50.95	51.32
Silt (%)	32.72	31.16
Sand (%)	16.33	17.52
Texture grade	Clay	Clay
Chemical properties:		
pH (1:2.5 soil-water suspension)	8.00	8.11
EC, soil paste (dS m-1)	1.11	1.53
Organic matter (%)	1.87	1.74
Available N (mg/kg)	23.0	20.3
Available P (mg/kg)	16.1	15.3
Available K (mg/kg)	175	194

- PG (pH of less than 3) was brought from the Phosphate Factory in Fayoum Governorate, which contained about less than 1% phosphorus and 90% gypsum, and superphosphate calcium (22.5 kg P_2O_5/fed.) were added to soil before planting during land preparation.
- PSB (Bacillus polymyxa) was supplied by Micro. Dept., Soil, Water and Environment, ARC, Egypt. Cotton seeds were directly inoculated before sowing with its special treatments. Other traditional methods of growing cotton were practiced as they were in the district.
- According to Klute (1986), the FYM used in the experiment was chemically analyzed. The findings are shown in Table 2.

Table 2. Some chemical properties of farmyard manure used in the experiment.

Properties	2021	2022
pH	8.13	8.10
EC, (dS m-1)	4.22	4.16
Total organic carbon (%)	15.43	15.66
Total organic matter (%)	25.59	26.99
Total nitrogen (%)	0.72	0.69
Total phosphorus (%)	0.21	0.20
Total potassium (%)	0.18	0.16
C/N ratio	21.43:1	22.70:1

Chemical analysis:

Cotton leaves were randomly selected from the top of fourth node leaves at flowering stage in order to measure the chemical constituents as follows:

- Total chlorophyll contents in accordance with Arnon (1949) and carotenoids content in accordance with Robbelen's method (1957).
- Total soluble sugars were measured in ethanol extract by phenol-sulfuric acid method in accordance with Cerning (1975).
-Total phenols were assayed by folin-ciocalteau method in accordance with Simons and Ross (1971).
- Total free amino acids were measured in ethanol extract in accordance with Rosen (1999).
- Total antioxidant capacity was assayed by phosphomolybdenum method in accordance with Kumaran and Karunakaran(2007).
- Relative water content (%) was calculated using the method of Schonfeld *et al.*(1988).

Growth characters, yield and its components:

Growth and yield components samples were taken from three plots at harvest stage. Growth traits included plant height (cm) and number of fruiting branches/plant. However, yield and its components included number of open bolls/plant, boll weight (g), lint %, seed index (g) and seed cotton yield (k/fed.).

Fiber quality:

According to A.S.T.M. (2012) fiber length, micronaire reading and fiber strength were determined. Fiber length, uniformity index, micronaire reading and fiber strength were recorded during data collection.

Soil analysis:

Following harvest, surface soil samples (0.0–30 cm) were collected to measure soil properties, such as pH, EC, O.M, and soil available N, P, and K, in accordance with the procedure outlined by Klute (1986).

Statistical analysis:

The variables analyzed by ANOVA using M Stat-C statistical package (Freed, 1991). Mean comparisons were done using method of least significant differences (L.S.D) at 5% level ($P \leq 0.05$) of probability for comparing differences between the means (Snedecor and Cochran, 1988).

RESULTS

Chemical constituents of cotton leaves:

Data provided in Table (3) demonstrated that the effect of phosphorus application (22.5 kg calcium superphosphate/fed, 1.5 ton PG/fed and 2.5 ton PG/fed), natural stimulants application (FYM and PSB) and their interaction on cotton leaves chemical constituents of total chlorophyll, carotenoids, total soluble sugars (TSS), total phenols (TP), total free amino acids (TFA), total antioxidant capacity (TAC) and relative water content (RWC).

Considering the effect of phosphorus application statistically affected all leaves chemical constituents (Table 3). Generally, the application of PG significantly raised all chemical constituents in leaves compared to calcium superphosphate application. In particular, PG application (2.5 ton/fed) gave the highest increases, followed by PG application (1.5 ton/fed) then calcium super phosphate application. The increases owing to PG application (2.5 ton/fed) were total chlorophyll by 31%, carotenoids by 30.26%, TSS by 12.45%, TP by 11.29%, TFA by 8.81%, TAC by 41.04% and RWC by 3.3% respectively higher that the corresponding effects of calcium superphosphate application.

As for the effect of natural stimulants application of FYM and PSB, the findings in Table (3) indicated that the treatments of FYM and PSB improved significantly all chemical constituents compared to control treatment. Adding FYM on the soil achieved the best means, followed by PSB application compared with control. FYM application recorded the highest means in all chemical constituents such, total chlorophyll by 15.57%, carotenoids by 30.88%, TSS by 12.55%, TP by 11.16%, TFA by 14.08%, TAC by 53.19% and RWC by 3.4% compared to control treatment. As well as, PSB application improved the contents of total chlorophyll, carotenoids, TSS, TP, TFA, TAC and RWC by 6.79, 5.41, 7.31, 9.83, 10.61, 22.02 and 1.87%, respectively, compared to control treatment.

The interaction between phosphorus application (calcium super phosphate and PG) and natural stimulants (FYM and PSB) application, the data in Table (3) pointed out that the interaction drastically affected most of chemical constituents (total chlorophyll, carotenoids, TSS, TFA, TAC and RWC), whereas the content of TP was insignificantly affected. Generally, the best results of leaves chemical constituents recorded via the application of PG (2.5 ton/fed) with FYM treatment, followed by applying PG (2.5 ton/fed) with PSB treatment compared to other treatments.

Table 3. Average and significance of total chlorophyll, carotenoids, total soluble sugars, total phenols, total free amino acids contents, total antioxidant capacity and relative water content % as affected by phosphorus and natural stimulants.

Treatments		Total Chlorophyll (mg/g; FW)	Carotenoids (mg/g; FW)	Total soluble sugars (mg/g; FW)	Total phenols (mg/g; FW)	Total free amino acids (mg/g; FW)	Total antioxidant capacity ($O.D_{695}$)	Relative water content (%)
Phosphorus application (A)	stimulants (B)							
22.5 kg P_2O_5 superphosphate calcium/fed	Control	3.48	0.319	30.35	11.29	13.26	0.479	53.74
	Bio-fertilizer	3.61	0.351	32.74	12.72	14.55	0.710	54.62
	Farmyard manure	3.88	0.395	35.06	12.98	15.07	0.845	55.06
mean		3.65	0.355	32.71	12.33	14.29	0.678	54.47
Phosphogypsum 1.5 ton/fed	Control	4.06	0.374	32.85	12.16	13.91	0.639	54.18
	Bio-fertilizer	4.46	0.386	37.29	12.94	15.28	0.784	55.77
	Farmyard manure	4.92	0.504	43.89	13.65	16.14	0.983	56.85
mean		4.48	0.421	35.01	12.91	15.11	0.802	55.60
Phosphogypsum 2.5 ton/fed	Control	4.84	0.408	34.65	12.85	14.02	0.668	55.53
	Bio-fertilizer	5.20	0.427	37.91	14.24	16.26	0.796	56.19
	Farmyard manure	5.86	0.693	39.53	14.61	16.75	1.985	57.29
mean		5.29	0.509	37.36	13.90	15.67	1.150	56.33
Mean of stimulants (B)	Control	4.12	0.367	32.61	12.10	13.73	0.595	54.48
	Bio-fertilizer	4.42	0.388	35.98	13.30	15.36	0.763	55.52
	Farmyard manure	4.88	0.531	39.49	13.74	15.98	1.271	56.40
LSD at 0.05 of	A	0.040	0.004	0.036	0.603	0.041	0.004	0.203
	B	0.041	0.002	0.015	0.782	0.017	0.001	0.197
	AB	0.070	0.008	0.064	N.S.	0.071	0.008	0.353

Growth characteristics, yield and its components:

The findings in Table (4) obtained that the effect of phosphorus application (calcium superphosphate and PG), natural stimulants application (FYM and PSB) and their interaction on growth characteristics (plant height and no. of fruiting branches/plant), yield and its components (no. of opened bolls/plant, boll weight, seed index, lint % and seed cotton yield/fed) during 2021 and 2022 seasons.

With regard to phosphorus application, it showed a significant effect on cotton growth characteristics, yield, and its components in both studied seasons. Overall, PG applications significantly improved growth characteristics, yield, and their components. PG applications (2.5 ton/fed) gave the best values, followed by PG applications (1.5 ton/fed) compared to calcium superphosphate applications in both seasons. The application of PG (2.5 tons/fed) recorded the best means on growth characteristics, yield, and its components: plant height (126.35 and 123.85 cm), no. of fruiting branches/plant (15.38 and 14.92), no. of opened bolls/plant (18.44 and 16.21), boll weight (3.02 and 2.86 g), seed index (10.55 and 10.32 g), and seed cotton yield (11.38 and 10.31 k/fed), in both seasons, respectively, compared to calcium superphosphate application.

The application of FYM and PSB stimulants statistically affected growth characteristics, yield, and its components during the 2021 and 2022 seasons.The application of FYM achieved the highest means, followed by the PSB application compared to control plants in both seasons. FYM application recorded the best mean on cotton growth characteristics, yield, and its components: plant height (126.05 and 123.75 cm), no. of fruiting branches/plant (15.62 and 15.27), no. of opened bolls/plant (18.36 and 15.92), boll weight (3.07 and 2.93 g), seed index (10.52 and 10.24 g), and seed cotton yield (11.54 and 10.4 k/fed), in both seasons, respectively, compared to control treatment.

Regarding the interaction between phosphorus application and natural stimulant application, the data in Table (4) reported that all growth characteristics, yield, and its components were significantly affected in the 2021 season only, while the number of fruiting branches per plant, seed index, and lint percentage were insignificantly affected in the 2022 season. Overall, PG treatment at the rate of 2.5 tons per acre with FYM returned the best values on growth characteristics, yield, and its components, followed by PG treatment at 2.5 tons per acre with PSB in both seasons.

Table 4. Average and significance of growth, yield and its components of cotton as affected by phosphorus and natural stimulants.

Treatments		Growth characteristics				Yield and its components									
		Plant height (cm)		No. of fruiting branches/plant		No. of open bolls/plant		Boll weight (g)		Seed index (g)		Lint %		Seed cotton yield (k/fed)	
Phosphorus application (A)	stimulants (B)	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
22.5 kg P_2O_5 superphosphate calcium/fed	Control	122.58	121.73	14.34	13.62	15.52	13.95	2.84	2.53	10.14	9.92	40.81	40.63	8.79	7.84
	Bio-fertilizer	123.71	122.04	14.66	13.81	16.37	14.18	2.93	2.65	10.35	9.93	40.12	39.91	9.75	8.45
	Farmyard manur	124.37	122.52	15.42	14.93	17.66	14.52	3.02	2.84	10.42	9.98	39.86	39.68	10.85	9.16
mean		**123.55**	**122.09**	**14.80**	**14.12**	**16.51**	**14.21**	**2.93**	**2.67**	**10.30**	**9.94**	**40.26**	**40.07**	**9.79**	**8.48**
Phosphogypsum 1.5 ton/fed	Control	124.59	122.18	14.72	13.94	16.48	14.38	2.88	2.61	10.28	9.97	40.65	40.42	9.58	8.34
	Bio-fertilizer	125.63	123.42	15.18	14.56	17.25	15.43	2.99	2.78	10.49	10.27	39.78	39.56	10.32	9.53
	Farmyard manur	126.14	123.92	15.59	15.28	18.47	16.38	3.09	2.95	10.52	10.30	39.54	39.32	11.68	10.73
mean		**125.45**	**123.17**	**15.16**	**14.59**	**17.40**	**15.39**	**2.98**	**2.78**	**10.43**	**10.18**	**39.99**	**39.76**	**10.52**	**9.53**
Phosphogypsum 2.5 ton/fed	Control	125.04	122.62	14.95	14.38	18.04	15.72	2.91	2.74	10.46	10.18	40.37	40.10	10.64	9.57
	Bio-fertilizer	126.38	124.10	15.34	14.79	18.34	16.05	3.05	2.82	10.56	10.34	39.95	39.77	11.43	10.05
	Farmyard manur	127.65	124.83	15.85	15.61	18.95	16.86	3.11	3.02	10.63	10.44	39.32	39.08	12.09	11.32
mean		**126.35**	**123.85**	**15.38**	**14.92**	**18.44**	**16.21**	**3.02**	**2.86**	**10.55**	**10.32**	**39.88**	**39.65**	**11.38**	**10.31**
Mean of stimulants (B)	Control	124.07	122.17	14.67	13.98	16.68	14.68	2.87	2.62	10.29	10.02	40.61	40.38	9.67	8.58
	Bio-fertilizer	125.24	123.18	15.06	14.38	17.32	15.22	2.99	2.75	10.46	10.18	39.95	39.74	10.50	9.34
	Farmyard manur	126.05	123.75	15.62	15.27	18.36	15.92	3.07	2.93	10.52	10.24	39.57	39.36	11.54	10.40
LSD at 0.05 of	A	0.087	0.356	0.039	0.168	0.062	0.162	0.009	0.021	0.031	0.119	0.059	0.232	0.080	0.206
	B	0.034	0.314	0.011	0.136	0.034	0.063	0.011	0.023	0.030	0.088	0.038	0.093	0.028	0.169
	AB	0.150	0.617	0.067	N.S.	0.108	0.281	0.016	0.037	0.052	N.S.	0.103	N.S.	0.140	0.358

Fiber quality properties:

Data in Table (5) cites the effect of phosphorus application (calcium superphosphate and PG), natural stimulant application (FYM and PSB), and their interaction on cotton fiber properties of fiber length, micronaire reading, and fiber strength during the 2021 and 2022 seasons. As for the effect of phosphorus application (calcium superphosphate and PG), it significantly affected all fiber properties. PG application at the rate of 2.5 tons per acre significantly increased all fiber properties, followed by PG application at 1.5 tons per acre, compared to calcium superphosphate application in both seasons. Findings in Table (5) revealed that the stimulant application of FYM and PSB significantly improved all fiber properties compared to the control treatment in both seasons, with FYM recording the best results, followed by PSB application. For the interaction between phosphorus application and natural stimulant application, data in Table (5) confirmed that the two factors insignificantly affected all cotton fiber properties in both seasons, while fiber strength was significantly affected only in the 2021 season. The best results were recorded by PG application (2.5 tons/fed) with FYM, followed by PSB treatment in both seasons.

Table 5. Average and significance of fiber properties of cotton as affected by phosphorus and natural stimulants.

Treatments		Fiber length (mm)		Micronaire reading		Fiber strength	
Phosphorus application (A)	stimulants (B)	2021	2022	2021	2022	2021	2022
22.5 kg P_2O_5 superphosphate calcium/fed	Control	30.64	30.42	4.35	4.22	10.28	10.12
	Bio-fertilizer	30.69	30.47	4.41	4.26	10.34	10.18
	Farmyard manure	30.77	30.57	4.50	4.38	10.63	10.28
mean		**30.72**	**30.51**	**4.42**	**4.30**	**10.45**	**10.20**
Phosphogypsum 1.5 ton/fed	Control	30.69	30.47	4.41	4.26	10.34	10.18
	Bio-fertilizer	30.73	30.56	4.48	4.34	10.71	10.33
	Farmyard manure	30.81	30.59	4.53	4.42	10.85	10.39
mean		**30.74**	**30.54**	**4.47**	**4.34**	**10.63**	**10.30**
Phosphogypsum 2.5 ton/fed	Control	30.75	30.53	4.43	4.29	10.57	10.25
	Bio-fertilizer	30.78	30.59	4.52	4.40	10.78	10.36
	Farmyard manure	30.86	30.62	4.62	4.45	10.92	10.41
mean		**30.79**	**30.58**	**4.52**	**4.38**	**10.75**	**10.34**
Mean of stimulants (B)	Control	30.69	30.47	4.39	4.25	10.39	10.18
	Bio-fertilizer	30.75	30.56	4.47	4.35	10.65	10.30
	Farmyard manure	30.81	30.59	4.55	4.41	10.80	10.36
LSD at 0.05 of	A	0.035	0.048	0.036	0.042	0.035	0.041
	B	0.040	0.024	0.030	0.043	0.031	0.021
	AB	N.S.	N.S.	N.S.	N.S.	0.061	N.S.

Soil analysis:

The information in Table (6) demonstrated the effect of phosphorus application (22.5 kg calcium superphosphate/fed, 1.5 ton PG/fed, and 2.5 ton PG/fed), natural stimulant application (FYM and PSB), and their interaction on the changes in the soil pH, Ec (electronic conductivity), soil organic matter (SOM), and soil available N, P, and K following cotton harvesting during the 2021 and 2022 seasons. The evidence in Table (6) revealed that only P availability was significantly impacted by PG application (1.5 and 2.5 tons/fed) compared to calcium superphosphate application in both study seasons. The best results were achieved by the application of PG (2.5 ton/fed), followed by PG application (1.5 ton/fed) compared to calcium superphosphate application. PG application at the rate of 2.5 ton/fed recorded the highest amount of available P in the soil after harvesting by 33.28 and 11.41% in season 2021 and 32.43 and 10.20% in season 2022, respectively, compared with calcium superphosphate application and PG application (1.5 ton/fed). The finding in Table (6) demonstrated that natural stimulant applications (FYM and PSB) significantly affected all soil properties after cotton harvesting during the two seasons compared to control. The application of FYM achieved the highest means, followed by the PSB application compared to control. As for the interaction between phosphorus application and stimulant application, results showed that this combination insignificantly affected all studied soil properties in both seasons. The interaction between PG application (2.5 tons/fed) and FYM treatment recorded the highest available N, P, K, EC, and SOM values, whereas the soil had the lowest pH values in both seasons. On the other hand, the application of calcium superphosphate gave the lowest levels of soil N, P, K, and SOM, while giving the highest pH levels in both seasons.

Table 6. Average and significance of some soil properties as affected by phosphorus and natural stimulants after cotton harvesting.

Treatments		pH		EC (dSm^{-1})		O.M (%)		Available (mg/kg)					
								N		P		K	
Phosphorus application (A)	stimulants (B)	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
22.5 kg P_2O_5 superphosphate calcium/fed	Control	8.01	8.12	1.12	1.52	1.85	1.71	22.2	20.2	15.8	15.2	172	192
	Bio-fertilizer	8.01	8.06	1.12	1.23	1.85	1.72	22.5	20.1	17.0	17.5	173	194
	Farmyard manure	7.90	8.05	1.26	1.66	1.97	1.89	26.7	25.6	19.2	19.0	176	197
mean		**7.97**	**8.08**	**1.17**	**1.57**	**1.89**	**1.77**	**23.80**	**21.97**	**17.3**	**17.23**	**174**	**194**
Phosphogypsum 1.5 ton/fed	Control	7.88	7.96	1.13	1.54	1.87	1.73	22.3	20.3	20.5	20.2	173	193
	Bio-fertilizer	8.12	7.99	1.13	1.53	1.86	1.72	22.3	20.2	23.4	22.7	173	194
	Farmyard manure	7.81	7.90	1.28	1.70	1.96	1.91	27.0	25.9	25.0	25.8	177	196
mean		**7.94**	**7.95**	**1.18**	**1.59**	**1.90**	**1.79**	**23.87**	**22.13**	**22.97**	**22.9**	**174**	**194**
Phosphogypsum 2.5 ton/fed	Control	7.80	7.90	1.15	1.53	1.85	1.72	22.3	20.3	23.1	22.9	172	192
	Bio-fertilizer	7.74	7.81	1.15	1.53	1.86	1.73	22.4	20.2	26.1	25.8	174	193
	Farmyard manure	7.70	7.81	1.32	1.71	1.97	1.90	26.8	26.1	28.6	27.9	176	197
mean		**7.75**	**7.84**	**1.21**	**1.59**	**1.89**	**1.78**	**23.83**	**22.2**	**25.93**	**25.5**	**174**	**194**
Mean of stimulants (B)	Control	7.90	7.99	1.13	1.53	1.86	1.72	22.3	20.3	19.8	19.4	172	192
	Bio-fertilizer	7.96	7.95	1.13	1.69	1.86	1.72	22.4	20.2	22.2	22.0	173	194
	Farmyard manure	7.80	7.92	1.29	1.53	1.97	1.90	26.8	25.9	24.3	24.2	176	197
LSD at 0.05 of	A	N.S.	N.S	N.S	N.S	N.S	N.S	N.S	N.S	2.16	1.95	N.S	N.S
	B	0.02	0.02	0.08	0.07	0.07	0.06	1.03	1.19	1.17	1.03	0.9	1.6
	AB	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

DISCUSSION

Cotton plants request optimum amount of phosphorus (P) as a nutrition element from germination stage to maturity. P promotes many physiological mechanisms of cotton plant that improves the root growth, supports the stem and ameliorates the flower and boll development (Ali and Ahmed, 2021). P is found in the soil as mainly P mineral (fluorapatite) and secondary clay minerals like iron, aluminium and calcium phosphates that are paramount for maintaining P accumulation and availability during adsorption and dissolving (Singh *et al.*, 2022).

Chemical constituents of cotton leaves:

It is clear from the data in Table (3) that the application of PG (1.5 and 2.5 tons/fed) both individually or combined with natural stimulants (FYM and PSB) drastically improved all cotton leaf chemical constituents (total chlorophyll, carotenoids, TSS, TP, TFA, TAC, and RWC), especially PG application at the rate of 2.5 tons/fed compared with calcium superphosphate application. The beneficial effect of PG application on soil basically depended on decreasing soil pH with increasing PG concentration, in which case PG released huge amounts of soluble SO4-2, Ca+2, and P into the soil solution. Also, the remaining effect of phosphoric and sulphoric acids in PG acidifies the soil, which reduces its pH easily (Samet *et al.,* 2018).

With respect to the application of natural stimulants FYM and PSB, the findings in Table 3 stated that FYM and PSB application significantly increased all leaf chemical constituents compared to control. FYM application gave the best results, followed by PSB application, compared to control. The positive effects of FYM and PSB application might be related to increasing P bioavailability and producing organic acid and plant growth hormones in the soil solution. These organic acids could help in reducing soil pH, which enhances P and growth hormone levels in cotton plants, which promote plant growth and development.

The decrement in soil pH caused by PG, FYM, and PSB applications increased the availability of macro- and micro-nutrient uptake by plants, which is necessary for different plant physiological processes and development. Thereby, the increase of Ca^{+2} ions and S concentration in plants multiplied CO_2 fixation from the air, increased nitrogen uptake, enhanced photosynthesis rate, and increased carbohydrate concentration (Ibrahim, 2022). Moreover, phosphorus has necessary roles in chlorophyll biosynthesis, CO_2 development, and sugar and carbohydrate biosynthesis. Therefore, the application of PG individually or with natural stimulants (FYM and PSB) increased the bioavailability of P, Ca, and S natural elements, organic acids, and growth hormones for cotton plant uptake, which improved plant photosynthesis rate and the contents of sugars, phenols, and amino acids.These results were consonance with the works of Quintero *et al.* (2014) on tomato; Zhang *et al.* (2014) on tobacco; Elloumi *et al.* (2015) on sun flowers; Bouray *et al.* (2020) on Lucerne; Ibrahim (2022) on cotton; Hasana *et al.* (2022); Pliaka and Gaidajis (2022). Similarly, the results obtained by Ibrahim (2016) noticed that the application of PG enhanced soil structure, due to improvement of cotton plant growth and productivity by improving cotton seedling emergency and increasing availability of Ca, S and P in soil solution for uptake by cotton plants. Samet *et al.* (2018) indicated that the combined application of PG and compost improved potato plant growth. Additionally, El-Shamy *et al.* (2022) pointed out that the application of PG with PSB enhanced chlorophyll a, b and carotenoids contents in leaves that helped in cell division and elongation (Osman *et al.*, 2021).

Growth characteristics, yield and its components:

As shown in Table (4), the application of PG (1.5 and 2.5 tons/fed) individually or combined with natural stimulants (FYM and PSB) significantly improved growth characteristics (plant height and no. of fruiting branches/plant) and yield components (no. of opened bolls/plants, boll weight, seed index, lint%, and seed cotton yield/fed) during the 2021 and 2022 seasons. The affirmative effects of PG, FYM, and PSB treatments might be due to their effect of increasing P accessibility and nutrients in cotton plants, which improved plant growth and development. In addition, their application released organic acids that reduced soil pH and increased macro-, micro-, and growth hormone uptake by cotton plants. This ultimately enhanced the synthesis and development of cotton flowers and bolls. Besides, FYM and PSB applications produced phytohormones that increased cotton productivity and fiber quality.(Ali and Ahmed, 2021). Furthermore, PG application in conjunction with FYM or PSB application increased soluble P uptake, photosynthesis rate, plant growth, boll set and maturity. These results are in line with those of Elloumi *et al.* (2015) on sunflower; Ibrahim (2016) on cotton; El-Ghamry *et al.* (2017) on faba bean; Arif *et al.* (2018); Ali and Ahmed (2021) on cotton; El-Shamy *et al.* (2022); Singh *et al.* (2022) on black gram; Jamal *et al.* (2023) on wheat. Likewise, Samet *et al.* (2018) unveiled that the combined application of PG and compost improved potato plants growth.

Fiber quality properties:

Results in Table (5) indicated that the effect of PG application (1.5 and 2.5 ton/fed) or natural stimulants application (FYM and PSB) significantly affected all fiber properties, while the interaction between the two factors insignificantly affected fiber properties during both seasons.

The positive roles of PG, FYM and PSB in cotton fiber properties might be related to increasing P availability and photosynthesis rate that improves cotton crop and was reflects on cotton fiber quality properties. These results agree with those of Ibrahim (2016); Arif *et al.* (2018); Ali and Ahmed (2021) in cotton.

Soil analysis:

The data in Table (6) documented that PG application only significantly affected P availability in soil after cotton harvesting. That might be attributed to the PG content of many available nutrients such as Ca, S, and P, which improved cotton growth and development. Additionally, PG is employed as an amendment to restore degraded soils, including saline, sodic, acidic, and alkaline soils (Saadaoui *et al.,* 2017). With respect to stimulant application (FYM and PSB), the data in Table (6) mention that FYM and PSB application significantly improved all soil properties after cotton harvesting during the two seasons. The application of FYM recorded the best results that might be related to their positive role in increasing soil availability of nutrients and SOM amount as well as improving soil physical properties such as soil aggregation, bulk density, penetration resistance, and water holding capacity. In addition, FYM has reduced soil temperatures and maintained moisture.These results supported by the findings of Ouedraogo *et al.* (2001); Palm *et al.* (2001); Soumare *et al.*(2003); Samet *et al.* (2018) on potato; Singh *et al.* (2022) on black gram; Jamal *et al.* (2023) on wheat.

CONCLUSION

It can be concluded that the interaction between PG application at a rate of 2.5 ton/fed and FYM treatment (5 ton/fed) significantly improved all study parameters, i.e., cotton leaf chemical constituents, growth, yield components, and fiber properties. However, after cotton harvesting, the interaction between the two factors did not significantly affect soil properties in both seasons. The integrated use of PG with natural stimulants (FYM and PSB) increased P bioavailability and uptake by cotton plants. Also, the application of PG alone or with FTM and PSB reduced soil pH, whereas it increased macro- and micro-nutrients in the soil compared with calcium superphosphate treatment. That generally improved cotton plant growth and productivity. Thus, the application of PG can be recommended instead of or with chemical fertilizer to reduce the cost and dependence on chemical fertilizer as well as enhance the soil health for sustainable and good crop production.

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دراسة كفاءه إستخدام الفوسفوجبسيوم مع التسميد العضوي والحيوي علي إنتاجية القطن

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يعتبر الفوسفوجبسيوم منتجًا ثانويًا من تحلل صخور الفوسفاتفي حامض الكبريتيك. يعمل الفوسفوجبسيوم علي تحسين خصائص التربة الفيزيائية والكيميائية مما يؤدي إلي زياده العناصر الغذائية الذائبة في التربة. أجريت التجربة خلال مواسم 2021-2022 بمحطة بحوث سدس ، مركز البحوث الزراعية ، بني سويف ، مصر ، باستخدام الصنف جيزة 95 لتقييم تأثير معاملات إضافة الفوسفورفي صورة كالسيوم سوبر فوسفات (22.5 كجم/فدان) والفوسفوجبسيوم (1.5 و 2.5 طن/فدان) إلى جانب المنشطات الطبيعية لسماد المزارع والبكتريا المذيبة للفوسفورعلى المكونات الكيميائية للأوراق ، وخصائص النمو والمحصول ، وخصائص الألياف القطن وخصائص التربة بعد حصاد القطن. تصميم التجربة قطع منشقة مره واحده بثلاث مكررات ، والتي تضمنت معاملات إضافة الفوسفور القطع المنشقه الرئيسية وتضمنت القطع المنشقهالفرعية إضافة سماد المزارع والبكتريا المذيبة للفوسفور. أوضحت النتائج أن إضافة الفوسفوجبسيوم بكميه (2.5 طن/فدان) سجلت أعلى متوسطات معنوية لجميع الصفات المدروسة في الموسمين. كما أوضحت النتائج ان إضافة السماد البلدي (5 طن/فدان) أعطي أعلي النتائج معنويا، يليها استخدام البكتريا المذيبة للفوسفور مقارنه بالكنترول في الموسمين. إضافة الفوسفوجبسيوم (2.5 طن/فدان) مع السماد البلدي (5 طن/فدان) اعطي أفضل النتائج على جميع الصفات المدروسة خلال موسمين. يرجع التأثير الإيجابي لإستخدام الفوسفوجبسيوم بمفرده او مع السماد البلدي أو البكتريا المذيبة للفوسفور إلي تحسين خصائص التربة ، وتقليل درجة الحموضة في التربة وإنتاج الأحماض العضوية و الهرمونات النباتية التي تؤدي إلي زيادة إمتصاص العناصر الغذائية الكبري والصغرى من قبل النبات وتحسين نمو نباتات القطن وتطورها.

الكلمات المفتاحية: القطن، الفوسفوجبسيوم ، السماد البلدي ، البكتريا المذيبة للفوسفور