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Effect of phosphorus and sulphur levels on growth and development of Chickpea (*Cicer arietinum* L.) in western Uttar Pradesh

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Abstract

A field experiment entitled “Effect of phosphorus and sulphur levels on productivity and profitability of chickpea (*Cicer arietinum* L.) in western Uttar Pradesh” was carried out during *rabi* season, 2023-24 and 2024-25 at Agricultural Research Farm of Raja Balwant Singh College, Bichpuri Agra. The variables involved in this study were three levels of phosphorus (Main plot) viz., @ 0 kg P₂O₅ (P₀), @ 30 kg P₂O₅ (P₁) and @ 60 kg P₂O₅ (P₂) along with PSB (Sub plot) viz., No PSB inoculation (PSB₀) and PSB inoculation (PSB₁) and three sulphur levels (Sub-sub plot) @ 0 kg S ha⁻¹ (S₀), @ 15 kg S ha⁻¹ (S₁) and @ 30 kg S ha⁻¹ (S₂). Thus, all factors were compared in a split plot design with three replications. The soil of the experimental field was sandy loam in texture with a pH 8.34. The soil was low in available nitrogen (183.00 Kg ha⁻¹), medium in available phosphorus (28.30 P₂O₅ ha⁻¹) and potash (290.00 kg K₂O ha⁻¹). The field capacity was 18.42 per cent. The results revealed that the application of @ 60 kg P ha⁻¹ + PSB inoculation + @ 30 kg S ha⁻¹ obtained for improving vegetative growth, root development, and symbiotic nitrogen fixation in chickpea, and may be recommended for achieving higher productivity under agro-climatic conditions in western Uttar Pradesh.

Keywords: Chickpea, growth and development, phosphorus, PSB inoculation and Sulphur.

Introduction

Chickpea (*Cicer kabulium* L.) is the major pulse crop in India. At global level it ranks third in terms in area and production under legumes. It is grown with levels care and less manurial requirement. (Singh *et al.* 2022) [13]. The importance of chickpeas is demonstrated by the fact that, even when adequate rains and fertilizers are supplied, many farmers are unable to achieve acceptable crop yields. Perhaps the greatest promise for increasing pulse supplies is found in instruments that may help you recognize and address the plant's development difficulties ahead of time. Higher yield along with good quality seed can be produced by proper packages of agronomic practices. The response of phosphorus are in leguminous crop like chickpea in higher than other crops for their root development metabolic activities. Phosphorus regulates protein synthesis in plants, because it is a component of the complex nucleic acid structure. Phosphorus is also important in cell division and development of new tissues. (Singh *et al.* 2022) [13]. Phosphate Solubilizing Bacteria (PSB) culture plays a vital role in chickpea production by converting insoluble soil phosphorus into plant-available orthophosphate through the secretion of organic acids and phosphatases, thereby enhancing phosphorus uptake and reducing dependence on chemical phosphatic fertilizers. PSB inoculation significantly improves root development, nodulation, and biological nitrogen fixation when applied in combination with Rhizobium culture, resulting in better crop establishment and yield. Sulphur (S) is an essential secondary macronutrient that plays a critical role in the growth, yield, and nutritional quality of chickpea. It is a structural constituent of the sulphur-containing amino acids cysteine and methionine, which are indispensable for seed protein synthesis and directly influence the nutritive value of the grain. In addition, sulphur is a key component of the nitrogenase enzyme complex, making it fundamental to the biological nitrogen fixation (BNF) process facilitated by *Mesorhizobium ciceri* in root nodules; sulphur-deficient plants consistently exhibit reduced nodule number, impaired

nitrogenase activity, and consequently lower nitrogen use efficiency.

Materials and Methods

The field experiment was carried out during *Rabi* season of 2023-24 and 2024-25 at Agricultural Research Farm, Department of Agronomy, R.B.S. College, Bichpuri, Agra (U.P.). The research farm is situated at about 11 km to the west of Agra on Agra-Bharatpur Road at latitude of 27° 02'N and longitude of 77° 09' E with an elevation of 163.4 m above the mean sea level. This region falls under south-western semi-arid zone of Uttar Pradesh. The variables involved in this study were three levels of phosphorus (Main plot) viz., @ 0 kg P₂O₅ (P₀), @ 30 kg P₂O₅ (P₁) and @ 60 kg P₂O₅ (P₂) along with PSB (Sub plot) viz., No PSB inoculation (PSB₀) and PSB inoculation (PSB₁) and three sulphur levels (Sub-sub plot) @ 0 kg S ha⁻¹ (S₀), @ 15 kg S ha⁻¹ (S₁) and @30 kg S ha⁻¹ (S₂). Thus, all factors were compared in a split plot design with three replications. The seeds of chickpea variety IPC 2004-98 were used obtained from Indian institute of pulse research (IIPR) kalyanpur, Kanpur. Recommended quantity of seeds @ 80 kg/ha was used for experimental area. The seeds were treated with thiram @ 3 g/kg of seed. Subsequently, the seeds were also treated with *Rhizobium* culture. From the treated seeds, plot wise quantity of seed was weighed and seeds were drilled at 5-7 cm depth. The recommended doses of nitrogen and potassium were applied at the rate of 20 kg ha⁻¹each through urea and muriate of potash (MOP). Phosphorus and sulphur was applied as per treatment and through DAP and single super phosphate (SSP). Phosphate solubilizing bacteria (PSB) plays an important role in mineralization of unavailable phosphorus into available forms,

there by increases its uptake by plants which in turn increase the productivity. PSB was used @ 250 g for 10 kg of seeds. The seeds were gently mixed with culture so that the culture could be applied uniformly. The seeds then were dried in shade.

Results and Discussion

Effect of phosphorus

The data presented in Table 4.1 reveals that plant height at harvest was significantly influenced by different levels of phosphorus application. The pooled mean values indicated a progressive increase in plant height with increasing phosphorus levels. Plant height at harvest was significantly influenced by phosphorus levels. The pooled data revealed that application of 60 kg P ha⁻¹ (P₂) recorded significantly the maximum plant height (63.24 cm) over 30 kg P ha⁻¹ (P₁) and 0 kg P ha⁻¹ (P₀) which recorded 56.60 cm and 51.16 cm, respectively. The trend was consistent across both years of study. The increased plant height with higher phosphorus levels may be attributed to the role of phosphorus in cell division, energy metabolism, and enhanced root development, which promotes greater nutrient and water uptake, thereby favouring shoot elongation. These findings are in accordance with Singh *et al.* 2022 ^[13]. Dry matter accumulation was significantly influenced by phosphorus application. The highest pooled dry matter (37.69 g plant⁻¹) was recorded with P₂, followed by P₁ (32.79 g) and P₀ (29.15 g). The positive effect of phosphorus on dry matter accumulation could be ascribed to its role in improving photosynthetic efficiency, carbohydrate synthesis, and assimilate translocation, resulting in greater biomass production.

Table: 4.1. Growth characteristics of Chickpea as influenced by various treatments at successive stages of crop growth

		Plant Height (cm) at harvest			Dry matter (g) at harvest			No. of primary branches plant ⁻¹ at 60 DAS			No. of secondary branches plant ⁻¹ at 60 DAS		
Treatments		2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
Phosphorus levels													
0 kg ha ⁻¹	P ₀	50.36	51.96	51.16	27.86	30.43	29.15	6.57	7.61	7.09	15.41	16.85	16.13
30 kg ha ⁻¹	P ₁	55.81	57.40	56.60	31.02	34.56	32.79	7.12	8.79	7.95	18.55	19.93	19.24
60 kg ha ⁻¹	P ₂	62.44	64.04	63.24	36.77	38.61	37.69	8.94	9.13	9.03	21.24	22.59	21.91
SE(m)±		1.46	1.36	1.25	0.47	0.52	0.20	0.29	0.23	0.25	0.37	0.53	0.44
C.D. (P = 0.05)		5.69	5.70	5.49	1.84	1.89	0.81	1.16	0.91	0.98	1.46	2.08	17.2
PSB inoculation													
No PSB inoculation	PSB ₀	54.12	55.72	54.92	31.04	33.87	32.46	6.23	7.31	6.77	17.76	18.21	17.98
PSB inoculation	PSB ₁	58.29	59.88	59.08	32.73	35.20	33.96	7.92	8.23	8.07	19.04	20.37	19.70
SE(m)±		0.52	0.51	0.58	0.48	0.17	0.27	0.18	0.21	0.15	0.30	0.26	0.27
C.D. (P = 0.05)		1.50	1.43	1.67	1.39	0.51	0.79	0.53	0.62	0.44	0.86	0.75	0.78
Sulphur levels													
0 kg ha ⁻¹	S ₀	54.45	56.05	55.25	30.89	33.85	32.37	6.20	7.17	6.68	17.43	18.30	17.86
15 kg ha ⁻¹	S ₁	56.25	57.85	57.05	31.67	34.84	33.25	7.51	7.70	7.60	18.17	19.43	18.80
30 kg ha ⁻¹	S ₂	57.90	59.50	58.70	33.10	34.91	34.01	8.03	8.88	8.45	19.19	20.63	19.91
SE(m)±		0.63	0.61	0.53	0.59	0.21	0.33	0.22	0.26	0.19	0.36	0.31	0.33
C.D. (P = 0.05)		1.84	1.76	1.87	1.70	0.62	0.97	0.60	0.73	0.51	1.01	0.81	0.94

Dry matter accumulation was significantly influenced by phosphorus application. The highest pooled dry matter (37.69 g plant⁻¹) was recorded with P₂, followed by P₁ (32.79 g) and P₀ (29.15 g). The positive effect of phosphorus on dry matter accumulation could be ascribed to its role in improving photosynthetic efficiency, carbohydrate synthesis, and assimilate translocation, resulting in greater biomass production. Similar results were reported by Chandra *et al.* (2021) ^[2]. The number of

primary and secondary branches plant⁻¹ at 60 DAS also increased significantly with increasing phosphorus levels. Maximum primary branches (9.03) and secondary branches (21.91) were recorded with P₂, which were significantly superior over P₁ and P₀. Enhanced branching under higher phosphorus supply may be due to stimulation of meristematic activity and axillary bud development. These results are in conformity with the findings of Abisha and Singh, (2022) ^[1].

Effect of PSB Inoculation

Plant height at harvest was significantly influenced by PSB inoculation. The pooled data revealed that PSB inoculated plots (PSB_i) recorded significantly higher plant height (59.08 cm) over uninoculated plots (PSB_o) which recorded 54.92 cm. The trend was consistent across both the years of study. The increase in plant height due to PSB inoculation may be attributed to the ability of phosphate solubilizing bacteria to solubilize insoluble soil phosphorus through production of organic acids, thereby increasing available phosphorus for plant uptake, which in turn enhanced cell division and elongation leading to greater plant height. These findings are in agreement with Kumar *et al.* (2014)^[5]. Dry matter accumulation at harvest was significantly influenced by PSB inoculation. PSB inoculated plants (PSB_i) recorded higher pooled dry matter (33.96 g plant⁻¹) as compared to uninoculated plants (PSB_o) which recorded 32.46 g plant⁻¹. The improvement in dry matter accumulation with PSB inoculation could be attributed to enhanced phosphorus availability resulting in better photosynthetic activity, enzyme functioning, and overall metabolic efficiency of the plant. Similar findings were reported by Kumar *et al.* (2015)^[6]. The number of primary and secondary branches plant⁻¹ at 60 DAS were also significantly influenced by PSB inoculation. PSB inoculated plants recorded significantly higher primary branches (8.07) and secondary branches (19.70) as compared to uninoculated plants which recorded 6.77 and 17.98, respectively. The enhanced branching under PSB inoculation may be due to increased availability of solubilized phosphorus, which stimulated meristematic activity and promoted axillary bud development, resulting in greater lateral branching. Furthermore, PSB inoculation is also known to produce phytohormones such as indole acetic acid (IAA) and gibberellins, which may have additionally contributed to improved vegetative growth. These results are in conformity with the finding of Pramanik *et al.* (2003)^[9].

Effect of Sulphur

Plant height at harvest was significantly influenced by different levels of sulphur application. The pooled data revealed that application of 30 kg S ha⁻¹ (S₂) recorded significantly the maximum plant height (58.70 cm) over 15 kg S ha⁻¹ (S₁) and 0 kg S ha⁻¹ (S₀) which recorded 57.05 cm and 55.25 cm, respectively. The trend was consistent across both the years of study. The progressive increase in plant height with increasing sulphur levels may be attributed to the role of sulphur in synthesis of sulphur containing amino acids such as cysteine and methionine, which are essential constituents of proteins required for cell division and elongation, thereby favouring vegetative growth. Dry matter accumulation at harvest increased significantly with increasing levels of sulphur application. The highest pooled dry matter (34.01 g plant⁻¹) was recorded with S₂ (30 kg S ha⁻¹), followed by S₁ (33.25 g) and S₀ (32.37 g). The positive influence of sulphur on dry matter accumulation could be ascribed to its role in chlorophyll synthesis, activation of enzymes involved in carbohydrate and nitrogen metabolism, and improved photosynthetic efficiency, which collectively enhanced assimilation and accumulation of dry matter in plant tissues. The number of primary and secondary branches plant⁻¹ at 60 DAS also increased significantly with increasing sulphur levels. Maximum primary branches (8.45) and secondary branches (19.91) were recorded with S₂ (30 kg S ha⁻¹), which were significantly superior

over S₁ and S₀ recording primary branches of 7.60 and 6.68 and secondary branches of 18.80 and 17.86, respectively. The enhancement in branching with higher sulphur application may be due to improved nitrogen fixation and protein synthesis facilitated by adequate sulphur nutrition, which promoted meristematic activity and lateral bud development. Sulphur is also known to improve the activity of nitrogenase enzyme in root nodules of legumes, thereby enhancing overall plant vigour and canopy development.

Root studies of chickpea

Effect of phosphorus

The data presented in Table 4.2 reveals that root nodules plant⁻¹ at 30 and 60 DAS, Root length at 60 DAS and Root weight at 60 DAS was significantly influenced by different levels of phosphorus application. The pooled data revealed that application of 60 kg P ha⁻¹ (P₂) recorded significantly the maximum root nodules (17.89) over 30 kg P ha⁻¹ (P₁) and 0 kg P ha⁻¹ (P₀) which recorded 16.03 and 14.73, respectively. The trend was consistent across both the years of study. The increase in root nodule number with higher phosphorus levels may be attributed to the role of phosphorus in enhancing *Rhizobium* activity and symbiotic nitrogen fixation, as phosphorus is an essential component of nitrogenase enzyme and ATP synthesis required for nodule development and functioning. These findings are in agreement with Sonia, *et al.*, 2023^[15]. Root nodule number at 60 DAS also responded significantly to phosphorus application. The highest pooled root nodules (38.02) were recorded with P₂, followed by P₁ (21.23) and P₀ (20.77). A notably large and significant difference was observed between P₂ and the lower phosphorus levels, indicating that adequate phosphorus supply considerably enhanced nodule proliferation and activity as the crop advanced towards its active vegetative stage. The enhanced nodulation with higher phosphorus application could be ascribed to improved root growth and greater colonization by *Rhizobium* bacteria, facilitated by better energy availability through phosphorus-driven ATP synthesis. Similar results were reported by Singh *et al.* 2022^[13]. Root length at 60 DAS increased significantly with increasing levels of phosphorus application. The maximum pooled root length (23.15 cm) was recorded with P₂ (60 kg P ha⁻¹), which was significantly superior over P₁ (17.64 cm) and P₀ (16.11 cm). The progressive increase in root length with higher phosphorus levels may be attributed to the direct role of phosphorus in stimulating root cell division, elongation, and lateral root initiation. Phosphorus promotes the development of a more extensive root system by enhancing the activity of root meristems, thereby facilitating deeper and wider root proliferation into the soil profile. These findings are in conformity with Kumar *et al.* (2025). Root weight at 60 DAS was also significantly influenced by phosphorus levels. The highest pooled root weight (4.16 g) was recorded with P₂, followed by P₁ (3.54 g) and P₀ (2.06 g), and the differences among all treatment means were statistically significant. The substantial increase in root weight with higher phosphorus application reflects the overall improvement in root biomass resulting from greater root branching, elongation, and nodule development. Phosphorus being a key driver of energy metabolism and structural root development, its adequate supply leads to denser and heavier root systems capable of exploring larger soil volumes for nutrient and water acquisition. These results are in agreement with Sonia, *et al.* 2023^[16].

Table 2: Root nodules plant⁻¹ at 30, 60 DAS, Root length (cm) and Root weight (g) at 60 DAS of chickpea as influenced by various treatments

Treatments		No. of Root nodules plant ⁻¹ at 30 DAS			No. of Root nodules plant ⁻¹ at 60 DAS			Root length (cm) at 60 DAS			Root weight (g) at 60 DAS		
		2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
Phosphorus levels													
0 kg ha ⁻¹	P ₀	13.22	16.29	14.73	19.67	21.86	20.77	15.18	17.04	16.11	1.68	2.33	2.06
30 kg ha ⁻¹	P ₁	14.47	17.59	16.03	20.14	22.32	21.23	16.38	18.89	17.64	2.28	4.80	3.54
60 kg ha ⁻¹	P ₂	16.39	19.38	17.89	36.67	39.37	38.02	21.72	24.58	23.15	2.73	5.58	4.16
SE(m)±		0.37	0.40	0.32	1.38	1.46	0.94	0.68	0.64	0.63	0.10	0.11	0.09
C.D. (P = 0.05)		1.46	1.57	1.26	5.39	5.71	3.68	2.67	2.50	2.46	0.42	0.44	0.38
PSB levels													
No PSB inoculation	PSB ₀	13.95	16.98	15.46	24.24	25.57	24.90	16.97	19.25	18.11	1.93	2.29	2.11
PSB inoculation	PSB ₁	15.44	18.49	16.97	26.76	29.12	27.94	18.55	21.09	19.82	2.53	5.07	3.80
SE(m)±		0.24	0.28	0.17	0.43	0.46	0.31	0.21	0.24	0.16	0.10	0.16	0.10
C.D. (P = 0.05)		0.69	0.81	0.51	1.25	1.33	0.91	0.60	0.71	0.48	0.30	0.47	0.31
Sulphur levels													
0 kg ha ⁻¹	S ₀	13.86	16.96	15.41	24.61	27.01	25.81	16.91	19.17	18.04	1.89	2.15	2.02
15 kg ha ⁻¹	S ₁	14.65	17.50	16.07	25.23	27.43	26.33	17.82	20.22	19.09	2.25	4.65	3.45
30 kg ha ⁻¹	S ₂	15.57	18.68	17.12	26.65	29.10	27.87	18.55	21.11	19.83	2.54	5.11	3.83
SE(m)±		0.29	0.34	0.21	0.53	0.56	0.38	0.25	0.30	0.20	0.12	0.20	0.13
C.D. (P = 0.05)		0.85	0.99	0.62	1.53	1.63	1.11	0.74	0.87	0.59	0.37	0.58	0.38

Effect of PSB Inoculation

The number of root nodules plant⁻¹ at 30 and 60 DAS, root length and root weight at 60 DAS were significantly influenced by PSB inoculation. The pooled data revealed that PSB inoculated plants (PSB₁) recorded significantly higher root nodules at 30 DAS (16.97) and 60 DAS (27.94), root length (19.82 cm) and root weight (3.80 g) over uninoculated plants (PSB₀) which recorded 15.46, 24.90, 18.11 cm and 2.11 g, respectively. The differences between the two treatments were statistically significant for all the parameters and the trend was consistent across both the years of study. A notable increase in nodule number was observed from 30 to 60 DAS in both inoculated and uninoculated treatments, however the increase was more pronounced in PSB inoculated plants, reflecting greater *Rhizobium* activity and symbiotic nitrogen fixation with advancing crop growth. The improvement in all root parameters with PSB inoculation may be attributed to the ability of phosphate solubilizing bacteria to solubilize insoluble soil phosphorus through production of organic acids such as gluconic and citric acid, thereby increasing available phosphorus for plant uptake, which in turn enhanced *Rhizobium* colonization, nodule formation, root cell division, and lateral root development. Furthermore, PSB inoculation is also known to produce phytohormones such as indole acetic acid (IAA) and gibberellins, which directly promote root initiation, elongation, and branching, leading to a more extensive root system with greater nodulation capacity and higher root biomass. The synergistic interaction between PSB and *Rhizobium* further strengthened nodule development and functioning, resulting in overall improvement in root architecture and weight. These findings are in conformity with the findings of Harika *et al.* (2022) [3].

Effect of Sulphur

The number of root nodules plant⁻¹ at 30 and 60 DAS, root length and root weight at 60 DAS were significantly influenced by different levels of sulphur application. The pooled data revealed that S₂ (30 kg S ha⁻¹) recorded significantly the maximum root nodules at 30 DAS (17.12) and 60 DAS (27.87), root length (19.83 cm) and root weight (3.83 g) over S₁ which recorded 16.07, 26.33, 19.09 cm and 3.45 g and S₀ which recorded 15.41, 25.81, 18.04 cm and 2.02 g, respectively. The differences among all the sulphur levels were statistically significant for all the parameters and the trend was consistent across both the years of study. A

progressive increase in nodule number was observed from 30 to 60 DAS across all sulphur levels, and this increase was most pronounced under S₂ treatment, reflecting enhanced *Rhizobium* activity and symbiotic nitrogen fixation with adequate sulphur nutrition. The positive response of all root parameters to increasing sulphur levels may be attributed to the essential role of sulphur in synthesis of sulphur containing amino acids such as cysteine and methionine, which are critical constituents of nitrogenase enzyme required for biological nitrogen fixation and nodule functioning. Adequate sulphur supply also enhances the activity of root meristems through improved protein synthesis and enzyme activation, thereby promoting lateral root initiation, elongation, and greater root biomass accumulation. Furthermore, sulphur is known to improve the efficiency of symbiotic nitrogen fixation in legumes by enhancing bacteroid metabolism within root nodules, which collectively resulted in higher nodule number, longer roots, and greater root weight under higher sulphur application. These findings are in conformity with the findings of Zala *et al.*, (2024) [17].

Conclusion

The present investigation revealed that growth and root characteristics of chickpea were significantly influenced by phosphorus levels, PSB inoculation, and sulphur levels. The results revealed that the application of @ 60 kg P ha⁻¹ + PSB inoculation + @ 30 kg S ha⁻¹ obtained for improving vegetative growth, root development, and symbiotic nitrogen fixation in chickpea, and may be recommended for achieving higher productivity under agro-climatic conditions in western Uttar Pradesh.

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