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Effect of P levels and foliar application of phosphate and phosphite on performance of soybean (*Glycine max* L.)

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Abstract

A field experiment was conducted to evaluate the foliar application of phosphorus (as phosphate and phosphite) on the performance of soybean (*Glycine max* L.) during summer season of 2025 at College of Agriculture, Navile, KSNUAHS, Shivamogga. The experiment was laid out in RCBD comprising 11 treatments, replicated thrice. The treatments comprised of varying levels of P (75% and 100% of RDP) and combinations of potassium phosphate and potassium phosphite at 1% and 2% concentrations applied at 30 DAS. Among the different treatments, treatment T₄ (100% RDP + 1% KH₂PO₄ foliar spray) recorded significantly higher plant height (47.33 cm), number of branches per plant (7.73), pods per plant (32.20), seeds per pod (2.86), seed yield of 23.04 q ha⁻¹ and stover yield of 30.76 q ha⁻¹. The crude protein (28.27), oil content (20.74) and phytate P (81.47) content of soybean seeds were also higher in treatment T₄ (100% RDP + 1% KH₂PO₄ foliar spray).

Keywords: Phosphate, phosphite, soybean, p status, Alfisols

Introduction

Soybean (*Glycine max* L.), a key member of the Fabaceae family, is one of the most important legume crops worldwide. Known as the “Golden Bean” or “Miracle Crop” of the 21st century, it is valued for its high protein (40%) and oil (20%) content, along with essential amino acids, vitamins (A, B, D), and minerals. Globally, it provides about 69% of plant-based protein meal and 29% of vegetable oil. In India, soybean is a major *kharif* crop cultivated over 13.084 million hectares, with a production of 149.85 million tonnes and productivity of 1,145 kg/ha. It is primarily grown in central and western regions and plays a vital role in oilseed production and rural livelihoods. Phosphorus (P) is a crucial macronutrient involved in root development, energy transfer, photosynthesis, and seed formation. However, its availability is often limited, particularly in tropical soils like Alfisols, where P gets fixed as insoluble compounds with iron and aluminium oxides. Only 10-25% of applied phosphorus becomes available to plants, while the remainder is immobilized in the soil, leading to inefficient use and environmental concerns such as eutrophication and soil degradation. Enhancing phosphorus use efficiency is therefore critical for sustainable crop production.

Traditional phosphorus fertilization methods, which rely on soil-applied phosphates, are limited by poor mobility and fixation. Foliar phosphorus application has emerged as a complementary strategy to improve nutrient uptake, especially under phosphorus-deficient conditions. The effectiveness of foliar applications depends on factors such as application timing, concentration, and environmental conditions. In recent years, phosphites (salts of phosphorous acid) have attracted interest due to their biostimulant properties, including the activation of systemic acquired resistance (SAR) and enhancement of plant stress tolerance and disease resistance. While phosphites are not direct phosphorus sources like phosphates, studies have reported improvements in crop yield and quality following their application. However, their role in plant metabolism remains under research, and their acceptance as efficient phosphorus sources is still debated. Given these factors, optimizing the form, rate, and method of phosphorus application is essential for enhancing soybean productivity and soil health. Therefore, the present study was undertaken to evaluate the effects of varying phosphorus levels and foliar applications of phosphate and phosphite on soybean yield and soil phosphorus status in Alfisols, aiming to improve phosphorus use efficiency and sustainable crop production.

Materials and Methods

Field Experiment: The field experiment was conducted during summer 2025 at the College of Agriculture, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences (KSNUAHS), Shivamogga, Karnataka. The site is located in the Southern Transitional Zone (Agro-Climatic Zone VII) at 13°97' N latitude, 75°57' E longitude, and 667.5 m MSL. The experimental soil was sandy loam with acidic pH 5.25, EC 0.112 dS m⁻¹ and organic carbon 3.90 g kg⁻¹ with available N (344.96 kg ha⁻¹) and K₂O (312.21 kg ha⁻¹) medium in range whereas available phosphorus was high (84.53 kg ha⁻¹ P₂O₅). The experiment was laid out in a Randomized Complete Block Design (RCBD) with 11 treatments replicated thrice. The treatments included different levels of recommended dose of phosphorus (RDP) along with foliar application of potassium phosphate (KH₂PO₄) and potassium phosphite (KH₂PO₃) at 1% and 2% concentrations applied at 30 DAS. FYM @ 6.25 t ha⁻¹ and RDF (25:60:25 N:P₂O₅:K₂O kg ha⁻¹) were applied as per treatment schedule and the net plot size was 2.4 m × 2.6 m with 62.5 kg ha⁻¹ seed rate. Data was calculated on growth, yield and quality parameters of soybean. Data were statistically analyzed using ANOVA as per Gomez and Gomez (1984). Significance was tested at a 5% probability level and critical differences (CD) were computed where applicable.

Total Protein (TP): The TP analysis of the samples in this study was conducted at the Laboratory of pesticide Residue Analysis Lab (PRAL) at the Department of Soil Science, College of Agriculture, Navile, Shivamogga, using the Kjeldahl (Kelplus Classic DX Vaste) method and following the procedure.

Oil extraction by Soxhlet apparatus: Oil was extracted by Soxhlet apparatus by the method followed (Wapwera *et al.*,

2021) ^[15], using petroleum ether as solvent. 100 g of the powdered samples were placed inside a 500 ml thimble tube. The extraction was run until it completed 12 cycles without any disturbance and temperature was maintained between 40-50°C. After the completion the solvents were redistilled and the oil obtained after re-distillation were used for further studies. The yield percentage of oil was calculated by differential weight method.

Estimation of the Phytate

One gram of seeds was extracted in 5 mL 0.4 M HCl for 12 h. Next, 100 µL extract and the same volume of Chen solution (Chen's reagent- 6 N H₂SO₄; 2.5% ammonium molybdate; 10% ascorbic acid; H₂O- 1:1:1:2 v/v/v/v) were mixed. The mixture was left to react for 15 min. When it turned blue, the absorbance value was recorded at 660 nm (Sureshkumar *et al.*, 2015) ^[13].

Results

Growth Parameters

Plant height (cm)

Plant height increased significantly with phosphorus levels. The highest was in T₄ (100% RDP + 1% KH₂PO₄) with 26.65 cm at 30 DAS, 40.88 cm at 60 DAS and 47.33 cm at harvest, followed by T₆ (46.77 cm) and T₅ (44.88 cm). The lowest was in T₁ (control) with 23.67, 24.07, and 27.87 cm, respectively (Table 1).

No. of branches plant⁻¹

Number of branches increased significantly with phosphorus application. The highest was in T₄ (100% RDP + 1% KH₂PO₄) with 3.73, 7.60, and 7.73 branches at 30, 60 DAS and harvest, respectively, followed by T₆ and T₅. The lowest was in T₁ (control) with 3.00, 5.20 and 5.33 branches (Table 1).

Table 1: Effect of P levels and foliar application of phosphate and phosphite on growth parameters of soybean

Treatments		Plant height (cm)			No. of branches plant ⁻¹		
		30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T ₁	Absolute Control	23.67	24.07	27.87	3.00	5.20	5.33
T ₂	RDF	25.60	38.11	43.77	3.80	6.73	6.80
T ₃	75% RDP	24.50	32.89	38.09	3.50	6.20	6.27
T ₄	100% RDP + 1% KH ₂ PO ₄ *	26.65	40.88	47.33	3.80	7.60	7.73
T ₅	100% RDP + 1% KH ₂ PO ₃ *	26.34	38.73	44.88	3.90	7.00	7.07
T ₆	100% RDP + 2% KH ₂ PO ₄ *	26.52	40.39	46.77	3.77	7.07	7.13
T ₇	100% RDP + 2% KH ₂ PO ₃ *	25.83	38.43	44.50	3.47	6.80	6.93
T ₈	75% RDP + 1% KH ₂ PO ₄ *	24.67	35.67	40.67	3.33	6.33	6.40
T ₉	75% RDP + 1% KH ₂ PO ₃ *	24.15	31.74	36.73	3.43	5.87	6.07
T ₁₀	75% RDP + 2% KH ₂ PO ₄ *	24.93	37.48	43.51	3.53	6.53	6.60
T ₁₁	75% RDP + 2% KH ₂ PO ₃ *	24.43	29.42	34.06	3.47	5.53	5.60
S. Em* ±		1.127	1.442	1.977	0.181	0.206	0.250
CD @ 5%		NS	4.26	5.83	NS	0.61	0.74

Yield Parameters

No of pods plant⁻¹: Phosphorus application markedly enhanced pod formation. At 60 DAS, T₄ (100% RDP + 1% KH₂PO₄) produced the maximum pods (30.47), maintaining superiority till harvest (32.20). Treatments T₆ (30.20) and T₅ (28.67) followed closely, while the minimum pods were observed in T₁ (control) with 17.53 and 18.67, respectively (Table 2).

No of seeds pod⁻¹

Phosphorus nutrition positively influenced seed formation. At 60 DAS, T₄ (100% RDP + 1% KH₂PO₄) produced the most seeds pod⁻¹ (2.76), maintaining its lead at harvest (2.86) (Table 2). Treatments T₆ and T₅ followed closely, while T₁ (control) consistently recorded the fewest seeds pod⁻¹ (2.27 and 2.36, respectively).

Table 2: Effect of P levels and foliar application of phosphate and phosphite on yield parameters of soybean

Treatments		No of pods plant ⁻¹		No. of seeds pod ⁻¹		Stover yield	Seed yield	Test weight (g)	Harvest Index (%)
		60 DAS	At harvest	60 DAS	At harvest				
T ₁	Absolute Control	17.53	18.67	2.27	2.36	12.27	6.95	8.61	36.21
T ₂	RDF	26.47	27.93	2.61	2.71	27.15	19.25	8.81	41.49
T ₃	75% RDP	25.27	26.67	2.48	2.58	20.89	14.61	8.79	41.14
T ₄	100% RDP + 1% KH ₂ PO ₄ *	30.47	32.20	2.76	2.86	30.76	23.04	8.85	42.83
T ₅	100% RDP + 1% KH ₂ PO ₃ *	27.13	28.67	2.67	2.77	29.65	19.54	8.82	39.67
T ₆	100% RDP + 2% KH ₂ PO ₄ *	28.53	30.20	2.73	2.82	30.43	22.27	8.83	42.26
T ₇	100% RDP + 2% KH ₂ PO ₃ *	26.73	28.20	2.64	2.74	27.09	19.34	8.81	41.66
T ₈	75% RDP + 1% KH ₂ PO ₄ *	25.53	26.93	2.51	2.61	24.54	15.75	8.80	39.05
T ₉	75% RDP + 1% KH ₂ PO ₃ *	24.43	25.73	2.45	2.55	20.13	13.80	8.79	40.67
T ₁₀	75% RDP + 2% KH ₂ PO ₄ *	26.27	27.73	2.56	2.66	25.10	16.02	8.80	39.00
T ₁₁	75% RDP + 2% KH ₂ PO ₃ *	22.27	23.87	2.41	2.51	21.67	13.21	8.78	37.87
S. Em* ±		0.876	0.958	0.081	0.079	0.610	0.585	0.270	1.540
CD @ 5%		2.59	2.83	0.24	0.23	1.80	1.73	NS	NS

Stover yield (q ha⁻¹)

Stover yield showed a marked response to phosphorus treatments. The maximum yield was obtained in T₄ (100% RDP + 1% KH₂PO₄, 30.76 q ha⁻¹), followed by T₆ (30.43 q ha⁻¹) and T₅ (29.65 q ha⁻¹). Treatments with 100% RDP + 1% KH₂PO₄ outperformed others, while T₁ (control) produced the lowest yield (12.27 q ha⁻¹) (Table 2).

Seed yield (q ha⁻¹), Test weight (g) and Harvest Index (%)

Seed yield, test weight, and harvest index exhibited positive responses to phosphorus application. The maximum seed yield was obtained in T₄ (100% RDP + 1% KH₂PO₄) with 23.04 q ha⁻¹, followed by T₆ (22.27 q ha⁻¹) and T₅ (19.54 q ha⁻¹). Test weight varied marginally, with the highest in T₄ (8.85 g) and the lowest in T₁ (8.61 g), showing non-significant differences (Table 2). Similarly, harvest index values ranged from 36.21% (T₁) to 42.83% (T₄), indicating a numerical but non-significant

improvement. Overall, treatments with 100% RDP combined with foliar phosphate recorded superior yield performance and efficiency over other treatments.

Oil content and crude protein and Phytate P (%)

The results indicated variations in crude protein, oil content, and phytate P among the treatments (Table 3). However, the differences in crude protein and oil content were statistically non-significant. The highest crude protein (28.27%) and oil content (20.74%) were recorded in T₄ (100% RDP + 1% KH₂PO₄), while the lowest values were observed in T₁ (Absolute control) with 18.22% and 17.46%, respectively. Phytate P content, which varied significantly from 55.69 to 81.47 mg 100 g⁻¹, was also highest in T₄ (81.47 mg 100 g⁻¹) followed by T₆ and T₅, whereas the lowest phytate P (55.69 mg 100 g⁻¹) was recorded in T₁, indicating the beneficial effect of phosphorus supplementation.

Table 3: Effect of P levels and foliar application of phosphate and phosphite on oil content, phytate P and crude protein content in soybean seeds

Treatments		Crude protein (%)	Oil content (%)	Phytate P mg 100g ⁻¹
T ₁	Absolute Control	18.22	17.46	55.69
T ₂	RDF	25.19	19.54	67.33
T ₃	75% RDP	23.74	19.44	60.54
T ₄	100% RDP + 1% KH ₂ PO ₄ *	28.27	20.74	81.47
T ₅	100% RDP + 1% KH ₂ PO ₃ *	26.15	19.75	75.78
T ₆	100% RDP + 2% KH ₂ PO ₄ *	27.69	20.53	79.67
T ₇	100% RDP + 2% KH ₂ PO ₃ *	25.96	19.62	73.71
T ₈	75% RDP + 1% KH ₂ PO ₄ *	24.60	19.39	63.31
T ₉	75% RDP + 1% KH ₂ PO ₃ *	23.29	19.25	59.71
T ₁₀	75% RDP + 2% KH ₂ PO ₄ *	24.86	19.45	65.67
T ₁₁	75% RDP + 2% KH ₂ PO ₃ *	23.19	19.21	58.74
S. Em* ±		2.371	0.653	2.087
CD @ 5%		NS	NS	6.16

Discussion: Growth parameters: Plant height and branching increased significantly with phosphorus supplementation. T₄ (100% RDP + 1% KH₂PO₄) recorded the highest plant height and branch number, followed by T₆. Adequate P enhanced cell division, elongation and cytokinin-mediated branching (Grant *et al.*, 2001; Eichert & Fernandez, 2012; Mannan, 2014) [3, 1, 4], ensuring improved vegetative growth and vigor.

Yield parameters of soybean: Phosphorus nutrition significantly influenced yield attributes and yield in soybean. T₄ (100% RDP + 1% KH₂PO₄) recorded the highest number of pods per plant, seeds per pod, 100-seed weight, seed yield (Fig. 1) and stover yield, followed by T₆ (100% RDP + 2% KH₂PO₄).

Adequate phosphorus enhanced photosynthesis, assimilate translocation, and energy transfer, supporting pod formation, seed setting and filling (Grant *et al.*, 2001; Mannan, 2014) [3, 4]. Foliar phosphate application minimized transient P deficiencies, improving pollen viability and pod retention (Mannan, 2014) [4]. In contrast, KH₂PO₃ showed minimal positive effects due to its limited metabolic role (Peirce *et al.*, 2014) [6]. The highest harvest index (42.83%) was also recorded in T₄, reflecting efficient assimilate partitioning toward seeds. Similar enhancements in yield and quality due to foliar phosphate were reported by Rickard (2000) [9], Peoples *et al.* (2009) [7], Silva *et al.* (2011) [12], and Zambrosi (2019) [16], whereas phosphite showed limited yield benefits (Sutradhar, 2019) [14].

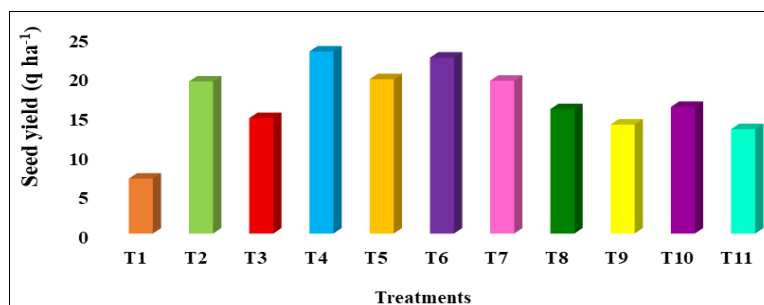


Fig 1: Effect of P levels and foliar application of phosphate and phosphite on yield of soybean

Quality parameters of soybean

Crude protein and oil contents in soybean seeds varied non-significantly with phosphorus levels and foliar applications. T₄ (100% RDF + 1% KH₂PO₄) recorded the highest crude protein and oil content, followed by T₆ (100% RDF + 2% KH₂PO₄). Enhanced protein synthesis under adequate P supply results from improved photosynthate production and translocation to seeds (Nget *et al.*, 2022) ^[5], while increased oil content reflects higher enzyme activity in lipid biosynthesis supported by phosphorus-driven ATP production (Rotundo and Westgate, 2009) ^[10]. Phytate P content increased significantly, ranging from 55.69 to 81.47 mg 100g⁻¹, with maximum accumulation in T₄. This positive correlation between P fertilization and phytate formation aligns with Raboy and Dickinson (1984) ^[8], emphasizing phosphorus's role in phytic acid biosynthesis in legumes.

5. Conclusion

The application of 100% RDF along with foliar application of 1% KH₂PO₄ at flowering (T₄) significantly improved plant height, number of branches per plant, pods per plant, seed yield and stover yield, which was on par with 100% RDF along with foliar application of 2% KH₂PO₄ (T₆). Hence, foliar supplementation of P as phosphate in combination with soil-applied P was found beneficial in soybean for improving its performance by producing higher yield.

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Conflict of interest

Authors declare no conflict of interest.

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