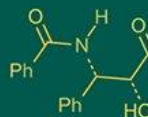


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(5): 545-548
www.biochemjournal.com
Received: 01-02-2026
Accepted: 05-03-2026

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Effect of phosphorus levels based on nodulation and nutrients uptake of soybean [*Glycine max* (L.)]

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i5Sg.8417>

Abstract

A field experiment was conducted to evaluate the effect of different phosphorus levels on the nodulation and nutrient uptake of soybean. The study was carried out under the ongoing AICRP on STCR program at JNKVV, Jabalpur (M.P.) during the year 2015-16. The experiment included five levels of phosphorus: 0, 60, 90, 120, and 118 kg P₂O₅ ha⁻¹, arranged in a randomized block design with three replications.

The results revealed that number of nodules plant⁻¹, Dry wt. of nodules plant⁻¹, NPK content in nodules and nutrient uptake of soybean were significantly influenced by phosphorus application, with minimum values recorded in the control treatment. nodulation and nutrient uptake were significantly higher with the application of 118 kg P₂O₅ ha⁻¹ compared to other treatments.

Based on these findings, it can be concluded that the application of phosphorus at 118 kg P₂O₅ ha⁻¹, as determined through the fertilizer adjustment equation for targeted yield, significantly improved the nodulation and nutrient uptake of soybean over the control and other treatments.

Keywords: Soybean, phosphorus levels, nodulation, nutrient uptake, NPK content and dry weight of nodules

1. Introduction

Soybean (*Glycine max* L.) is one of the most important leguminous crops worldwide, valued for its high protein and oil content. It plays a crucial role in improving soil fertility through biological nitrogen fixation, a process carried out by symbiotic *Rhizobium* bacteria present in root nodules. Efficient nodulation not only enhances nitrogen availability to the plant but also reduces dependence on external nitrogen fertilizers, thereby contributing to sustainable agriculture (Salvagiotti *et al.*, 2008) [3].

Phosphorus is a vital macronutrient required for various physiological and biochemical processes in plants, including energy transfer, root development, and nodulation. Adequate phosphorus supply is essential for proper root growth and the establishment of effective symbiosis between soybean roots and rhizobia. It directly influences nodule formation, nodule biomass, and nitrogen fixation efficiency (Vance *et al.*, 2003) [4]. Deficiency of phosphorus often leads to poor nodulation, reduced nutrient uptake, and ultimately lower crop productivity.

In addition to its role in nodulation, phosphorus significantly affects nutrient uptake by enhancing root surface area and increasing the availability and absorption of essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K). Balanced fertilization, particularly phosphorus management, is therefore critical for optimizing soybean growth and yield (Grant *et al.*, 2001) [1].

The Soil Test Crop Response (STCR) approach under the All India Coordinated Research Project (AICRP) provides a scientific basis for fertilizer recommendations based on soil fertility status and targeted yield. This approach ensures efficient use of fertilizers while maintaining soil health and improving crop productivity (Ramamoorthy *et al.*, 1967) [2].

Considering the importance of phosphorus in nodulation and nutrient uptake, the present study was undertaken to evaluate the effect of different phosphorus levels on nodulation parameters and nutrient uptake of soybean under field conditions.

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2. Material and Methods

In 2015-16, researchers at JNKVV, Jabalpur (M.P.) ran a study under the AICRP on STCR program to see how different phosphorus levels affect soybean nodulation and nutrient uptake. They set up five treatments (see Table 1) using a randomized block design, with three repetitions for each treatment. Forty-five days after sowing, they checked nodule formation. They pulled up five plants from each plot, making sure the nodules stayed intact. After shaking off the soil, they rinsed the roots under running water to clear any remaining dirt from the rhizosphere. Then, they counted the nodules on each plant by hand. Once they had the numbers, they plucked the nodules off, put them in small paper bags, and dried them in a hot air oven at 60 °C. After 3-4 days once the nodules stopped losing weight they recorded the final dry weight in grams.

Table 1: Treatment Details

Notation	Treatments
T ₁	Control
T ₂	60 kg P ₂ O ₅ ha ⁻¹
T ₃	66 kg P ₂ O ₅ ha ⁻¹
T ₄	92 kg P ₂ O ₅ ha ⁻¹
T ₅	118 kg P ₂ O ₅ ha ⁻¹

2.1 Preparation of plant and Nodule samples

First, I dried the collected plant samples at 60±2 °C in a hot air oven for eight to ten hours. Once dried, I ground them to get a consistent texture.

2.2 Statistical analysis

We gathered all the data for each soybean trait and ran a standard statistical analysis. Then we used analysis of variance for the randomized block design, just like Gomez and Gomez described back in 1984, to check if our results were actually significant and to draw solid conclusions.

3. Results and Discussion

3.1 Effect of phosphorus levels based on targeted yield on nodulation of soybean

Number of nodules per plant and dry weight of nodules per plant as well as NPK content in nodules as affected by phosphorus levels recorded at 45 DAS of soybean crop are presented in Table 1

3.1.1 Number of nodules

Looking at the data for nodules per plant under different phosphorus levels at 45 days after sowing, things stand out pretty clearly. Plants in treatment T₅ had the most nodules — 51.33 per plant. On the other hand, T₁ ended up with just 38.45 nodules per plant, the lowest count. The nodules formed with higher phosphorus doses looked healthy and active, showing the treatment worked.

3.1.2 Dry weight of nodules

Table 1 shows that plants had a higher dry weight of nodules at 45 DAS, and the numbers really shifted with different phosphorus levels. At 45 DAS, treatment T₅ stood out with a nodule dry weight of 0.57 grams per plant, which

For nutrient analysis, I used wet digestion. To measure all nutrients except nitrogen, I digested the samples with a mix of nitric acid and perchloric acid. I weighed out one gram of each sample and placed it into digestion tubes. These tubes went into a chamber set to 160 °C. After that, I ramped up the temperature to 210 °C and waited for the red NO₂ vapours to disappear. I kept heating until the sample was down to about 3-5 ml but still not totally dry that meant digestion was done.

After letting the tubes cool, I diluted the digested solution with glass-distilled water and brought the final volume up to 100 ml in a volumetric flask. I used portions from this solution to measure phosphorus, potassium, calcium, magnesium, and sulphur. As for soybean nutrient content specifically nitrogen, phosphorus, and potassium. I measured these at different growth stages, always working with dry samples and following standard protocols, like the ones shown in the table below.

Table 2: Methods of plant chemical analysis

Nutrients	Analytical method	Method employed
Nitrogen (%)	Micro-Kjeldahl method	A.O.A.C. (1995)
Phosphorus (%)	Vanado molybdate yellow colour method	Bhargava and Raghupathi (1984)
Potassium (%)	Flame-photometric method	Bhargava and Raghupathi (1984)

Nutrient uptake (kg ha⁻¹) Nutrient uptake by Soybean was calculated in kg ha⁻¹ in relation to yield ha⁻¹ by using the following formula.

$$\text{Nutrient Uptake (kg ha}^{-1}\text{)} = \frac{\text{Grain/Straw yield (kg)}}{100} \times \text{Nutrient content (\%)}$$

was clearly higher than all the other P levels.

3.1.3 NPK content in nodules

Researchers checked the NPK content in nodules at different phosphorus levels, and the results are in Table 1. They found that NPK was highest at 45 days after sowing (DAS), and phosphorus really made a difference at that stage. When they applied 118 kg P₂O₅ per hectare (the T₅ treatment), NPK content in the nodules went up by 3.43% for nitrogen, 0.14% for phosphorus, and 4.67% for potassium much better than the control.

The number of nodules per plant and their dry weight also changed a lot depending on how much phosphorus plants got. At 45 DAS, T₅ treatment had the highest results: 51.33 nodules per plant and 0.57 grams' dry weight. The lowest numbers 38.45 nodules and 0.47 grams also showed up under T₁, which raises an eyebrow, considering T₅ is supposed to give the best results. That said, phosphorus clearly played a big role in stimulating nodulation.

Legumes need a lot of phosphorus since it's vital for growth and nitrogen fixation. It's well-known that phosphorus boosts biomass, nodule number, and mass in all kinds of legume crops. So, it's no surprise that as phosphorus levels went up, so did the NPK content in the nodules. Even though T₅ sometimes showed fewer nodules, every nodule was effective at doing its job. Similar findings have been also reported by Sharma *et al* (2014) ^[10], Nandini Devi *et al* (2012) ^[12], Lamptey S *et al* (2014) ^[5] and Matusso *et al* (2015) ^[6]. justifying the result obtained in this investigation.

Table 3: Effect of phosphorus levels on nodulation based on targeted yield of soybean.

P-levels	Nodules plant ⁻¹ (no.)	Dry wt. of Nodules plant ⁻¹ (g)	N content in Nodules (%)	P content in Nodules (%)	K content in Nodules (%)
T ₁	38.45	0.47	3.11	0.11	4.36
T ₂	47.47	0.53	3.15	0.12	4.47
T ₃	42.88	0.50	3.27	0.13	4.56
T ₄	41.67	0.48	3.36	0.13	4.63
T ₅	51.33	0.57	3.43	0.14	4.67
SE m±	1.19	0.013	0.055	0.002	0.079
CD (p = 0.05)	3.67	0.041	0.169	0.006	0.243

3.2 Effect of phosphorus levels based on targeted yield on uptake by soybean seed and straw

3.2.1 Nitrogen Uptake

Take a look at Table 3 and we will see how soybean grabs nitrogen from the soil split by seed, straw, and total yield. When the phosphorus levels go up, nitrogen uptake shoots up too. The highest numbers came with 118 kg P₂O₅ per hectare (T₅): seeds pulled in 105.88 kg nitrogen per hectare, straw took 66.75 kg, and the combined total hit 172.63 kg. That is appealing close to what happened with T₄ 96.35 for seeds, 63.57 for straw, and 159.90 overall. On the other hand, the control group (T₁), with no phosphorus added, really lagged. Seeds barely managed 50.97 kg, straw came in at 41.90 kg, and total uptake only reached 92.87 kg per hectare a lot lower than plots with phosphorus.

3.2.2 Phosphorus Uptake

Table 4 lays it all out when you crank up the phosphorus levels, the plants soak up way more phosphorus. Tossing in inorganic fertilizers really boosts uptake compared to leaving the field alone. Treatment T₅ aiming for a target yield of 35 q ha⁻¹ scored the best numbers: 7.93 kg ha⁻¹ in the seed, 5.55 kg ha⁻¹ in the straw, and a total of 13.48 kg ha⁻¹. These results are pretty much in line with what T₄ pulled off. On the other end, the control group (T₁) lagged

way behind, only managing 3.87 kg ha⁻¹ in seed, 3.11 kg ha⁻¹ in straw, and a total uptake of 6.96 kg ha⁻¹.

3.2.3 Potassium Uptake

Honestly, the numbers from Table 4 make it pretty clear: potassium uptake in seed, straw, and total biomass jumps when you add more phosphorus. Using inorganic fertilizers really boosted potassium uptake compared to the control group. The best results showed up in treatment T₅ that's the target yield of 35 q ha⁻¹. Here, the seed pulled in 34.19 kg ha⁻¹, straw grabbed 72.49 kg ha⁻¹, and the total hit 106.68 kg ha⁻¹. This matched pretty well with T₄, so not a massive difference between those two. On the flip side, the control treatment (T₁) lagged behind, with potassium uptake numbers of 15.27 in seed, 47.37 in straw, and 62.64 kg ha⁻¹ total.

If you look at the whole picture, T₅ (where phosphorus was at 118 kg P₂O₅ ha⁻¹) came out on top for total nitrogen, phosphorus, and potassium uptake. Potassium, especially, reached 106.68 kg ha⁻¹, clearly beating the other phosphorus levels. Similar findings were also reported by Laharia *et al* (2004) [7], Morshed *et al* (2008) [8], Rahman *et al* (2008) [8], Jahangir *et al* (2009) [9], Sharma *et al* (2014) [10] and Yadav *et al* (2013) [11]

Table 4: Effect of phosphorus levels based on targeted yield on nutrients uptake by seed and straw of soybean

P-levels	Nutrient uptake (kg ha ⁻¹)								
	Nitrogen			Phosphorus			Potassium		
	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total
T ₁ : Control (0 kg P ₂ O ₅ ha ⁻¹)	50.97	41.90	92.87	3.87	3.11	6.96	15.27	47.37	62.64
T ₂ : GRD (60 kg P ₂ O ₅ ha ⁻¹)	74.51	54.45	128.96	5.57	4.48	10.11	23.6	59.41	82.96
T ₃ : T.Y. 25 q ha ⁻¹ (66 kg P ₂ O ₅ ha ⁻¹)	83.13	59.80	145.93	6.41	4.93	11.34	27.34	64.97	92.31
T ₄ : T.Y. 30 q ha ⁻¹ (92 kg P ₂ O ₅ ha ⁻¹)	96.35	63.57	159.9	7.15	5.27	12.42	30.93	69.18	100.11
T ₅ : T.Y. 35 q ha ⁻¹ (118 kg P ₂ O ₅ ha ⁻¹)	105.88	66.75	172.63	7.93	5.55	13.48	34.19	72.49	106.68
SE m±	3.53	2.39	5.88	0.24	0.19	0.43	1.11	2.74	3.79
CD (p = 0.05)	10.88	7.37	18.11	0.75	0.58	1.34	3.41	8.45	11.67

4. Conclusion

The present field experiment clearly demonstrates that phosphorus application has a significant positive effect on nodulation and nutrient uptake in soybean. Among the different phosphorus levels tested, the highest dose of 118 kg P₂O₅ ha⁻¹ (T₅) proved to be the most effective.

Application of this level resulted in maximum number of nodules per plant and higher dry weight of nodules, Enhanced N, P, and K content in nodules. Significantly higher uptake of nitrogen, phosphorus, and potassium by both seed and straw. In contrast, the control treatment (no phosphorus) recorded the lowest values for all parameters, highlighting the essential role of phosphorus in soybean growth and symbiotic nitrogen fixation.

Therefore, it can be concluded that application of 118 kg P₂O₅ ha⁻¹, as determined through the Soil Test Crop Response (STCR) approach, is optimal for improving nodulation, nutrient content, and overall nutrient uptake in soybean. This not only enhances crop productivity but also supports sustainable soil fertility management.

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