



E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(8): 1203-1207
Received: 30-05-2026
Accepted: 03-07-2026

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International Journal of Research in Agronomy

Effect of phosphorus solubilizing bacteria on growth and yield of soybean (*Glycine max* L.)”

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i8o.6406>

Abstract

The present field study was carried out on “Effect of Phosphorus Solubilizing Bacteria on Soil Nutrient Dynamics, Nutrient Uptake and Yield of Soybean (*Glycine max* L.)” during the Kharif season of 2025–26 at Research farm, Department of Soil Science, College of Agriculture, Latur. The experiment was laid out in a Randomized Block Design (RBD) comprising eight treatments, each replicated thrice. The experiment was conducted using MAUS 158, the recommended soybean variety, as the test crop. The experiment comprised the following treatments: T1- Control, T2- RDF (30:60:30:20), T3- 100% RDNKS + 75%RDP + PSB seed treatment, T4- 100% RDNKS + 50% RDP + PSB seed treatment, T5- 100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 DAS, T6- 100% RDNKS + 50% RDP + PSB seed treatment + Drenching of PSB at 20 DAS, T7- 100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS and T8-100% RDNKS + 50% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS. The experimental results revealed that the application of 100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS recorded significantly higher values for growth and yield parameters viz. plant height 22.76, 36.33, 43.1 cm at 30, 40, 60 DAS respectively, leaf area (441.23, 673.6 cm²) 30, 45 DAS respectively, number of nodules (47.50), number of pods plant⁻¹(52.30), number of seeds pod⁻¹(3.0), seed yield (18.90 q ha⁻¹), straw yield (23.23 q ha⁻¹), at par with 100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 DAS and 100% RDNKS + 50% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS significantly superior over rest of the treatments. In contrast the lowest values recorded under treatment control.

Keywords: Soybean, phosphorus solubilizing bacteria, nutrient uptake, nutrient use efficiency, apparent nutrient balance

Introduction

Soybean (*Glycine max* L.) is a self-pollinated crop belonging to the family Leguminosae, subfamily Papilionaceae, and genus Glycine. The crop is normally diploid with a chromosome number of 2n = 40 and is believed to have originated in China. Soybean is one of the most important oilseed crop due to its high protein content (40–42%), abundant lysine and oil content (20–22%) rich in essential fatty acids. Soybean is popularly known as the "Golden Bean" or the "Miracle Crop" of the twentieth century. Owing to its superior nutritional composition and high-quality protein, soybean is widely recognized as the "poor man's meat" at the global level. Integrated Nutrient Management (INM) is a sustainable approach to crop nutrition that involves the combined and balanced use of chemical fertilizers, organic sources of nutrients, and beneficial microorganisms to achieve higher crop productivity while maintaining soil fertility. Bioinoculants are an important component of integrated nutrient management and are regarded as cost-effective, eco-friendly, and renewable sources of plant nutrients. They serve as non-bulky and low-cost supplements to chemical fertilizers, thereby contributing to sustainable agricultural production systems in India. Pulse seeds are commonly inoculated with phosphorus-solubilizing microorganisms (PSM) to enhance their population in the rhizosphere, thereby increasing phosphorus (P) availability and improving plant growth. A wide range of microorganisms inhabit the soil, among which Phosphorus Solubilizing Bacteria (PSB) have been utilized as biofertilizers

since the 1950s (Kudashev, 1956; Krasilnikov, 1957) [6, 7]. PSB play a vital role in enhancing the availability of soil phosphorus by secreting various organic acids, including formic, acetic, butyric, propionic, citric, gluconic, succinic, oxalic, maleic, malic, and lactic acids, which convert insoluble phosphorus into forms readily available for plant uptake. In addition to solubilizing native soil phosphorus, PSB increase phosphorus availability by releasing fixed phosphorus into plant-accessible forms (Khan and Zaidi, 2007) [4]. Genera such as *Pseudomonas* and *Bacillus* are among the most effective phosphorus-solubilizing bacteria, converting insoluble soil phosphorus into soluble forms that can be readily absorbed by plants. The soybean variety MAUS 158 is a high-yielding, early maturing soybean cultivar developed by Vasantrao Naik Marathwada Krishi Vidyapeeth (VNMKV) in Parbhani and its tolerance to stem fly pests and good seed longevity. Inoculation of PSB significantly increased the growth and yield of soybean by providing optimum amount of nutrient.

Materials and Method

The experiment was conducted at the research farm of Department of Soil Science, College of Agriculture, Latur, during *Kharif* season of the year 2025-2026, the variety of soybean used for experiment MAUS-158, and the topography of experimental field was uniform and levelled. The soil of the research farm was dark grey to brown in colour and clayey in texture (2:1 smectite type). The soil was moderately calcareous, moderately alkaline (pH 7.87), low in available nitrogen (120.34 kg ha⁻¹), medium in available phosphorus (21.40 kg ha⁻¹), high in available potassium (545.0 kg ha⁻¹) and high in available sulphur (29.4 kg ha⁻¹). The experiment implemented in randomized block design (RBD) with a plot size of 4.05 m × 3 m, and row-to row and plant-to-plant distances of 45 cm and 5 cm, respectively. Fertilizers used in this experiment include Urea, SSP, MOP and Bensulf by soil application. The seed rate used was 70 kg ha⁻¹. Seed treated with *Rhizobium* and PSB. Sowing was done by dibbling method. The recommended cultural practices and plant protection measures were taken. Five plants were randomly selected and tagged from each net plot to record biometric observations at various growth stages. These same plants were later harvested individually for post-harvest analysis. The data collected from various observations were organized into tables and analyzed using analysis of variance (ANOVA).

Result and Discussion

Plant height (cm)

Among the different treatments, T7 (100% RDNKS + 75% RDP + PSB seed treatment + drenching of PSB at 20 and 40 DAS) recorded the maximum plant height of 22.76 cm, 36.33 cm, and 43.1 cm at 30 DAS, 45 DAS, and 60 DAS respectively. This was followed by T5 (100% RDNKS + 75% RDP + PSB seed treatment + drenching of PSB at 20 DAS), which recorded plant heights of 22.25 cm, 35.07 cm, and 42.93 cm at 30, 45, and 60 DAS, respectively, and remained statistically comparable with T7. Treatment T8 (100% RDNKS + 50% RDP + PSB seed treatment + drenching of PSB at 20 and 40 DAS) also exhibited improved plant height of 21.99 cm, 34.70 cm, 40.87 cm at 30, 45, and 60 DAS, respectively. The control (T1) recorded the lowest plant height of 17.97 cm, 30.27 cm, and 35.32 cm at 30, 45, and 60 DAS respectively. Overall, the results indicate that the combined application of PSB through seed treatment and split drenching, along with balanced fertilization, improved phosphorus solubilization and maintained its availability throughout the crop growth period. This integrated nutrient management strategy

enhanced nutrient uptake, root development, and physiological activities, thereby promoting vigorous vegetative growth. Similar results were found by Jhansi *et al.* (2023) [3] in soybean that the maximum plant height was observed at 86.4 cm in 75%P2 O5 + PSB and the minimum was recorded as 70.9 cm in Absolute control. Akhila *et al.* (2025) [1] observed in soybean significantly highest plant height of 23.7, 53.1, 61.3 and 59.4 cm at 30 DAS, 60 DAS, 90 DAS by PSB strains, seed inoculation with *Bacillus subtilis* over uninoculated control.

Leaf area (cm²) plant⁻¹

Application of 100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS (T7) recorded the highest leaf area values i.e. 441.23 cm² at 30 DAS, 673.6 cm² plant⁻¹ at 45 DAS which was found at par with treatment T5 i.e. (438.03 and 633.89 cm² plant⁻¹ at 30 and 45 DAS), T8 (435.26 and 626.67 cm² plant⁻¹ at 30 and 45 DAS) and recorded significantly higher values than the remaining treatments. Leaf area was recorded to be lowest with treatment T1 control (326.2, 428.5 cm² plant⁻¹ at 30 and 45 DAS) in soybean.

Improved phosphorus nutrition promoted vigorous root development, increased nutrient uptake, and stimulated cell division and expansion, leading to greater leaf development. Repeated PSB application at critical growth stages also helped sustain microbial activity in the rhizosphere, thereby enhancing photosynthetic surface area and overall vegetative growth. Similar results were observed by Jhansi *et al.* (2023) [3] the leaf area index of soybean was found highest in 75% P2O5 + PSB at 30 DAS (1.49), 60 DAS (2.67) and at 90DAS (3.24) over all other treatments. Souza *et al.* (2023) [11] revealed that the highest dose of P2O5 resulted larger leaf area when the plants were inoculated with PSB doses of up to 198.1 mL ha⁻¹ in common bean,

Number of nodules plant⁻¹

The maximum number of nodules plant⁻¹ (47.50) was observed in Treatment T7 (100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS). This was followed by T5 (100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 DAS), i.e. (46.13) nodules plant⁻¹ and T8 (100% RDNKS + 50% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS) recorded a marked increase, reaching (45.68) nodules plant⁻¹. Significantly, a smaller number of nodules plant⁻¹ (37.07) was observed at flowering stage in treatment T1 control. Enhanced phosphorus nutrition favoured root growth, nodule initiation, and the establishment of an efficient symbiotic association with *Rhizobium* and repeated PSB application sustained beneficial microbial activity in the rhizosphere, resulting in improved nodulation and a greater number of nodules plant⁻¹. Similar results were found by Rathia *et al.* (2025) [9] the highest number of nodules plant⁻¹ was recorded in 66 nodules plant⁻¹ which received 75% N and 100% P and K along with *Bradyrhizobium daqingense*, followed by 63 nodules plant⁻¹ with *Rhizobium japonicum*. The lowest nodule counts 43 was observed in which received reduced phosphorus without rhizobial inoculation. In soybean the application of 80 kg P2O5 ha⁻¹ significantly increased no of nodules plant⁻¹ observed by Kore *et al.* (2025) [5].

Number of pods plant⁻¹ and Number of seeds pod⁻¹

The greater number of pods plant⁻¹ (52.30) was recorded in T7 (100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS). Treatment T5 (100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 DAS) recorded 50.17 pods plant⁻¹ at harvest while treatment T8 (100%

RDNKS + 50% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS) recorded 48.70 pods plant⁻¹. Both T5 and T8 were statistically at par with T7. Unlike the lowest number of pods plant⁻¹ was observed in the T1 control treatment, (41.47) pods plant⁻¹ at harvest. The maximum number of seeds pod⁻¹ (3) was also observed in T7 (100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS), followed by all the treatments are statistically at par with T7. The number of seeds pod⁻¹ remained non-significant among the treatments, which due to the strong genetic control of this yield component and the relatively limited influence of nutrient management practices on varietal characteristics. Better phosphorus supply supported stronger photosynthetic activity, more assimilate production, and improved reproductive development, which reduced flower and pod drop. As a result, more flowers were retained and converted into pods, and more seeds were successfully developed within each pod. Related findings have been reported by Jhansi *et al.* (2023) [3] in soybean that maximum number of pods plant⁻¹ (142.2) in 75%P₂O₅ + PSB. Shome *et al.* (2022) [10] reported that the seed treated with *Rhizobium japonicum* and *Pseudomonas striata* inoculant, and 50% N and 75% P recorded maximum number of pods plant⁻¹, number of seeds pod⁻¹ in soybean. Kore *et al.* (2025) [5] revealed that the application of 80 kg P₂O₅ ha⁻¹ significantly increased number of pods plant⁻¹, number of seeds pod⁻¹ in soybean

Seed yield (q ha⁻¹)

The highest seed yield (18.90 q ha⁻¹) was recorded under T7 (100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS), which significantly outperformed all other treatments, including the control and RDF alone. Treatments T5 (18.25 q ha⁻¹) and T8 (18.11 q ha⁻¹) were statistically at par with T7. In contrast, the lowest yield (13.13 q ha⁻¹) was observed in the control (T1). PSB seed treatment and drenching at 20 and 40 DAS improved phosphorus availability in the soil. This promoted better root growth and stronger nodulation in soybean. As a result, the plants absorbed nutrients more efficiently during critical growth stages. Improved nutrient uptake supported better vegetative growth and more dry matter accumulation. This also helped in pod formation, seed filling and ultimately higher yield. Similar results were reported by Swain *et al.* (2025) [13] in soybean that the combined application of 40 kg P₂O₅ ha⁻¹ + 20 kg S ha⁻¹ + PSB (4.0 kg ha⁻¹) recorded the highest seed yield (8.50 q ha⁻¹). Amanullah *et al.* (2025) [2] reported that PSB inoculation significantly improved soybean grain yield to 3,051 kg ha⁻¹. Similar observations were reported by Massucato *et al.* (2025) [8], Rathia *et al.* (2025) [9], Akhila *et al.* (2025) [1], in soybean. Sushmita *et al.* (2025) [12] in black gram.

Straw yield (q ha⁻¹)

Application of 100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS (T7) i.e. (23.23 q ha⁻¹) resulted the highest straw biomass. This was followed by T5 (22.83 q ha⁻¹) and T8 (22.63 q ha⁻¹). In contrast the control (T1) i.e. 19.55 q ha⁻¹. Improved phosphorus availability supported root proliferation, nodulation, and greater uptake of nutrients needed for photosynthesis and biomass formation. This led to increased leaf area development, higher chlorophyll activity, and better assimilate production. The additional assimilates were efficiently partitioned into stems and leaves, resulting in greater dry matter accumulation and higher straw biomass. A similar trend was observed by Akhila *et al.* (2025) [1] in soybean that the seed inoculation with *Bacillus subtilis* recorded the highest straw yield (4,381 kg ha⁻¹). Waghmode *et al.* (2024) [14] reported that

seed inoculation with *Aspergillus awamori* @ 10 ml kg⁻¹ seed along with 75 kg P₂O₅ ha⁻¹ resulted in the highest straw yield (1952.8 kg ha⁻¹).

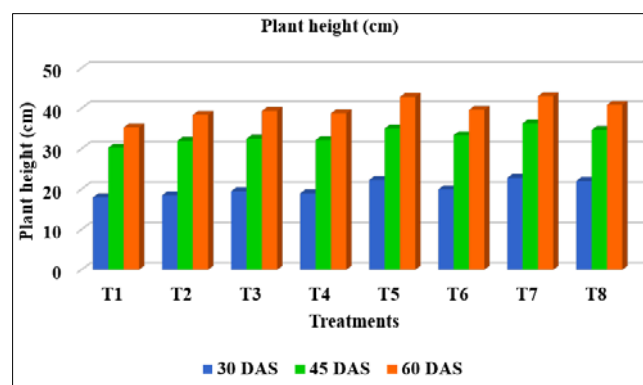


Fig 1: Effect of PSB on plant height (cm) of soybean at 30, 45, 60 DAS.

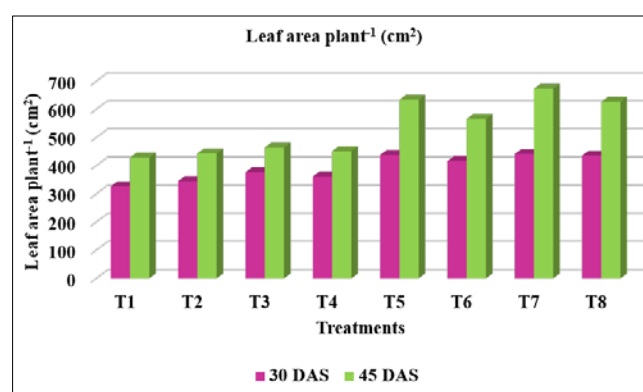


Fig 2: Effect of PSB on leaf area plant⁻¹ (cm²) of soybean at 30 and 45 DAS

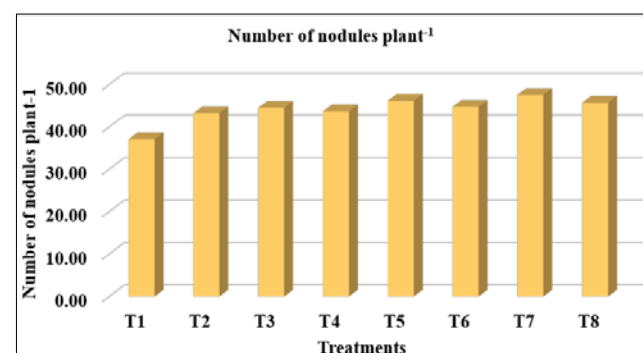


Fig 3: Effect of PSB on nodulation of soybean at flowering stage

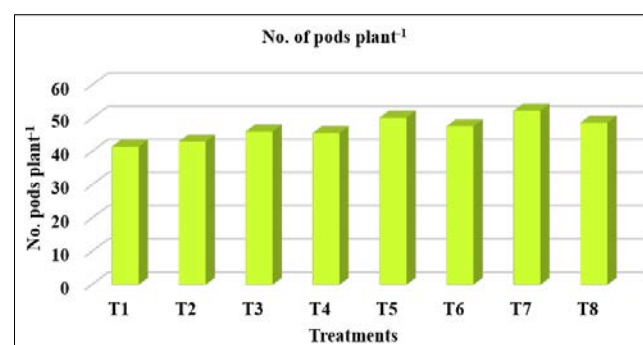


Fig 4: Effect of PSB on number of pods plant⁻¹ of soybean at harvest

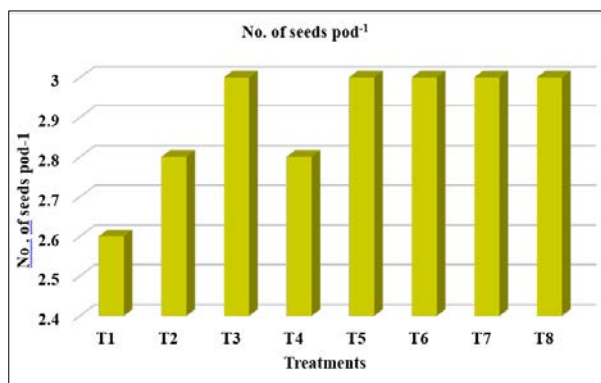


Fig 5: Effect of PSB on number of seeds pod⁻¹ of soybean at harvest.

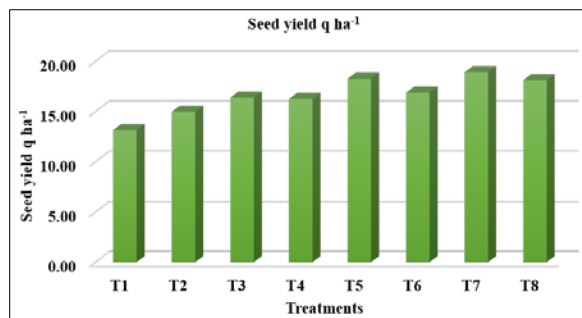


Fig 6: Effect of PSB on seed yield of soybean crop

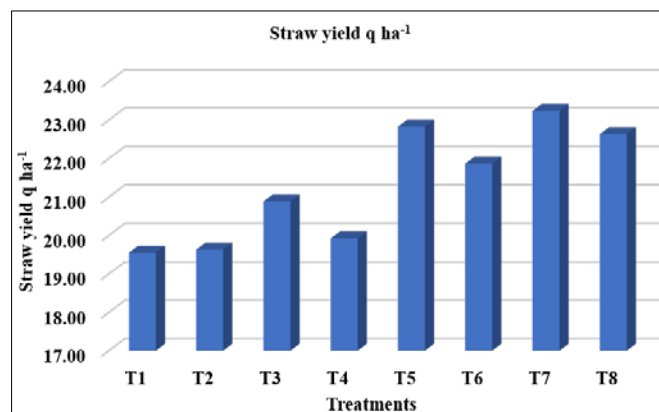


Fig 7: Effect of PSB on straw yield of soybean crop

Conclusion

The application of 100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS treatment showed significantly highest growth and yield parameters viz. plant height (22.76 cm, 36.33 cm, 43.1 cm at 30, 45 and 60 DAS), leaf area (441.23 cm², 673.6 cm² at 30 and 45 DAS), number of nodules plant⁻¹(47.50), number of pods plant⁻¹ (52.30), number of seeds pod⁻¹ (3), seed yield (18.90 q ha⁻¹), and straw yield (23.23 q ha⁻¹) concluded superior over rest of treatments

Table 1: Mean of growth and yield parameters of soybean as influenced by various treatments

Treatments	Plant height (cm)			Leaf area (cm ²)		No. of nodules plant ⁻¹	No. of pods plant ⁻¹	No. of seeds pod ⁻¹	Seed yield (q ha ⁻¹)	Straw yield (q ha ⁻¹)
	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS					
T1 - Control	17.97	30.27	35.32	326.2	428.5	37.07	41.47	2.8	13.13	19.55
T2 - RDF	18.47	31.93	38.40	345.05	443.4	43.2	43.00	2.8	14.97	19.63
T3 - 100% RDNKS + 75% RDP + PSB seed treatment.	19.47	32.46	39.37	375.81	464.13	44.46	46.60	2.8	16.36	20.89
T4 - 100% RDNKS + 50% RDP + PSB seed treatment.	18.96	32.13	38.79	361.28	451.53	43.64	45.53	2.8	16.23	19.92
T5 - 100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 DAS.	22.25	35.07	42.93	438.03	633.89	46.13	50.17	3.0	18.25	22.83
T6 - 100% RDNKS + 50% RDP + PSB seed treatment + Drenching of PSB at 20 DAS.	19.93	33.37	39.63	416.1	566.12	44.73	47.60	2.8	16.87	21.86
T7 - 100% RDNKS + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS.	22.76	36.33	43.1	441.23	673.6	47.50	52.30	3.0	18.90	23.23
T8 - 100% RDNKS + 50% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS.	21.99	34.70	40.87	435.26	626.67	45.68	48.70	3.0	18.11	22.63
SE ±	0.5	0.55	0.95	5.87	20.20	1.52	1.41	0.01	0.76	0.42
CD @ 5%	1.53	1.66	2.88	17.81	61.26	4.60	4.28	NS	2.31	1.27

*DAS- days after sowing

Acknowledgement

We are grateful to College of Agriculture Latur, VNMKV, and Parbhani for the financial assistance and infrastructural facilities provided for the conduct of this research work

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