

## ORIGINAL ARTICLE

# Phosphorus Management through Phosphate-Solubilizing Bacteria for Improved Growth, Yield, Nutrient Uptake and Economic Returns of Summer Green Gram

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### ABSTRACT

Green gram (*Vigna radiata* L. Wilczek) is an important pulse crop valued for its high protein content, short growth duration, and ability to improve soil fertility through biological nitrogen fixation. However, its productivity is often constrained by inadequate phosphorus availability and poor phosphorus use efficiency in soils. A field experiment was conducted during the summer season to evaluate the effect of different phosphorus levels and phosphate-solubilizing bacteria (PSB) on the growth, yield, quality, nutrient uptake, and economics of green gram. The experiment comprised nine treatment combinations of phosphorus levels (0, 40, 60, and 80 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>) with and without PSB inoculation, laid out in a Randomized Block Design with three replications. The results revealed that the combined application of 80 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + PSB (T<sub>9</sub>) significantly enhanced plant height, nodulation, dry matter accumulation, yield attributes, grain yield, straw yield, biological yield, protein content, and nitrogen and phosphorus uptake compared with the control. The treatment also recorded the highest economic returns, with a gross return of ₹70,860 ha<sup>-1</sup>, net return of ₹47,200 ha<sup>-1</sup>, and a benefit-cost ratio of 2.99, indicating its economic superiority. Overall, the integrated application of phosphorus and PSB proved more effective than the sole application of phosphorus in improving crop productivity, nutrient uptake, grain quality, and profitability. Therefore, the application of 80 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> along with PSB inoculation can be recommended as an efficient nutrient management strategy for enhancing the productivity and economic returns of summer green gram under similar agro-climatic conditions.

**Key words:** Phosphorus, Phosphate-solubilizing bacteria (PSB), Nutrient uptake, Yield.

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### INTRODUCTION

Green gram (*Vigna radiata* L. Wilczek) is an important pulse crop belonging to the family Fabaceae and is widely cultivated in tropical and subtropical regions. Due to its short growth duration, drought tolerance, and adaptability to diverse cropping systems, it is grown during the *Kharif*, *Rabi*, and summer seasons in India and other Asian countries [11]. The crop is highly valued for its nutritional quality, containing 22–24% protein along with essential minerals and vitamins, making it an important source of dietary protein [2]. India is the largest producer and consumer of green gram; however, its average productivity (500–800 kg ha<sup>-1</sup>) remains much lower than its potential because of poor soil fertility, imbalanced nutrient management, and low nutrient use efficiency [2, 3, 14, 15].

Phosphorus is an essential nutrient involved in energy transfer, photosynthesis, root development, nodulation, and biological nitrogen fixation in legumes. However, its availability is often limited because a large proportion becomes fixed in insoluble forms in the soil, reducing phosphorus use efficiency [20, 1]. Phosphate-solubilizing bacteria (PSB) enhance phosphorus availability by converting insoluble phosphorus into plant-available forms through the production of organic acids and other biochemical mechanisms [16, 4, 5].

Several studies have reported that the combined application of phosphorus and PSB improves plant growth, nodulation, yield attributes, nutrient uptake, seed quality, and economic returns in green gram compared with the application of phosphorus alone [18, 19, 8]. However, information on the optimum phosphorus level in combination with PSB under summer conditions is still limited. Therefore, the present study was undertaken to evaluate the effect of different phosphorus levels and PSB on the growth, yield, quality, nutrient uptake, and economics of summer green gram.

## MATERIAL AND METHODS

A field experiment was conducted during the summer season of 2025 at the Agricultural Research Farm, G.D. Goenka University, Gurugram, Haryana, India (28.31° N, 76.99° E; 228 m above mean sea level) to evaluate the response of different phosphorus levels and phosphate-solubilizing bacteria (PSB) on summer green gram (*Vigna radiata* L.). The experimental site has a semi-arid subtropical climate. The soil was sandy loam in texture, slightly alkaline in reaction, low in available nitrogen, medium in available phosphorus, and adequate in available potassium. The experiment was laid out in a Randomized Block Design (RBD) with three replications, comprising four phosphorus levels (20, 40, 60, and 80 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>) with and without PSB inoculation, along with an untreated control. Phosphorus was applied through single super phosphate (SSP), while seeds of green gram variety MH 421 were inoculated with PSB (25 g kg<sup>-1</sup> seed) according to the treatment before sowing in 28<sup>th</sup> March 2025 at a spacing of 30 × 10 cm. Recommended agronomic practices, including irrigation, manual weeding, and plant protection measures, were followed throughout the crop growth period. Five randomly selected plants from each plot were used to record plant height, primary and secondary branches, nodules per plant, and dry matter accumulation at 30 DAS, 60 DAS, and harvest. Yield attributes, including pods per plant, grains per pod, and 1000-seed weight, were recorded at harvest. Grain yield, straw yield, biological yield, protein content, nitrogen and phosphorus uptake, and economic parameters were determined using standard procedures. The experimental data were analyzed using analysis of variance (ANOVA) for a Randomized Block Design with AgriAnalysis statistical software, and treatment means were compared using the Critical Difference (CD) test at the 5% level of significance.

## RESULT AND DISCUSSION

### Growth parameters

The application of phosphorus and phosphate-solubilizing bacteria (PSB) significantly influenced the growth of summer green gram (Table 1). The highest plant height at 30 DAS, 60 DAS, and harvest was recorded with 80 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + PSB (T<sub>9</sub>), which remained statistically at par with 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + PSB (T<sub>8</sub>), whereas the lowest plant height was observed in the control (T<sub>1</sub>). The improvement in plant height may be attributed to enhanced phosphorus availability, better root development, and increased nutrient uptake. Similar findings were reported by Meena et al. [10] and Kumar and Yadav [6]. The number of primary and secondary branches was not significantly influenced by the treatments; however, the highest values at all growth stages were consistently recorded under T<sub>9</sub>, while the lowest values were observed in the control. The increased branching under integrated phosphorus and PSB application may be due to improved nutrient availability and enhanced vegetative growth. Similar observations were reported by Patel et al. [13] and Sharma et al. [17].

The number of nodules per plant was significantly increased by phosphorus and PSB application. Treatment T<sub>9</sub> produced the highest number of nodules and remained statistically at par with 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + PSB (T<sub>7</sub>), while the control recorded the lowest nodulation. Enhanced nodulation could be attributed to improved phosphorus availability, better root growth, and increased biological nitrogen fixation. These findings are in agreement with Meena and Gupta [10] and Kumar et al. [7]. Dry matter accumulation was also significantly influenced by the treatments. The maximum dry weight at all growth stages was recorded under T<sub>9</sub>, whereas the minimum was observed in the control. The higher dry matter production under integrated phosphorus and PSB application may be due to improved nutrient uptake, photosynthetic efficiency, and biomass accumulation. Similar results were reported by Patel et al. [12] and Yadav and Singh [22].

Table 1: Effect of PSB and variable Phosphorus fertilizer dose on growth parameters of summer green gram

| Treatments     | Plant Height (cm) |        |            | No. of primary branches /plant |        |            | No. of secondary branches / plant |        |            | No. of nodules /plant |        | Dry matter accumulation (g/m <sup>2</sup> ) |        |        |            |
|----------------|-------------------|--------|------------|--------------------------------|--------|------------|-----------------------------------|--------|------------|-----------------------|--------|---------------------------------------------|--------|--------|------------|
|                | 30 DAS            | 60 DAS | At harvest | 30 DAS                         | 60 DAS | At harvest | 30 DAS                            | 60 DAS | At harvest | 40 DAS                | 60 DAS | 20 DAS                                      | 40 DAS | 60 DAS | At Harvest |
| T <sub>1</sub> | 19.5              | 27.2   | 32.4       | 3.65                           | 6.88   | 8.42       | 4.50                              | 5.76   | 6.47       | 11.2                  | 40.1   | 0.95                                        | 2.5    | 3.2    | 6.2        |
| T <sub>2</sub> | 24.1              | 34.2   | 38.6       | 3.66                           | 6.91   | 8.44       | 4.51                              | 5.78   | 6.48       | 13.5                  | 41     | 1.2                                         | 3.4    | 4.5    | 7.8        |
| T <sub>3</sub> | 28.5              | 39.1   | 41.2       | 3.67                           | 6.94   | 8.46       | 4.52                              | 5.80   | 6.49       | 15.2                  | 41.5   | 1.4                                         | 4.1    | 5.3    | 8.5        |
| T <sub>4</sub> | 30.4              | 42.3   | 45.8       | 3.69                           | 7.00   | 8.50       | 4.54                              | 5.84   | 6.51       | 16.4                  | 42.2   | 1.6                                         | 4.8    | 6.2    | 9.2        |
| T <sub>5</sub> | 33.6              | 44.8   | 47.6       | 3.70                           | 7.03   | 8.52       | 4.55                              | 5.86   | 6.52       | 17                    | 43.1   | 1.7                                         | 5.2    | 6.8    | 9          |
| T <sub>6</sub> | 27.8              | 40.5   | 43.2       | 3.68                           | 6.97   | 8.48       | 4.53                              | 5.82   | 6.50       | 15.8                  | 43.8   | 1.3                                         | 4.7    | 6      | 8.6        |
| T <sub>7</sub> | 32.1              | 43.7   | 46.9       | 3.71                           | 7.06   | 8.54       | 4.56                              | 5.88   | 6.53       | 16.9                  | 45.2   | 1.5                                         | 5.1    | 6.7    | 9.8        |
| T <sub>8</sub> | 35.9              | 46.2   | 49.3       | 3.72                           | 7.09   | 8.56       | 4.57                              | 5.90   | 6.54       | 17.6                  | 46.4   | 1.7                                         | 5.8    | 7.4    | 10.2       |
| T <sub>9</sub> | 38.4              | 48.7   | 52.1       | 3.73                           | 7.12   | 8.58       | 4.58                              | 5.92   | 6.55       | 18.3                  | 47.2   | 1.85                                        | 6.9    | 7.9    | 10.5       |
| S.Ed (±)       | 0.78              | 0.92   | 1.05       | 0.14                           | 0.07   | 0.06       | 0.03                              | 0.06   | 0.03       | 0.55                  | 0.95   | 0.1                                         | 0.35   | 0.55   | 0.75       |
| C.D. (P=0.05)  | 2.34              | 2.75   | 3.12       | NS                             | NS     | NS         | NS                                | NS     | NS         | 1.65                  | 2.85   | 0.3                                         | 1.05   | 1.65   | 2.25       |

#### Yield attributes and yield

The application of different phosphorus levels in combination with phosphate-solubilizing bacteria (PSB) significantly improved the yield attributes and yield of summer green gram (Table 2). The highest number of pods per plant was recorded under the application of 80 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + PSB (T<sub>9</sub>), which remained statistically at par with 80 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> (T<sub>5</sub>), while the maximum number of seeds per pod was also obtained under T<sub>9</sub> and was statistically at par with 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> (T<sub>4</sub>). Similarly, the highest test weight was recorded under T<sub>9</sub>, remaining statistically at par with T<sub>5</sub>, whereas the control treatment (T<sub>1</sub>) consistently recorded the lowest values for all yield attributes. The improvement in yield attributes may be attributed to enhanced phosphorus availability, improved nutrient uptake, better flowering, efficient translocation of photosynthates, and improved grain filling due to the synergistic effect of phosphorus and PSB.

Table 2: Effect of PSB and variable Phosphorus fertilizer dose on yield attributes and yields of summer green gram

| Treatment      | Number of pods/plants | Number of pods/plants | Test weight (g) | Grain yield (kg ha <sup>-1</sup> ) | Straw yield (kg ha <sup>-1</sup> ) | Biological Yield (kg ha <sup>-1</sup> ) |
|----------------|-----------------------|-----------------------|-----------------|------------------------------------|------------------------------------|-----------------------------------------|
| T <sub>1</sub> | 27.0                  | 6.0                   | 38.5            | 4.59                               | 9.79                               | 14.38                                   |
| T <sub>2</sub> | 30.5                  | 6.6                   | 40.2            | 5.69                               | 16.10                              | 21.79                                   |
| T <sub>3</sub> | 33.0                  | 7.2                   | 41.0            | 6.70                               | 17.65                              | 24.35                                   |
| T <sub>4</sub> | 36.8                  | 7.9                   | 41.5            | 7.98                               | 19.82                              | 27.80                                   |
| T <sub>5</sub> | 38.5                  | 8.1                   | 42.0            | 8.85                               | 21.05                              | 29.90                                   |
| T <sub>6</sub> | 36.5                  | 7.0                   | 41.3            | 6.89                               | 17.87                              | 24.76                                   |
| T <sub>7</sub> | 38.9                  | 8.2                   | 42.4            | 9.88                               | 21.43                              | 31.31                                   |
| T <sub>8</sub> | 41.2                  | 8.6                   | 43.2            | 10.95                              | 21.75                              | 32.70                                   |
| T <sub>9</sub> | 43.5                  | 8.9                   | 43.8            | 11.81                              | 22.57                              | 34.38                                   |
| S.Ed(±)        | 1.8                   | 0.4                   | 0.6             | 0.017                              | 0.416                              | 0.417                                   |
| C.D.(P=0.05)   | 5.4                   | 1.2                   | 1.8             | 0.051                              | 1.258                              | 1.26                                    |

Grain yield, straw yield, and biological yield were also significantly influenced by the treatments. The highest grain yield was recorded under T<sub>9</sub>, which remained statistically at par with 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + PSB (T<sub>8</sub>), while straw yield under T<sub>9</sub> was statistically at par with 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + PSB (T<sub>7</sub>). The maximum biological yield was also obtained under T<sub>9</sub>, whereas the control recorded the lowest values for all yield parameters. The increased yield under integrated phosphorus and PSB application could be attributed to enhanced root development, improved phosphorus solubilization, greater nutrient use efficiency, increased biomass production, and efficient partitioning of assimilates towards reproductive organs. These findings are in close agreement with those of Meena *et al.* [9], Jat *et al.* [4], Kumar *et al.* [7], who

also reported that integrated application of phosphorus and PSB significantly enhanced yield attributes and productivity of green gram and other pulse crops.

### Economics

The economic analysis revealed that the cost of cultivation, gross return, net return and benefit–cost ratio varied with phosphorus levels and PSB inoculation (Table 3). The cost of cultivation increased progressively from ₹18,610 ha<sup>-1</sup> in the control (T<sub>1</sub>) to ₹23,660 ha<sup>-1</sup> in T<sub>9</sub> (80 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + PSB), mainly due to the increased quantity of phosphorus fertilizer and additional cost of PSB inoculation. Gross return also increased with increasing phosphorus levels and PSB application, ranging from ₹27,540 ha<sup>-1</sup> in T<sub>1</sub> to ₹70,860 ha<sup>-1</sup> in T<sub>9</sub>. The higher gross return under T<sub>9</sub> may be attributed to improved nutrient availability, crop growth and productivity resulting from the combined application of phosphorus and PSB.

Table 3: Effect of PSB and variable Phosphorus fertilizer dose on economics of summer green gram

| Treatments     | Cost of cultivation<br>(₹ ha <sup>-1</sup> ) | Gross Returns<br>(₹ ha <sup>-1</sup> ) | Net Returns<br>(₹ ha <sup>-1</sup> ) | B:C<br>(₹ ha <sup>-1</sup> ) |
|----------------|----------------------------------------------|----------------------------------------|--------------------------------------|------------------------------|
| T <sub>1</sub> | 18610                                        | 27540                                  | 8930                                 | 1.48                         |
| T <sub>2</sub> | 19810                                        | 34134                                  | 14324                                | 1.72                         |
| T <sub>3</sub> | 21010                                        | 40200                                  | 19190                                | 1.91                         |
| T <sub>4</sub> | 22210                                        | 47880                                  | 25670                                | 2.16                         |
| T <sub>5</sub> | 23410                                        | 53100                                  | 29690                                | 2.27                         |
| T <sub>6</sub> | 20060                                        | 41340                                  | 21280                                | 2.06                         |
| T <sub>7</sub> | 21260                                        | 59280                                  | 38020                                | 2.79                         |
| T <sub>8</sub> | 22460                                        | 65700                                  | 43240                                | 2.93                         |
| T <sub>9</sub> | 23660                                        | 70860                                  | 47200                                | 2.99                         |

Similarly, net return increased from ₹8,930 ha<sup>-1</sup> in T<sub>1</sub> to ₹47,200 ha<sup>-1</sup> in T<sub>9</sub>. The highest net return in T<sub>9</sub> indicates that the additional cultivation cost was compensated by the substantial increase in crop returns. The benefit–cost ratio followed a similar trend, increasing from 1.48 in T<sub>1</sub> to 2.99 in T<sub>9</sub>. Among all treatments, T<sub>9</sub> (80 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + PSB) recorded the highest gross return (₹70,860 ha<sup>-1</sup>), net return (₹47,200 ha<sup>-1</sup>) and benefit–cost ratio (2.99), although it also had the highest cost of cultivation (₹23,660 ha<sup>-1</sup>). The next best economic performance was observed in T<sub>8</sub> (60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + PSB), with a gross return of ₹65,700 ha<sup>-1</sup>, net return of ₹43,240 ha<sup>-1</sup> and B ratio of 2.93. Overall, the application of 80 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> along with PSB (T<sub>9</sub>) proved to be the most economically efficient treatment.

### CONCLUSION

The present study demonstrated that the combined application of phosphorus and phosphate-solubilizing bacteria (PSB) significantly improved the growth, yield, and quality of summer green gram. Among the treatments, the application of 80 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + PSB (T<sub>9</sub>) proved to be the most effective, recording superior plant growth, nodulation, dry matter accumulation, yield attributes, grain and straw yield, protein content, and nitrogen and phosphorus uptake compared with the other treatments. The integrated application of phosphorus and PSB enhanced phosphorus availability and nutrient uptake, resulting in improved crop productivity. Therefore, under the agro-climatic conditions of the study, application of 80 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> along with PSB inoculation is recommended as an effective and economically viable phosphorus management strategy for achieving higher productivity and profitability in summer green gram. Further multi-location and multi-season studies may be undertaken to validate this recommendation under different soil and climatic conditions.

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