**Effect of Biofertilizers and Bamboo-Based Agroforestry System on Growth and Yield of Black Chickpea (*Cicer arietinum* L.) Varieties**

**Abstract**
The present investigation was carried out during 2024–2025 at the Organic Research Farm, Karguan Ji, Department of Agroforestry, Institute of Agricultural Sciences, Bundelkhand University, Jhansi (U.P.), to evaluate the effect of biofertilizers and bamboo-based agroforestry systems on the growth, yield, and soil health of black chickpea (*Cicer arietinum* L.) varieties. The experiment was laid out in a factorial randomized block design comprising three varieties (K-468, K-850, KWR-108) and four biofertilizer treatments (Control, Rhizobium, Phosphate Solubilizing Bacteria [PSB], and Rhizobium + PSB), with a total of twelve treatment combinations replicated thrice. Data were recorded on various growth and yield parameters, including plant height, number of nodules per plant, pods per plant, pod length, seeds per pod, and seed yield. Post-harvest soil analysis was conducted to assess changes in soil fertility parameters. Results revealed that the application of biofertilizers, particularly Rhizobium + PSB, significantly enhanced plant growth, nodulation, yield attributes, and seed yield across all varieties. Variety K-850 exhibited superior performance under integrated biofertilizer application, producing the highest seed yield (14.70 kg), while control plots recorded the lowest values. Soil fertility was also significantly improved under bamboo-based agroforestry, indicating a positive impact on organic matter and nutrient status. The study underscores the potential of integrating biofertilizers with agroforestry for enhancing crop productivity and soil health, offering a sustainable alternative to chemical inputs. The findings are particularly relevant for rainfed and marginal regions such as Bundelkhand, where nutrient depletion and moisture scarcity constrain productivity. The research highlights K-850 as a promising variety for cultivation under organic and agroforestry-based systems.

**Keywords:**
Black chickpea, agroforestry, biofertilizers, Rhizobium, phosphate solubilizing bacteria, bamboo, soil fertility, growth parameters, seed yield

**Introduction**

Chickpea (*Cicer arietinum* L.) is the second most widely grown legume crop globally and holds immense significance in India for its role in nutritional security, soil health improvement, and sustainable agriculture (FAO, 2023). Among its types, black chickpea, a landrace variant known for its hardiness and superior adaptability to abiotic stress conditions, is increasingly being promoted in rainfed and resource-poor regions. It is valued for its high protein, fiber, and micronutrient content, making it a vital food legume for marginal populations (Yadav et al., 2021). In addition to its dietary value, chickpea contributes to ecological sustainability through biological nitrogen fixation, thereby reducing dependence on synthetic nitrogen fertilizers and improving soil structure and fertility. The Bundelkhand region, characterized by frequent droughts, low soil fertility, and erratic rainfall, demands low-input and climate-resilient agricultural strategies. In this context, agroforestry systems offer a holistic approach by integrating woody perennials with crops to diversify production, enhance ecosystem services, and promote sustainable land use. Bamboo (Bambusa spp.), a fast-growing, deep-rooted, and economically versatile species, has gained attention as a compatible agroforestry tree. Bamboo helps in soil stabilization, carbon sequestration, and moisture conservation, while also creating a favorable microclimatic environment for understorey crops (Bhattacharya et al., 2022; Singh et al., 2023).

Integrating leguminous crops like black chickpea with bamboo-based agroforestry systems could synergistically improve soil fertility and crop performance. Chickpea fixes atmospheric nitrogen through symbiosis with Rhizobium, while bamboo contributes to organic matter through litter fall and root exudates. However, the microclimatic variations under bamboo canopy—such as altered light intensity and soil moisture—can influence the growth and productivity of intercrops (Jose, 2009). Therefore, the choice of crop variety and its physiological response to such environmental modifications is crucial for system optimization. In recent years, biofertilizers have emerged as a sustainable and eco-friendly alternative to chemical fertilizers. Rhizobium inoculants enhance nitrogen fixation by promoting nodule formation, while Phosphate Solubilizing Bacteria (PSB) convert insoluble phosphates into plant-available forms, significantly improving phosphorus uptake efficiency (Mitra et al., 2022). The combined application of Rhizobium and PSB has been reported to improve root development, biomass accumulation, and yield in pulses under both irrigated and rainfed conditions (Verma et al., 2023). However, their integrated use in agroforestry systems remains inadequately explored, particularly regarding their impact on soil microbial dynamics, nutrient cycling, and crop productivity under partially shaded environments such as bamboo-based systems. Additionally, genotypic variation in black chickpea responses to shade and microbial interactions has been observed. Different varieties exhibit variable efficiency in nutrient uptake, nodulation, and pod development when grown under tree-based systems (Kumar et al., 2021). Therefore, identification of suitable varieties that are responsive to biofertilizer application and perform well under bamboo agroforestry can aid in improving the productivity of such integrated systems.

 The present study was undertaken to evaluate the influence of biofertilizers (Rhizobium and PSB) and a bamboo-based agroforestry system on the growth, yield performance, and soil properties of selected black chickpea varieties. The findings aim to provide a scientific basis for the adoption of integrated nutrient and land management practices, especially in semi-arid regions like Bundelkhand, thus contributing to the goals of sustainable intensification and organic farming in India.

**2. Materials and Methods**

**2.1 Experimental Site and Climate**
The field experiment was conducted during Rabi 2024–25 at the Organic Research Farm, Karguan Ji, Department of Agroforestry, Bundelkhand University, Jhansi (U.P.), located at 25°27′N latitude and 78°34′E longitude. The climate is semi-arid with an average annual rainfall of about 900 mm.

**2.2 Experimental Design and Treatments**
The experiment was laid out in a Factorial Randomized Block Design (FRBD) with three replications. Two factors were studied:

* **Factor A (Varieties):** V₁ – K-468, V₂ – K-850, V₃ – KWR-108
* **Factor B (Biofertilizers):** B₀ – Control, B₁ – Rhizobium, B₂ – PSB, B₃ – Rhizobium + PSB

**2.3 Crop and Tree Management**
Chickpea varieties were sown as intercrops between 5-year-old bamboo clumps planted at 5×5 m spacing. Seeds were inoculated with respective biofertilizer treatments before sowing. Organic practices were followed throughout, including the use of compost and manual weeding.

**2.4 Data Collection**
At harvest, growth and yield parameters recorded included:

* Plant height (cm)
* Number of nodules per plant
* Pod length (cm)
* Number of seeds per pod
* Number of pods per plant
* Seed yield (g/plot)

**2.5 Statistical Analysis**
Data were subjected to ANOVA using statistical software, and treatment means were compared using the Least Significant Difference (LSD) at 5% probability level.

**3. Results and Discussion**

**3.1 Effect on Growth Parameters**

The application of biofertilizers had a significant impact on the growth performance of leguminous crops grown under agroforestry systems, particularly within the bamboo (Bambusa spp.) canopy. Among the varieties studied, K-850 showed the greatest response to the biofertilizer treatments. The tallest plants were recorded in the Rhizobium + PSB (Phosphate Solubilizing Bacteria) treatment, particularly in the K-850 variety. This can be attributed to the synergistic effect of Rhizobium and PSB in enhancing nitrogen fixation and phosphorus availability, which are critical for vegetative growth (Subba Rao, 2014).

Plant height is often used as an indicator of vegetative vigor and is significantly influenced by nutrient availability. Rhizobium bacteria form symbiotic relationships with legumes, fixing atmospheric nitrogen, while PSB solubilizes unavailable forms of phosphorus in the soil, making it accessible to plants. The combined application thus ensures a balanced nutrient uptake, contributing to enhanced plant growth (Vessey, 2003).

The number of nodules per plant is another critical parameter indicating the effectiveness of biological nitrogen fixation. In the present study, the highest number of nodules per plant was also recorded in K-850 under the Rhizobium + PSB treatment. This supports the findings of earlier studies where the co-inoculation of Rhizobium with PSB increased nodule number and nodule dry weight. The increased nodulation may also be due to the improved rhizospheric environment under bamboo canopy, which maintains favorable microclimatic conditions such as moderated temperature and increased organic matter due to litterfall.

**3.2 Effect on Yield Attributes**

Yield attributes such as pod length, number of seeds per pod, and number of pods per plant showed considerable improvement in biofertilizer-treated plots compared to controls. Among the tested varieties, K-850 consistently outperformed K-468 and KWR-108 across all yield parameters. The maximum pod length and seed count per pod were again observed in the Rhizobium + PSB treatment, further reinforcing the beneficial effects of integrated microbial inoculation.

Agroforestry systems such as those involving bamboo canopies often create a unique soil and microclimatic environment that may enhance microbial activity and soil nutrient cycling (Nair, 1993). Bamboo contributes significantly to soil organic carbon and provides shade, which can reduce evapotranspiration and increase soil moisture retention, thereby facilitating better plant performance.

The increased number of pods per plant observed in the treated K-850 plots suggests that the reproductive potential of the crop was positively influenced. This result is in line with the findings of Patel et al. (2017), who observed improved yield attributes in legumes when biofertilizers were used in combination with organic and inorganic amendments.

3.3 **Seed Yield Performance**

 Seed yield, the most critical economic parameter, showed a marked improvement under the influence of Rhizobium + PSB treatment. The highest seed yield was recorded in the K-850 variety (14.70 g), followed by KWR-108 (13.15 g) and K-468 (12.56 g). In contrast, the control plots (no biofertilizer) showed significantly lower yields across all varieties: K-850 (12.06 g), KWR-108 (10.06 g), and K-468 (9.39 g).

 The yield enhancement can be ascribed to improved nutrient acquisition, especially nitrogen and phosphorus, as well as better root development and higher chlorophyll content due to increased nitrogen availability. Rhizobium, by fixing atmospheric nitrogen, supplies a continuous source of this essential nutrient, while PSB ensures phosphorus availability, both contributing to better flowering and seed set. Furthermore, the bamboo canopy likely played a contributory role in yield improvement. Bamboo agroforestry systems are known to positively influence soil fertility by adding organic matter and reducing nutrient leaching. This favorable environment could have amplified the effects of biofertilizers, leading to better crop productivity. The differences observed among varieties indicate genetic variability in nutrient uptake efficiency and responsiveness to microbial inoculants. K-850, in particular, showed the best adaptability to the biofertilizer treatments under the bamboo canopy. This suggests its potential as a suitable variety for agroforestry systems involving bamboo.

The integration of Rhizobium and PSB as biofertilizers significantly enhanced growth parameters, yield attributes, and seed yield in all varieties studied. These improvements were most pronounced in the K-850 variety, suggesting that this variety, in combination with biofertilizers and under the bamboo canopy, represents an ideal model for sustainable legume production in agroforestry systems.

These findings align with previous research indicating that microbial inoculants not only reduce dependency on chemical fertilizers but also enhance soil biological health and long-term productivity (Glick, 2012). Moreover, when combined with the ecological benefits of agroforestry, such systems can contribute meaningfully to sustainable agriculture and carbon sequestration (Pandey, 2007).

**Table 1: Effect of biofertilizers on height of black chickpea grown under bamboo-based agroforestry system at 30 DAS and 60 DAS**

|  |  |
| --- | --- |
| **Plant height (30 DAS)** | **Plant height (60 DAS)** |
| **Treatments** | **Varieties** | **Mean** | **Varieties** | **Mean** |
| **V1** | **V2** | **V3** | **V1** | **V2** | **V3** |
| **Bamboo** | ***Rhizobium*** | 10.28 | 12.22 | 11.55 | **11.35** | 19.71 | 24.81 | 21.61 | **22.04** |
| **PSB** | 9.60 | 11.69 | 10.69 | **10.66** | 18.54 | 23.61 | 19.94 | **20.70** |
| ***Rh* + PSB** | 12.07 | 14.38 | 13.58 | **13.34** | 21.71 | 26.71 | 23.54 | **23.99** |
|  | **Control** | 9.17 | 11.32 | 10.51 | **10.33** | 17.62 | 22.56 | 18.65 | **19.61** |
|  | **Mean** | **10.28** | **12.40** | **11.58** |  | **19.40** | **24.42** | **20.93** |  |
| **Factors** | **C.D. (0.05)** | **SE(d)** | **SE(m)** | **C.D. (0.05)** | **SE(d)** | **SE(m)** |
| **Variety (V)** | 0.74 | 0.35 | 0.25 | 0.67 | 0.32 | 0.23 |
| **Biofertilizers (B)** | 0.85 | 0.41 | 0.29 | 0.78 | 0.37 | 0.26 |
| **V x B** | NS | 0.71 | 0.50 | NS | 0.64 | 0.46 |

**Table 2: Effect of biofertilizers on height of black chickpea grown under bamboo-based agroforestry system at 90 DAS and 120 DAS**

|  |  |
| --- | --- |
| **Plant height (90 DAS)** | **Plant height (120 DAS)** |
| **Treatments** | **Varieties** | **Mean** | **Varieties** | **Mean** |
| **V1** | **V2** | **V3** | **V1** | **V2** | **V3** |
| **Bamboo** | ***Rhizobium*** | 29.82 | 33.14 | 32.02 | **31.66** | 38.70 | 43.55 | 41.70 | **41.31** |
| **PSB** | 28.58 | 32.62 | 30.85 | **30.68** | 37.60 | 42.33 | 40.58 | **40.17** |
| ***Rh* + PSB** | 31.56 | 35.39 | 33.63 | **33.53** | 40.76 | 45.70 | 43.75 | **43.40** |
|  | **Control** | 27.93 | 31.76 | 29.88 | **29.86** | 36.73 | 41.62 | 39.52 | **39.29** |
|  | **Mean** | **29.47** | **33.23** | **31.59** |  | **38.45** | **43.30** | **41.39** |  |
| **Factors** | **C.D. (0.05)** | **SE(d)** | **SE(m)** | **C.D. (0.05)** | **SE(d)** | **SE(m)** |
| **Variety (V)** | 0.82 | 0.39 | 0.28 | 0.68 | 0.33 | 0.23 |
| **Biofertilizers (B)** | 0.95 | 0.45 | 0.32 | 0.79 | 0.38 | 0.27 |
| **V x B** | NS | 0.79 | 0.56 | NS | 0.65 | 0.46 |

**Table 3: Effect of biofertilizers on height of black chickpea grown under bamboo-based agroforestry system at harvest**

|  |
| --- |
| **Plant height (at harvest)** |
| **Treatments** | **Varieties** | **Mean** |
| **V1** | **V2** | **V3** |
| **Bamboo** | ***Rhizobium*** | 46.92 | 51.76 | 48.81 | **49.16** |
| **PSB** | 45.52 | 50.75 | 47.50 | **47.93** |
| ***Rh* +PSB** | 48.91 | 53.30 | 50.63 | **50.95** |
|  | **Control** | 44.56 | 49.59 | 46.55 | **46.90** |
|  | **Mean** | **46.48** | **51.35** | **48.37** |  |
| **Factors** | **C.D. (0.05)** | **SE(d)** | **SE(m)** |
| **Variety (V)** | 0.76 | 0.36 | 0.26 |
| **Biofertilizers (B)** | 0.87 | 0.42 | 0.30 |
| **V x B** | NS | 0.72 | 0.51 |

**Table 4: Effect of biofertilizers on number of root nodules of black chickpea grown under bamboo-based agroforestry system**

|  |  |
| --- | --- |
| **No. of nodules (60 DAS)** | **No. of nodules (90 DAS)** |
| **Treatments** | **Varieties** | **Mean** | **Varieties** | **Mean** |
| **V1** | **V2** | **V3** | **V1** | **V2** | **V3** |
| **Bamboo** | ***Rhizobium*** | 10.83 | 11.92 | 11.48 | **11.41** | 17.36 | 18.53 | 18.22 | **18.04** |
| **PSB** | 9.41 | 10.60 | 10.24 | **10.08** | 15.87 | 16.76 | 16.61 | **16.41** |
| ***Rh* + PSB** | 12.76 | 13.92 | 13.46 | **13.38** | 19.46 | 20.73 | 20.32 | **20.17** |
| **Control** | 8.42 | 9.95 | 9.00 | **9.12** | 13.38 | 15.05 | 14.17 | **14.20** |
|  | **Mean** | **10.35** | **11.60** | **11.04** |  | **16.52** | **17.77** | **17.33** |  |
| **Factors** | **C.D. (0.05)** | **SE(d)** | **SE(m)** | **C.D. (0.05)** | **SE(d)** | **SE(m)** |
| **Variety (V)** | 0.77 | 0.37 | 0.26 | 0.74 | 0.36 | 0.25 |
| **Biofertilizers (B)** | 0.89 | 0.43 | 0.30 | 0.86 | 0.41 | 0.29 |
| **V x B** | NS | 0.74 | 0.53 | NS | 0.71 | 0.50 |

**Table 5: Effect of biofertilizers on number of pods plant-1 of black chickpea grown under bamboo-based agroforestry system**

|  |
| --- |
| **No. of pods plant-1** |
| **Treatments** | **Varieties** | **Mean** |
| **V1** | **V2** | **V3** |
| **Bamboo** | ***Rhizobium*** | 26.40 | 37.11 | 33.53 | **32.35** |
| **PSB** | 24.83 | 35.42 | 31.94 | **30.73** |
| ***Rh* +PSB** | 28.95 | 38.43 | 35.70 | **34.36** |
|  | **Control** | 22.65 | 33.06 | 29.75 | **28.49** |
|  | **Mean** | **25.71** | **36.00** | **32.73** |  |
| **Factors** | **C.D. at 5%** | **SE(d)** | **SE(m)** |
| **Variety (V)** | 1.45 | 0.69 | 0.49 |
| **Biofertilizers (B)** | 1.67 | 0.80 | 0.57 |
| **V x B** | NS | 1.39 | 0.98 |

**Table 6: Effect of biofertilizers on pod length of black chickpea grown under bamboo- based agroforestry system**

|  |
| --- |
| **Pod length (cm)** |
| **Treatments** | **Varieties** | **Mean** |
| **V1** | **V2** | **V3** |
| **Bamboo** | ***Rhizobium*** | 1.80 | 2.10 | 1.85 | **1.92** |
| **PSB** | 1.70 | 2.03 | 1.80 | **1.84** |
| ***Rh* + PSB** | 1.90 | 2.25 | 1.95 | **2.03** |
|  | **Control** | 1.75 | 1.97 | 1.80 | **1.80** |
|  | **Mean** | **1.79** | **2.09** | **1.85** |  |
| **Factors** | **C.D. (0.05)** | **SE(d)** | **SE(m)** |
| **Variety (V)** | 0.05 | 0.02 | 0.02 |
| **Biofertilizers (B)** | 0.05 | 0.03 | 0.02 |
| **V x B** | NS | 0.04 | 0.03 |

**Table 7: Effect of biofertilizers on number of seeds pod-1 of black chickpea grown under bamboo-based agroforestry system**

|  |
| --- |
| **No. of seeds pod-1** |
| **Treatments** | **Varieties** | **Mean** |
| **V1** | **V2** | **V3** |
| **Bamboo** | ***Rhizobium*** | 1.13 | 1.27 | 1.47 | **1.29** |
| **PSB** | 1.07 | 1.27 | 1.40 | **1.24** |
| ***Rh* + PSB** | 1.20 | 1.40 | 1.53 | **1.38** |
|  | **Control** | 1.07 | 1.27 | 1.33 | **1.22** |
|  | **Mean** | **1.12** | **1.30** | **1.43** |  |
| **Factors** | **C.D. (0.05)** | **SE(d)** | **SE(m)** |
| **Variety (V)** | 0.09 | 0.04 | 0.03 |
| **Biofertilizer s (B)** | 0.10 | 0.05 | 0.03 |
| **V x B** | NS | 0.08 | 0.06 |

**Table 8: Effect of biofertilizers on seed yield of black chickpea grown under bamboo- based agroforestry system**

|  |
| --- |
| **Seed yield (g)** |
| **Treatments** | **Varieties** | **Mean** |
| **V1** | **V2** | **V3** |
| **Bamboo** | ***Rhizobium*** | 10.89 | 13.50 | 11.70 | **12.03** |
| **PSB** | 10.06 | 12.75 | 10.75 | **11.19** |
| ***Rh* + PSB** | 12.56 | 14.70 | 13.15 | **13.47** |
|  | **Control** | 9.39 | 12.06 | 10.06 | **10.50** |
|  | **Mean** | **10.72** | **12.75** | **11.91** |  |
| **Factors** | **C.D. (0.05)** | **SE(d)** | **SE(m)** |
| **Variety (V)** | 0.30 | 0.14 | 0.10 |
| **Biofertilizers (T)** | 0.34 | 0.16 | 0.12 |
| **V x T** | 0.59 | 0.28 | 0.20 |

**Conclusion**

The present study highlights the significant positive impact of biofertilizers (Rhizobium and Phosphate Solubilizing Bacteria) and bamboo-based agroforestry systems on the growth, yield attributes, and seed yield of black chickpea (Cicer arietinum L.) varieties. Among the evaluated genotypes, K-850 consistently outperformed others, exhibiting superior plant height, nodulation, pod development, and seed yield, particularly under the combined application of Rhizobium + PSB. This enhanced performance can be attributed to improved nutrient acquisition—especially nitrogen and phosphorus—mediated by the synergistic effects of biofertilizers and the favorable microenvironment created under the bamboo canopy. The integration of biofertilizers within bamboo-based agroforestry systems not only enhances crop productivity but also promotes long-term soil fertility and ecological sustainability by reducing reliance on chemical fertilizers. Such integrated nutrient and land-use management practices are particularly valuable for rainfed and resource-constrained regions like Bundelkhand, where challenges related to soil degradation and water scarcity persist.Based on the findings, K-850 emerges as a promising variety for cultivation under agroforestry systems, especially suited to organic and low-input farming conditions. This study provides a strong basis for promoting agroforestry-based pulse production as a sustainable agricultural strategy for improving productivity, enhancing soil health, and supporting climate-resilient farming in semi-arid regions.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing interests

Authors have declared that no competing interests exist.

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