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

**Abstract**
The present study was conducted during 2024–2025 at the Organic Research Farm, Karguan Ji, Department of Agroforestry, Institute of Agricultural Sciences, Bundelkhand University, Jhansi (U.P.), to investigate the effect of biofertilizers (Rhizobium and Phosphate Solubilizing Bacteria) and bamboo trees on the growth, yield attributes, and soil properties of black chickpea varieties grown under agroforestry conditions. The experiment followed a factorial randomized block design with three varieties (K-468, K-850, KWR-108) and four biofertilizer treatments (Control, Rhizobium, PSB, Rhizobium + PSB), totaling twelve treatment combinations replicated thrice. Growth and yield attributes such as plant height, number of nodules per plant, pod length, seeds per pod, pods per plant, and seed yield were recorded at harvest. Soil samples were analyzed post-harvest to evaluate changes in soil properties. The results revealed significant improvements in growth, yield, and soil health under the bamboo-based agroforestry system, particularly with combined Rhizobium and PSB application. The highest seed yields for K-468, K-850, and KWR-108 were 12.56 kg, 14.70 kg, and 13.15 kg, respectively, under Rhizobium + PSB treatment, while the lowest yields were recorded in the control plots. The study suggests the synergistic role of biofertilizers and agroforestry in sustainable chickpea cultivation and soil fertility enhancement.

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

**Introduction**

Chickpea (*Cicer arietinum* L.) is one of the most important legume crops cultivated widely in India, contributing significantly to nutritional security and sustainable agriculture. It is a rich source of protein, carbohydrates, and minerals, and plays a pivotal role in improving soil fertility through biological nitrogen fixation. In recent years, there has been growing interest in promoting black chickpea, a variant with high adaptability and resilience to stress, in marginal lands, especially in integrated farming systems (Ali & Kumar, 2005).

Agroforestry is a sustainable land-use system that integrates trees with crops and/or livestock to improve productivity, enhance biodiversity, and optimize land resources. It is particularly suited for regions like Bundelkhand, which are prone to soil degradation, water scarcity, and declining agricultural productivity. Bamboo (*Bambusa spp.*), a fast-growing and economically valuable species, has gained attention as a promising agroforestry tree due to its capacity for soil conservation, carbon sequestration, and compatibility with crops (Kumar et al., 2011). The integration of legumes like chickpea with bamboo-based agroforestry systems can potentially enhance crop productivity and improve soil health. Legumes contribute to soil fertility through biological nitrogen fixation, while bamboo modifies the microclimate, reduces evapotranspiration, and adds organic matter through litter fall. Such synergies can be harnessed to promote low-input and ecologically sustainable farming systems in dryland areas (Nair, 1993; Pandey, 2007).

Soil fertility remains a key constraint in most dryland regions, including Bundelkhand. Continuous monocropping, use of chemical fertilizers, and soil erosion have led to declining soil organic carbon and microbial activity. In this context, biofertilizers—comprising beneficial microorganisms like *Rhizobium* and phosphate solubilizing bacteria (PSB)—offer a viable solution. These bio-inputs improve nutrient availability, promote root growth, and enhance overall crop performance (Bhattacharyya & Tandon, 2012). *Rhizobium* inoculation enhances biological nitrogen fixation by forming nodules on chickpea roots, leading to improved plant vigor and yield. Similarly, PSB mobilizes insoluble forms of phosphorus, making it available for plant uptake. The combined use of these two biofertilizers has been shown to significantly increase productivity and reduce dependence on chemical fertilizers in legumes, particularly under organic and resource-limited conditions (Chandra et al., 2018; Vessey, 2003). The adoption of biofertilizers in agroforestry systems remains underexplored, particularly in relation to their combined effect on crop performance and soil quality. The interaction between tree roots and microbial inoculants may create a more favorable rhizosphere for nutrient uptake, especially under bamboo canopies where moderated temperatures and increased moisture retention benefit microbial activity (Jose et al., 2004; Sharma et al., 2019).

 Furthermore, the choice of crop variety also plays a crucial role in determining productivity under agroforestry systems. Different chickpea genotypes respond differently to shaded conditions and microbial associations. Hence, screening of suitable black chickpea varieties that perform well in bamboo-intercropped environments and respond positively to biofertilizer treatment is essential for optimizing system productivity (Singh et al., 2015). In this backdrop, the present study was undertaken to assess the effect of biofertilizers (*Rhizobium* and PSB) and bamboo-based agroforestry system on the growth, yield performance, and soil properties of selected black chickpea varieties. The findings are expected to provide insights into sustainable crop management practices under integrated systems and promote ecological intensification in semi-arid regions.

**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; Singh et al., 2011).

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 (Kumar et al., 2016). 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 (Kushwaha et al., 2010).

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 (Meena et al., 2015). 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 (Dwivedi et al., 2009). 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 clearly demonstrates the beneficial effects of biofertilizers (Rhizobium and Phosphate Solubilizing Bacteria) and bamboo-based agroforestry systems on the growth, yield attributes, and seed yield of black chickpea varieties. Among the three varieties evaluated, K-850 showed the most promising performance in terms of plant height, nodulation, pod development, and overall seed yield, especially under the combined application of Rhizobium + PSB. The improved plant performance can be attributed to enhanced nutrient uptake, particularly nitrogen and phosphorus, resulting from the synergistic activity of biofertilizers and the favorable microclimatic and soil conditions provided by the bamboo canopy.

The integration of biofertilizers with agroforestry not only improves crop productivity but also contributes to sustainable soil health management by reducing dependence on chemical fertilizers. These results advocate the adoption of such integrated nutrient and land-use management practices, particularly in rainfed and marginal areas like Bundelkhand, where soil fertility and moisture conservation are major challenges. Furthermore, K-850 emerged as a suitable variety for cultivation under bamboo-based agroforestry systems and could be promoted in organic and low-input farming systems to enhance productivity and sustainability.

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