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Rupak Kumar
Department of Soil Science and
Agricultural Chemistry, Chandra Shekhar
Azad University of Agriculture and
Technology, Kanpur, Uttar Pradesh, India

Sarvesh Kumar
Department of Soil Science and
Agricultural Chemistry, Chandra Shekhar
Azad University of Agriculture and
Technology, Kanpur, Uttar Pradesh, India

Ragini Verma
Department of Soil Science and
Agricultural Chemistry, Chandra Shekhar
Azad University of Agriculture and
Technology, Kanpur, Uttar Pradesh, India

Nidhi Mahendru
Assistant Professor & Head, Guru Nanak
Khalsa College, Yamuna Nagar, Haryana,
India

Utkal Yadav
Research Scholar, Department of
Silviculture and Agroforestry, Acharya
Narendra Deva University of Agriculture
and Technology, Kumarganj, Ayodhya,
Uttar Pradesh, India

Ashutosh Yadav
Department of Soil Science and
Agricultural Chemistry, Chandra Shekhar
Azad University of Agriculture and
Technology, Kanpur, Uttar Pradesh, India

Anas Siddiqui
Department of Soil Science and
Agricultural Chemistry, Chandra Shekhar
Azad University of Agriculture and
Technology, Kanpur, Uttar Pradesh, India

Amreen Siddiqui
Department of Soil Science and
Agricultural Chemistry, Chandra Shekhar
Azad University of Agriculture and
Technology, Kanpur, Uttar Pradesh, India

Corresponding Author:
Sarvesh Kumar
Department of Soil Science and
Agricultural Chemistry, Chandra
Shekhar Azad University of
Agriculture and Technology,
Kanpur, Uttar Pradesh, India

Synergistic Effects of Phosphorus Solubilising Bacteria on Biological Properties & Growth attributes of Chickpea in Central Plain Zone of Uttar Pradesh

**Rupak Kumar, Sarvesh Kumar, Ragini Verma, Nidhi Mahendru, Utkal
Yadav, Ashutosh Yadav, Anas Siddiqui and Amreen Siddiqui**

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Abstract

A field experiment was conducted during 2024 and 2025 at the Student Instructional Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, to evaluate the effect of phosphorus-solubilizing bacteria (PSB), farmyard manure (FYM), and boron on the growth and biological properties of chickpea (*Cicer arietinum* L.) under the Central Plain Zone of Uttar Pradesh. The experiment was laid out in a Randomized Block Design (RBD) with three replications. Treatments consisted of different combinations of recommended fertilizer dose (RDF), FYM (2 and 4 t ha⁻¹), PSB inoculation (20 g kg⁻¹ seed), and boron (1 and 2 kg ha⁻¹). Growth parameters, including plant height and plant population, along with soil biological properties such as bacterial, fungal, and actinomycetes populations, were recorded and analyzed. The results revealed that the integrated application of RDF, FYM, PSB, and boron significantly improved plant growth and soil microbial activity. The highest plant height was recorded under treatment T₁₈ (100% RDF + 2 kg ha⁻¹ B + 4 t ha⁻¹ FYM @ + PSB @ 20 g kg⁻¹ seed), with a pooled mean of 45.50 cm, followed closely by T₁₇ and T₁₂. Plant population was not significantly influenced by the treatments, although the maximum pooled population (25.84 plants m⁻²) was observed under T₁₈. Soil biological properties responded positively to integrated nutrient management. Treatment T₁₈ recorded the highest bacterial population (23.87 × 10⁵ CFU g⁻¹ soil), fungal population (1.29 × 10⁴ CFU g⁻¹ soil), and actinomycetes population (17.86 × 10⁶ CFU g⁻¹ soil), while the lowest values were observed in the control treatment. The combined use of FYM and PSB enhanced microbial proliferation by improving soil organic carbon availability and phosphorus solubilization, whereas boron further supported plant growth and nutrient utilization. The study demonstrated that the integrated application of 100% RDF along with 4 t ha⁻¹ FYM, PSB inoculation, and 2 kg ha⁻¹ boron is an effective and sustainable nutrient management strategy for improving chickpea growth and soil biological health in the Central Plain Zone of Uttar Pradesh.

Keywords: Chickpea, Phosphorus Solubilizing Bacteria, Farmyard Manure, Boron, Soil Microbial Population, Integrated Nutrient Management, Growth Attributes

Introduction

Chickpea (*Cicer arietinum* L.) is one of the most important pulse crops cultivated in India and serves as a major source of dietary protein, carbohydrates, minerals, and vitamins for a large vegetarian population. India accounts for nearly 70–75% of the global chickpea production, and the crop occupies a significant area in the Central Plain Zone of Uttar Pradesh, where it contributes substantially to food security, nutritional security, and soil fertility improvement through biological nitrogen fixation. However, the productivity of chickpea in this region remains below its potential due to several constraints, among which phosphorus (P) deficiency is one of the most critical factors affecting growth and yield. Phosphorus is an essential macronutrient involved in energy transfer, root development, nodulation, biological nitrogen fixation, flowering, and seed formation. Despite adequate total phosphorus content in many soils, a major proportion remains in insoluble and unavailable forms, limiting its uptake by plants (Sharma *et al.*, 2023; Meena *et al.*, 2024) [5, 4]. The alluvial soils of the Central Plain Zone of Uttar Pradesh are often characterized by low available phosphorus, declining organic matter content, and reduced microbial activity due to continuous cultivation and imbalanced fertilizer use. Under such conditions, the application of large quantities of chemical phosphorus fertilizers is not only costly but also inefficient because a

substantial fraction becomes fixed in the soil shortly after application. Therefore, sustainable nutrient management strategies that enhance phosphorus availability and improve soil biological health are increasingly being emphasized (Singh *et al.*, 2023; Kumar *et al.*, 2024) ^[6, 1]. Phosphorus Solubilizing Bacteria (PSB) have emerged as an effective biofertilizer technology for improving phosphorus nutrition in crops. These beneficial microorganisms convert insoluble phosphates present in soil into plant-available forms through the secretion of organic acids, enzymes, and chelating compounds. The increased availability of phosphorus enhances root growth, nodulation, nutrient uptake, photosynthetic efficiency, and ultimately crop productivity. In chickpea, PSB inoculation has been reported to improve seed germination, plant height, root biomass, nodulation, dry matter accumulation, and grain yield while reducing dependence on chemical phosphorus fertilizers (Yadav *et al.*, 2023) ^[8]. Farmyard manure (FYM) is another important component of integrated nutrient management systems. FYM supplies essential macro- and micronutrients, improves soil structure, increases water-holding capacity, and stimulates beneficial microbial populations. The decomposition of FYM releases organic acids that aid in the solubilization of native and applied phosphorus. Furthermore, FYM provides a favorable environment and energy source for microbial growth, thereby enhancing the survival and activity of phosphate-solubilizing bacteria in the rhizosphere (Verma *et al.*, 2023; Chaudhary *et al.*, 2024) ^[7, 2]. The combined application of FYM and PSB has been found to exert synergistic effects on nutrient availability, microbial activity, and soil biological properties. Soil biological properties such as microbial population density are widely recognized as sensitive indicators of soil health. Enhanced microbial activity accelerates nutrient cycling, organic matter decomposition, and phosphorus mineralization, thereby improving soil fertility and crop performance. Recent studies have demonstrated that the integrated use of FYM and PSB significantly increases microbial biomass and enzyme activities, leading to improved nutrient-use efficiency and sustainable crop production (Bhardwaj *et al.*, 2024) ^[1]. In the context of the Central Plain Zone of Uttar Pradesh, where soil fertility degradation and rising fertilizer costs pose major challenges, the integration of FYM and PSB offers a sustainable and eco-friendly approach for enhancing chickpea productivity. This strategy not only improves phosphorus availability and biological soil health but also reduces the dependence on chemical fertilizers.

2. Material and Methods:

2.1 Geographical situation of the experimental site

The field experiment was carried out on Student Instructional Farm of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh. Geographically, the experimental site is situated at 26.45° N latitude and 80.33° E longitude, with an elevation of approximately 125.9 m above mean sea level. The region falls under the Central Plain Zone of Uttar Pradesh and experiences a subtropical semi-arid climate, characterized by hot summers, cool winters, and a distinct monsoon season. The mean annual rainfall of the area ranges between 800 and 900 mm, of which nearly 80–85% is received during the southwest monsoon period.

2.2 Experiment Detail

Soil samples were collected from the 0–15 cm depth at both the beginning of the experiment and after crop harvest to assess soil properties. After collection, the samples were air-dried and stored in polythene bags. Soil clods were carefully crushed using a wooden roller on a wooden surface, and the soil was then sieved through a 2 mm mesh before analysis. The Chickpea variety KPG-59 (UDAY) was used as the test crop. The experiment was

laid out with a spacing of 40cm × 10 cm, and fertilizers were applied at the recommended rate of 20:40:20 kg ha⁻¹ of N, P₂O₅, and K₂O. The experiment was carried out in a randomized block design (RBD) with replicated thrice T₁: Control, T₂: 100% RDF + 2 t ha⁻¹ FYM, T₃: 100% RDF + 4 t ha⁻¹ FYM, T₄: 100% RDF + PSB @ 20 gkg⁻¹, T₅: 100% RDF + 2 t ha⁻¹ FYM + PSB @ 20 gkg⁻¹, T₆: 100% RDF + 4 t ha⁻¹ FYM + PSB @ 20 gkg⁻¹, T₇: 100% RDF + 1 kgha⁻¹ B, T₈: 100% RDF + 1 kg ha⁻¹ B + 2 t ha⁻¹ FYM, T₉: 100% RDF + 1 kgha⁻¹ B + 4 t ha⁻¹ FYM, T₁₀: 100% RDF + 1 kgha⁻¹ B + PSB @ 20 gkg⁻¹, T₁₁: 100% RDF + 1 kgha⁻¹ B + 2 t ha⁻¹ FYM + PSB @ 20 gkg⁻¹, T₁₂: 100% RDF + 1 kgha⁻¹ B + 4 t ha⁻¹ FYM + PSB @ 20 gkg⁻¹, T₁₃: 100% RDF + 2 kgha⁻¹ B, T₁₄: 100% RDF + 2 kgha⁻¹ B + 2 t ha⁻¹ FYM, T₁₅: 100% RDF + 2 kgha⁻¹ B + 4 t ha⁻¹ FYM, T₁₆: 100% RDF + 2 kgha⁻¹ B + PSB @ 20 gkg⁻¹, T₁₇: 100% RDF + 2 kg ha⁻¹ B + 2 t ha⁻¹ FYM + PSB @ 20 gkg⁻¹, T₁₈: 100% RDF + 2 kgha⁻¹ B + 4 t ha⁻¹ FYM + PSB @ 20 gkg⁻¹. Bacteria, fungi, and actinomycetes were isolated using Plate Count Agar, Czapek–Dox Agar (Thom and Raper, 1945), Kenknight and Munaier's medium, Yeast Extract Mannitol Agar, and Pikovskaya's medium (Rao and Sinha, 1963) respectively. The populations of these microorganisms were estimated in each plot using the serial dilution pour plate technique (Subba Rao, 1982), and the results were expressed as colony-forming units. Standard procedures were followed for measuring Growth and Biological yield. The effects of different experimental treatments were evaluated through one-way analysis of variance (ANOVA). Differences among treatment means were compared using Duncan's test at a significance level of $p \leq 0.05$. All statistical analyses performed in this study followed the standard procedures recommended by IBM Corp. (2020).

Results and Discussion:

After completion of the two-year experiment, soil samples were collected and analyzed for Plant height and Plant population at the 5% level of significance which showed in Table 1. The highest plant height was recorded under treatment T₁₈ (100% RDF + 2 kg ha⁻¹ B + 4 t ha⁻¹ FYM + PSB @ 20 g kg⁻¹ seed), which produced plant heights of 45.48 cm and 45.52 cm during 2024 and 2025, respectively, with a pooled mean of 45.50 cm. This treatment was statistically at par with T₁₇ (100% RDF + 2 kg ha⁻¹ B + 2 t ha⁻¹ FYM + PSB @ 20 g kg⁻¹ seed) and T₁₂ (100% RDF + 1 kg ha⁻¹ B + 4 t ha⁻¹ FYM + PSB @ 20 g kg⁻¹ seed), indicating the beneficial role of integrated nutrient management in promoting vegetative growth. In contrast, the lowest plant height was recorded under the control treatment (T₁), with pooled plant height of 32.16 cm. The beneficial effect of FYM on plant growth has been reported by Marschner (2012) ^[10] and Verma *et al.* (2023) ^[7], who observed improved nutrient uptake and enhanced vegetative growth under organic amendments. Similarly, Sharma *et al.* (2023) ^[5] reported that phosphate-solubilizing bacteria increased phosphorus availability and promoted root and shoot development in pulse crops. The positive influence of boron on growth attributes has also been documented by Gupta (2018) and Patel *et al.* (2024), who observed enhanced plant vigor and stem elongation following boron application. The maximum pooled plant population (25.84 plants m⁻²) was observed under treatment T₁₈ (100% RDF + 2 kg ha⁻¹ B + 4 t ha⁻¹ FYM + PSB @ 20 g kg⁻¹ seed), followed closely by T₁₇ (25.72 plants m⁻²) and T₁₂ (25.36 plants m⁻²). The minimum plant population (21.09 plants m⁻²) was recorded under the control treatment. The non-significant effect of FYM, PSB, and boron on plant population may be attributed to the fact that these inputs mainly influence post-emergence growth, nutrient uptake, physiological processes, and biomass accumulation rather than seed germination and initial plant stand. Similar findings were reported by Meena *et al.* (2022) ^[4], Yadav *et al.* (2023) ^[8], and Kumar *et al.* (2024), who observed

non-significant variations in plant population of chickpea and other pulse crops under different nutrient management treatments.

Table 1: Effects of Phosphorus Solubilising Bacteria on Growth properties.

S. No	Treatment	Plant height (cm)			Plant population		
		2024	2025	Pooled	2024	2025	Pooled
T ₁	(Control)	32.14	32.17	32.16	21.08	21.09	21.09
T ₂	100% RDF + 2 t ha ⁻¹ FYM	38.74	38.77	38.76	22.90	22.92	22.91
T ₃	100% RDF + 4 t ha ⁻¹ FYM	39.32	39.37	39.35	23.13	23.16	23.15
T ₄	100% RDF + PSB @ 20 g kg ⁻¹	37.69	37.72	37.71	22.73	22.76	22.75
T ₅	100% RDF + 2 t ha ⁻¹ FYM + PSB @ 20 g kg ⁻¹	42.89	42.93	42.91	24.72	24.74	24.73
T ₆	100% RDF + 4 t ha ⁻¹ FYM + PSB @ 20 g kg ⁻¹	43.24	43.27	43.26	24.89	24.92	24.91
T ₇	100% RDF + 1 g kg ⁻¹ B	35.56	35.59	35.58	22.12	22.15	22.14
T ₈	100% RDF + 1 g kg ⁻¹ B + 2 t ha ⁻¹ FYM	41.12	41.17	41.15	23.88	23.92	23.90
T ₉	100% RDF + 1 g kg ⁻¹ B + 4 t ha ⁻¹ FYM	41.84	41.89	41.87	24.02	24.06	24.04
T ₁₀	100% RDF + 1 g kg ⁻¹ B + PSB @ 20 g kg ⁻¹	39.86	39.89	39.88	23.42	23.44	23.43
T ₁₁	100% RDF + 1 g kg ⁻¹ B + 2 t ha ⁻¹ FYM + PSB @ 20 g kg ⁻¹	43.88	43.91	43.90	25.10	25.13	25.12
T ₁₂	100% RDF + 1 g kg ⁻¹ B + 4 t ha ⁻¹ FYM + PSB @ 20 g kg ⁻¹	44.12	44.16	44.14	25.35	25.37	25.36
T ₁₃	100% RDF + 2 g kg ⁻¹ B	36.92	36.95	36.94	22.45	22.49	22.47
T ₁₄	100 % RDF + 2 kg ha ⁻¹ B + 2 t ha ⁻¹ FYM	42.01	42.06	42.04	24.22	24.26	24.24
T ₁₅	100% RDF + 2 kg ha ⁻¹ B + 4 t ha ⁻¹ FYM	42.52	42.54	42.53	24.45	24.47	24.46
T ₁₆	100% RDF + 2 kg ha ⁻¹ B + PSB @ 20 g kg ⁻¹	40.78	40.81	40.80	23.69	23.72	23.71
T ₁₇	100 % RDF + 2 kg ha ⁻¹ B + 2 t ha ⁻¹ FYM + PSB @ 20 g kg ⁻¹	44.98	45.06	45.02	25.71	25.73	25.72
T ₁₈	100% RDF + 2 kg ha ⁻¹ B + 4 t ha ⁻¹ FYM + PSB @ 20 g kg ⁻¹	45.48	45.52	45.50	25.82	25.86	25.84
	SEm±	1.45	1.45	1.46	0.85	0.86	0.87
	CD at 5%	4.20	4.19	4.18	NS	NS	NS

The bacterial population ranged from 13.44 to 23.87 × 10⁵ CFU g⁻¹ soil during 2024 and from 13.47 to 23.87 × 10⁵ CFU g⁻¹ soil during 2025 presented in Table 2. Among all treatments, the highest bacterial population was recorded under T₁₈ (100% RDF + 2 kg ha⁻¹ B + 4 t ha⁻¹ FYM + PSB @ 20 g kg⁻¹ seed) with values of 23.87 and 23.87 × 10⁵ CFU g⁻¹ soil during 2024 and 2025, respectively, resulting in a pooled mean of 23.87 × 10⁵ CFU g⁻¹ soil. This treatment remained statistically at par with T₁₇ (23.29 × 10⁵ CFU g⁻¹ soil) and T₁₂ (22.95 × 10⁵ CFU g⁻¹ soil). The lowest bacterial population (13.46 × 10⁵ CFU g⁻¹ soil) was observed under the control treatment (T₁). FYM acts as a carbon source for soil microorganisms and improves soil physical conditions, thereby creating a favorable environment for microbial proliferation (Marschner, 2012; Verma *et al.*, 2023) [10, 7]. Inoculation with PSB further stimulated microbial multiplication through phosphorus solubilization and secretion of growth-promoting metabolites (Sharma *et al.*, 2023) [5]. The maximum fungal population was recorded under T₁₈, which produced pooled fungal counts of 1.29 × 10⁴ CFU g⁻¹ soil,

followed by T₁₇ (1.28 × 10⁴ CFU g⁻¹ soil) and T₁₂ (1.25 × 10⁴ CFU g⁻¹ soil). The minimum fungal population (0.72 × 10⁴ CFU g⁻¹ soil) was observed under the control treatment. The pooled data indicated an increase of approximately 79.2% in fungal population under T₁₈ compared with the control. The present results corroborate the findings of Jat *et al.* (2024) and Chaudhary *et al.*, (2024) [2], who reported higher fungal populations following the integrated application of FYM and biofertilizers. Among the treatments, T₁₈ (100% RDF + 2 kg ha⁻¹ B + 4 t ha⁻¹ FYM + PSB @ 20 g kg⁻¹ seed) recorded the highest actinomycetes population of 17.86 × 10⁶ CFU g⁻¹ soil, which was statistically comparable with T₁₇ (17.55 × 10⁶ CFU g⁻¹ soil) and T₁₂ (16.82 × 10⁶ CFU g⁻¹ soil). The lowest actinomycetes population was observed under the control treatment (10.43 × 10⁶ CFU g⁻¹ soil). FYM supplies sufficient organic substrates that support actinomycetes growth, while PSB contributes to improved phosphorus availability and microbial interactions within the soil ecosystem (Paul, 2015; Sharma *et al.*, 2023) [5].

Table 2: Effects of Phosphorus Solubilising Bacteria on Biological properties.

S. No.	Treatments	Bacteria (10 ⁵ CFU g ⁻¹)			Fungi (10 ⁴ CFU g ⁻¹)			Actinomycetes (10 ⁶ CFU g ⁻¹)		
		2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T ₁	(Control)	13.44	13.47	13.46	0.71	0.73	0.72	10.41	10.44	10.43
T ₂	100% RDF + 2 t ha ⁻¹ FYM	16.12	16.42	16.27	1.06	1.09	1.08	12.19	12.25	12.22
T ₃	100% RDF + 4 t ha ⁻¹ FYM	16.75	16.84	16.8	1.09	1.11	1.1	12.88	12.91	12.9
T ₄	100% RDF + PSB @ 20 g kg ⁻¹	15.74	15.79	15.77	1.01	1.04	1.03	11.89	11.93	11.91
T ₅	100% RDF + 2 t ha ⁻¹ FYM + PSB @ 20 g kg ⁻¹	21.15	21.49	21.32	1.21	1.24	1.23	15.51	15.56	15.54
T ₆	100% RDF + 4 t ha ⁻¹ FYM + PSB @ 20 g kg ⁻¹	21.86	21.94	21.9	1.22	1.25	1.24	15.84	15.86	15.85
T ₇	100% RDF + 1 g kg ⁻¹ B	13.94	13.98	13.96	0.88	0.92	0.9	10.92	10.98	10.95
T ₈	100% RDF + 1 g kg ⁻¹ B + 2 t ha ⁻¹ FYM	18.86	18.88	18.87	1.15	1.19	1.17	13.93	13.95	13.94
T ₉	100% RDF + 1 g kg ⁻¹ B + 4 t ha ⁻¹ FYM	19.3	19.3	19.3	1.16	1.18	1.17	14.11	14.15	14.13
T ₁₀	100% RDF + 1 g kg ⁻¹ B + PSB @ 20 g kg ⁻¹	17.08	17.11	17.1	1.11	1.14	1.13	13.09	13.12	13.11
T ₁₁	100% RDF + 1 g kg ⁻¹ B + 2 t ha ⁻¹ FYM + PSB @ 20 g kg ⁻¹	22.24	22.29	22.27	1.23	1.25	1.24	16.22	16.26	16.24
T ₁₂	100% RDF + 1 g kg ⁻¹ B + 4 t ha ⁻¹ FYM + PSB @ 20 g kg ⁻¹	22.92	22.97	22.95	1.24	1.26	1.25	16.79	16.84	16.82
T ₁₃	100% RDF + 2 g kg ⁻¹ B	14.48	14.51	14.5	0.95	0.98	0.97	11.46	11.49	11.48
T ₁₄	100 % RDF + 2 kg ha ⁻¹ B + 2 t ha ⁻¹ FYM	19.92	19.96	19.94	1.18	1.2	1.19	14.67	14.69	14.68
T ₁₅	100% RDF + 2 kg ha ⁻¹ B + 4 t ha ⁻¹ FYM	20.67	20.69	20.68	1.19	1.21	1.2	15.01	15.07	15.04
T ₁₆	100% RDF + 2 kg ha ⁻¹ B + PSB @ 20 g kg ⁻¹	18.46	18.49	18.48	1.13	1.15	1.14	13.58	13.63	13.61
T ₁₇	100 % RDF + 2 kg ha ⁻¹ B + 2 t ha ⁻¹ FYM + PSB @ 20 g kg ⁻¹	23.28	23.3	23.29	1.26	1.29	1.28	17.54	17.56	17.55
T ₁₈	100% RDF + 2 kg ha ⁻¹ B + 4 t ha ⁻¹ FYM + PSB @ 20 g kg ⁻¹	23.87	23.87	23.87	1.27	1.3	1.29	17.82	17.89	17.86
	SEm±	0.67	0.68	0.65	0.04	0.05	0.06	0.50	0.51	0.50
	CD at 5%	1.94	1.95	1.96	0.11	0.13	0.12	1.45	1.46	1.47

Conclusion

Based on the findings of the two-year field investigation, it can be concluded that integrated nutrient management involving phosphorus-solubilizing bacteria (PSB), farmyard manure (FYM), and boron significantly improved the growth performance and biological properties of soil under chickpea cultivation. Among all the treatments, the application of 100% RDF combined with 4 t ha⁻¹ FYM, PSB inoculation at 20 g kg⁻¹ seed, and 2 kg ha⁻¹ boron (T18) proved to be the most effective treatment.

Treatment T18 recorded the maximum plant height (45.50 cm pooled mean) and significantly enhanced soil microbial populations, including bacteria (23.87×10^5 CFU g⁻¹ soil), fungi (1.29×10^4 CFU g⁻¹ soil), and actinomycetes (17.86×10^6 CFU g⁻¹ soil). The improvement in soil biological activity may be attributed to the synergistic effects of FYM as a source of organic matter, PSB as a phosphorus-solubilizing biofertilizer, and boron as an essential micronutrient involved in physiological and metabolic processes. Although plant population was not significantly affected by the treatments, integrated nutrient application contributed substantially to enhanced vegetative growth and microbial activity.

Therefore, the combined use of 100% RDF + 4 t ha⁻¹ FYM + PSB @ 20 g kg⁻¹ seed + 2 kg ha⁻¹ boron may be recommended as a sustainable and economically viable nutrient management practice for chickpea cultivation in the Central Plain Zone of Uttar Pradesh. This approach not only improves crop growth but also strengthens soil biological health, enhances nutrient-use efficiency, and promotes long-term agricultural sustainability.

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