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Dual Variety-based Evaluation of Soil Biological Resilience and Agronomic Gains under Integrated Nutrient Protocols in Mung Bean

Balveer Singh[1], Rohit Kumar[2], Avdhesh Pratap Singh[3], Kunal[4], Subhash Kumar Jawla[5], Pankaj Kumar[6], Maqsood Ul Hussan[7], Mohamed A. Mattar[8]

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ABSTRACT

Background: A field study was conducted to evaluate integrated nutrient management practices involving organic, inorganic, microbial and nano-fertilizer approaches for improving growth, yield, phosphorus uptake, economics and soil biological properties of mung bean varieties.

Methods: Two mung bean varieties, Pusa-1431 and Virat, were tested under six nutrient management treatments in a factorial randomized block design during the Kharif season. Observations on growth, yield, phosphorus uptake, economics and soil biological activity were analyzed using ANOVA.

Result: Pusa-1431 performed better than Virat in growth, yield, phosphorus uptake and soil biological activity. The treatment comprising 75% NPK + FYM @ 5 t ha^{-1} + NPK consortia + Nano-P spray at 25 DAS produced the highest grain yield (12.4 q ha^{-1}), benefit:cost ratio (2.35), phosphorus uptake and soil microbial activity, indicating that integrated nutrient management enhanced productivity, nutrient-use efficiency and soil health compared to sole chemical fertilization.

Key words: Integrated nutrient management, Microbial consortia, Mung bean, Nano-phosphorus, Phosphorus uptake, Soil biological activity.

INTRODUCTION

Mung bean [*Vigna radiata* (L.) Wilczek] is the paradigm of pulse crop growth, that is, it crops under high special rates of biological nitrogen fixation (Niranjan *et al*., 2023) a condensed growth cycle and rapid biomass growth due to effective photosynthesis. Mung bean is planted on the global level, with an area of approximately 8.5 million ha and yields of 7.2 million tonnes in 2021 (FAO, 2023). However, in most of Africa including parts of Asia, its yield is less than 1.5 t ha $^{-1}$ and the 0.5 t ha $^{-1}$ to 1.5 t ha $^{-1}$ range is always achieved under sub-optimal soil conditions and under minimal management (Maphosa *et al.,* 2022).

Integrated nutrient management (INM) has provided an affordable agronomic solution, it is a synergistic method of utilising both organic and chemical nutrient supplies to achieve maximum crop yields and system sustainability. Empirical studies confirm that farmyard manure (FYM) improves soil structure, increases nutrient bioavailability and promotes carbon sequestration (Krause *et al*., 2024). For example, in key production regions like Ethiopia and the aral sea area applying 5-10 t ha^{-1} FYM alongside inorganic fertilizers increased mung bean yields by 15-25% compared to synthetic fertilizers alone (Shah *et al*., 2024). Modern innovations like nitrogen-fixing and phosphate-solubilizing microbial consortia further optimize nutrient use. Trials show these biofertilizers, when combined with carrier materials like aggregated sand, boost mung bean yields by 9-18% over conventional NPK fertilization. Similarly, nano-phosphorus (nano-P) fertilizers enhance phosphorus uptake efficiency, increasing yields by 12% compared to traditional P sources (Kumar, 2024).

[1]Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur- 208 002, Uttar Pradesh, India.
[2]Faculty of Agricultural Sciences, GLA University, Mathura-281 406, Uttar Pradesh, India.
[3]Department of Agricultural Chemistry and Soil Science, Amar Singh College, CCS University, Lakhaoti, Bulandshahr-203 407, Meerut, Uttar Pradesh, India.
[4]Department of Life Sciences, School of Allied Health Sciences, Shree Guru Gobind Singh Tricentenary University, Budhera, Gurugram-122 505, Haryana, India.
[5]Department of Agricultural Economics and Extension, Lovely Professional University, Phagwara-144 411, Punjab, India.
[6]Department of Entomology, Sardar Vallabh Bhai Patel University of Agriculture and Technology, Meerut-250 110, Uttar Pradesh, India.
[7]Zhejiang Provincial Key Laboratory of Agricultural Microbiomics, Institute of Biotechnology, Zhejiang University, Hangzhou, 310 058, China.
[8]Prince Sultan Bin Abdulaziz International Prize for Water Chair, Prince Sultan Institute for Environmental, Water and Desert Research, King Saud University, P.O. Box 2454, Riyadh 11451, Saudi Arabia.

Corresponding Authors: Rohit Kumar, Mohamed A. Mattar; Faculty of Agricultural Sciences, GLA University, Mathura-281 406, Uttar Pradesh, India; Prince Sultan Bin Abdulaziz International Prize for Water Chair, Prince Sultan Institute for Environmental, Water and Desert Research, King Saud University, P.O. Box 2454, Riyadh 11451, Saudi Arabia.
Email: kumar.rohit@gla.ac.in, mmattar@ksu.edu.sa

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The current field experiment aims at assessing the relative effect of crop-synchronized NPK addition and FYM fertilizing, combined with microbial consortia and nano-P fertilization, versus monolithic NPK fertilization. The hypothesis is that the combined fertilization regimes will overcompensate the single NPK fertilization in aspects of crop growth, the composition of the yield, the acquisition of nutrients and soil biology.

MATERIALS AND METHODS

Experimental site and methodology

The experiment was conducted during the *Kharif* season of 2021-22 at the Crop Research Farm, CSA University of Agriculture and Technology, Kanpur, Uttar Pradesh, located in the Gangetic alluvial plains of central Uttar Pradesh (Fig 1). The soil was Fluvisol with loam texture, pH 7.8 and available N, P and K of 225, 18.2 and 278 kg ha^{-1}, respectively. The study was laid out in a factorial randomized block design (FRBD) with three replications using two mungbean varieties (V_1: Pusa 1431; V_2: Virat) along with six integrated nutrient management treatments: M_1 (100% NPK: 20-40-20 kg ha^{-1}), M_2 (75% NPK + FYM @ 5 t ha^{-1}), M_3 (75% NPK + FYM @ 5 t ha^{-1} + NPK consortia), M_4 (75% NPK + FYM @ 5 t ha^{-1} + nano-phosphorus spray at 25 DAS), M_5 (75% NPK + NPK consortium + Nano-P spray at 25 DAS) and M_6 (75% NPK + FYM @ 5 t ha^{-1} + NPK consortium + Nano-P spray at 25 DAS). The field was prepared by ploughing, harrowing and leveling. Seeds were sown at 30 cm × 10 cm spacing with a seed rate of 20 kg ha^{-1} and fertilizer was applied as per treatment using urea, DAP and MOP. FYM was incorporated 15 days before sowing, while nano-phosphorus (500 ppm, 30 nm) was applied as foliar spray at 25 DAS. Standard agronomic practices were followed throughout the crop period. IFFCO's NPK consortium contains N-fixing, phosphate-solubilizing and potassium-mobilizing bacteria. Nano-phosphorus (30 nm, 500 ppm) provides high-efficiency, bioavailable nutrition for improved crop uptake. NPK consortium and Nano-phosphorus have obtained from the Indian certified company- IFFCO (Indian Farmer Fertilizer Cooperative Limited).

Observations recorded and soil biological analysis

Plant height, dry matter accumulation, yield attributes, grain and biological yields, harvest index, phosphorus content, uptake and benefit:cost ratio were recorded at harvest. Plant height was measured from five randomly selected plants $plot^{-1}$, while grain and biological yields were estimated from the net plot area and expressed in kg ha^{-1}. Phosphorus content (%) in grain and straw was determined using the vanado-molybdo phosphoric yellow color method and total P uptake was calculated accordingly. Soil samples collected before and after harvest from 0-15 cm depth were air-dried, sieved (2 mm) and analyzed for soil biological properties including microbial biomass carbon (MBC) using the fumigation-extraction method described by Vance *et al.* (1987).

Statistical analysis

The recorded data were statistically analyzed using ANOVA in IBM SPSS statistics. Treatment means were compared using the critical difference (CD) test at $p \leq 0.05$ following Gomez and Gomez (1984).

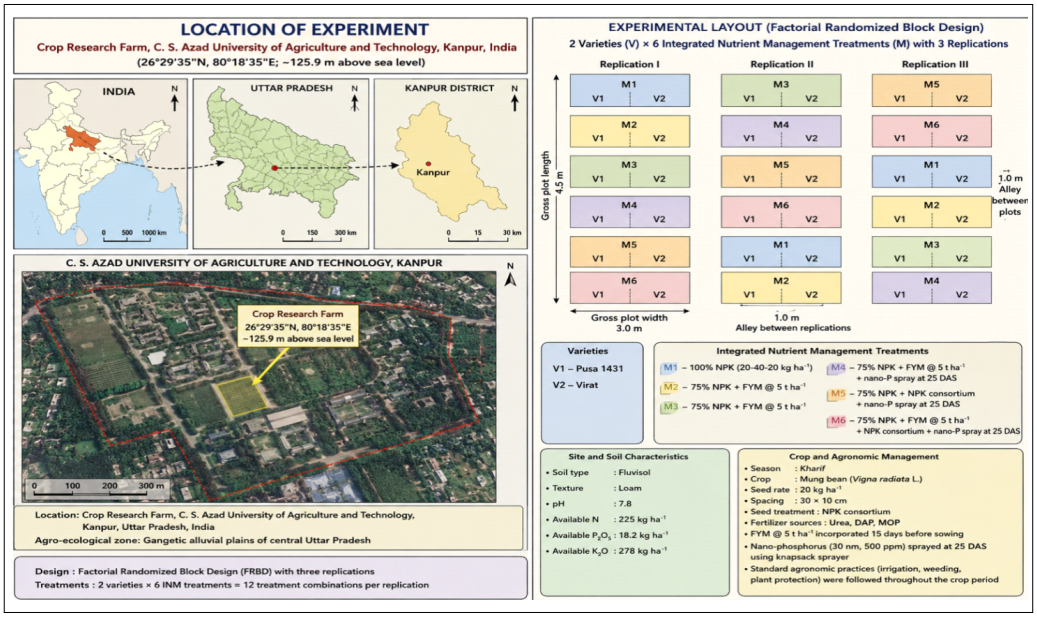


Fig 1: Experimental layout of mung bean varieties under different nutrient management treatments.

RESULTS AND DISCUSSION

Growth parameters

Inter-varietal differences were also significant, with Pusa 1431 (V_2) outperforming virat (V_1) across all growth stages (Table 1). At harvest, Pusa 1431 (V_2) plants were taller, exhibited more branches plant and accumulated higher dry matter (10.6 g plant) compared to virat (V_1). These observations align with reports of substantial genotypic diversity in mungbean regarding growth development and nutrient use efficiency (Hasanain *et al*., 2020). The superior performance of Pusa 1431 (V_2) stems from its inherent genetic vigor, facilitating enhanced nutrient uptake and biomass accumulation (Ali *et al*., 2024 and Arya *et al*., 2024).

The most effective nutrient management treatment was M_6 (75% NPK + FYM @ 5 t ha^{-1} + NPK consortia + Nano-P spray at 25 DAS), which recorded the highest plant height, branches plant^{-1} and dry matter accumulation (11.2 g plant^{-1}) at harvest. This superior performance likely stemmed from the synergy among organic, inorganic (reduced NPK), biofertilizers and nano-fertilizers, which provided sustained nutrient release, improved soil health and enhanced nutrient use efficiency (Cathrine *et al*., 2024). Foliar nano-P application at the critical 25 DAS stage boosted P nutrition, root proliferation, photosynthetic activity and overall vegetative growth (Dhiman *et al*., 2025). Nano-fertilizers' nanoscale particle size and high surface area further facilitate superior nutrient absorption and plant physiological functions (Channab *et al*., 2024).

Yield attributes and yield

Varietal analysis of yield attributes demonstrated that Pusa 1431 (V_2) significantly outperformed virat (V_1) across major yield parameters, reflecting its superior genotypic potential. Pusa 1431 (V_2) recorded higher number of pods plant^{-1} (13.8), pod length (8.2 cm), seeds pod^{-1} (7.1), grain yield (11.0 q ha^{-1}) and straw yield (33.6 q ha^{-1}) as compared to Virat (V_1). However, test weight and harvest index showed only marginal differences between the two varieties. The superior performance of Pusa 1431 (V_2) may be attributed to its better vegetative growth, efficient nutrient utilization, enhanced photosynthetic activity and greater adaptability to prevailing agro-climatic conditions Gogoi *et al.* (2024). Pusa-1431 (V_2) recorded significantly higher grain and straw yield than virat (V_1). Pusa-1431 (V_2) exhibited a grain yield of 11.0 q ha^{-1}, which was 11.8% higher than V_1 (9.7 q ha^{-1}) and a straw yield of 33.6 q ha^{-1}, representing a 12.2% increase over V_1 (29.5 q ha^{-1}). Among the nutrient management treatments, M_1 (75% NPK + FYM @ 5 t ha^{-1} + NPK consortia + Nano-P spray at 25 DAS) produced significantly higher grain yield (12.4 q ha^{-1}) and straw yield (35.7 q ha^{-1}). The treatment recorded 49.4% higher grain yield and 30.8% higher straw yield over M_1 [100% NPK (20 N, 40 P_2O_5, 20 K_2O kg ha^{-1})], which produced grain and straw yields of 8.3 and 27.3 q ha^{-1}, respectively (Fig 2). The superior yield performance of Pusa-1431 (V_2) may be attributed to its better photosynthetic efficiency, enhanced root growth and greater nutrient uptake capacity, which collectively improved vegetative growth and assimilate production. Increased leaf area and better plant vigor under V_2 likely contributed to higher grain and straw yields. The enhanced yield under M_6 (75% NPK + FYM @ 5 t ha^{-1} + NPK consortia + Nano-P spray at 25 DAS) may be due to the integrated effect of inorganic fertilizers, FYM, NPK microbial consortia and Nano-P application. The combined use of nano-

Table 1: Effect of varieties and nutrient management practices on growth parameters of mung bean (Pooled data).

		Plant height (cm)			No of branches plant^{-1}		Dry matter accumulation plant^{-1}	
		25 DAS	40 DAS	At harvest	40 DAS	At harvest	40 DAS	At harvest
A. Varieties								
V_1	Virat	25.9	41.2	51.8	2.81	3.87	6.4	8.6
V_2	PUSA -1431	26.3	43.1	53.7	3.10	4.16	7.4	10.6
	SEm+	0.4	0.6	0.8	0.04	0.061	0.09	0.15
	CD (P=0.05)	NS	1.9	NS	0.13	0.185	0.26	0.44
B. Nutrient management treatments								
M_1	100% NPK (20:40:20 N:P_2O_5:K_2O kg ha^{-1})	25.6	33.7	46.1	2.22	3.31	5.3	7.2
M_2	75% NPK + FYM @ 5 t ha^{-1}	24.1	40.0	50.2	1.75	3.68	6.1	8.6
M_3	75% NPK+ FYM @ 5 t ha^{-11} + NPK consortia	27.1	43.8	53.9	3.12	4.15	7.3	10.2
M_4	75% NPK + FYM @ 5 t ha^{-1} + nano-P spray at 25 DAS	25.9	46.5	55.82	3.32	4.42	7.7	10.9
M_5	75% NPK + NPK consortia + nano-P spray at 25 DAS	26.4	42.6	51.3	3.30	3.97	6.8	9.6
M_6	75% NPK + FYM @ 5 t ha^{-1} + NPK consortia + nano-P spray at 25 DAS	27.2	47.2	59.1	3.60	4.62	8.2	11.2
	SEm±	0.7	1.0	1.3	0.07	0.14	0.15	0.26
	CD (P=0.05)	NS	2.3	4.0	0.22	0.31	0.25	0.77

fertilizers and microbial consortia probably improved nutrient availability, soil microbial biomass, nutrient uptake and root proliferation, thereby enhancing crop growth and productivity. Similar findings were also reported by (Karunakaran *et al*., 2024; Upadhyay *et al*., 2025 and Shiny *et al*., 2025). However, the magnitude of yield improvement was primarily influenced by the nutrient management strategy, particularly the integration of Nano-P and microbial consortia, rather than the varietal effect alone. Similar findings were also reported by Hasanain *et al*. (2020); Kumar *et al*. (2024); Priya and Babu (2021) and Sawarkar *et al*. (2025).

Phosphorus content in grain, straw and total uptake

Phosphorus analysis further confirmed the varietal superiority of Pusa 1431 (V2) over Virat (V1), with V2 recording higher phosphorus concentrations in both grain and straw, indicating better phosphorus uptake and utilization efficiency (Table 2). Specifically, Pusa 1431 (V_2) registered 3.84 kg ha^{-1} by grain and 6.59 kg ha^{-1} by straw, whereas Virat (V_1) recorded 4.56 kg ha^{-1} by grain and 8.13 kg ha^{-1} by straw. This superiority of Pusa 1431 (V_2) may be attributed to its inherent genetic potential for improved phosphorus absorption, root exudation and nutrient-use efficiency, as supported by previous studies on crop nutrient acquisition and soil resource utilization. Among the nutrient management treatments, M6, which integrated FYM, NPK consortia and nano-P spray, recorded the highest phosphorus uptake in both grain and straw. The treatment M_6 produced 0.43% P content by grain and 0.25% content by straw, surpassing M_1, which recorded 0.36 % P content by grain P and 0.25% P content by straw. The enhanced performance of M_6 may be due to the complementary action of organic manure for gradual nutrient release, biofertilizers for nutrient mobilization and nano-P spray for improved solubility, foliar absorption and reduced fixation, thereby increasing phosphorus availability and translocation within the plant (Singh *et al*., 2024, Singh *et al*., 2026 and Balveer *et al*., 2026).

Benefit/cost ratios

Pusa 1431 (V_2) showed better overall performance than virat (V_1) and this superiority was reflected in both productivity and economic return (Table 2). The variety's stronger growth, higher yield and better phosphorus uptake likely contributed to improved profitability under the integrated nutrient treatments. Among nutrient management options, M6 recorded the highest benefit:cost ratio (2.35), followed by M_4 (2.25) and M_3 (2.13). All integrated treatments maintained BCR values above 2.0, confirming that these practices were economically worthwhile despite the added cost of biofertilizers and nano-P. The strong performance of M_6 can be explained by its combined effect of NPK,FYM, NPK consortia and Nano-P, which improved nutrient availability, phosphorus uptake and final yield. This aligns with earlier findings that integrated nutrient management can enhance both crop productivity and farm economics (Kumar *et al*., 2023; Cathrine *et al*., 2024 and Rajitha *et al*., 2024).

Soil biological parameters

The microbial biomass carbon (MBC), dehydrogenase activity (DA) and soil respiration were significantly higher in variety Pusa 1431 (V_2), with values of 213.1 mg ha^{-1}, 2.54 mg TPF g-1 h^{-1} and 33.9 mg CO_2 kg^{-1} day^{-1}, respectively, compared to Virat (V_1), which recorded 198.3 mg kg^{-1}, 2.18 mg TPF g^{-1} h^{-1} and 29.6 mg CO_2 kg^{-1} day^{-1}. This higher soil biological activity under Pusa 1431 (V_2) may be attributed to its superior genetic traits, including a vigorous root system, greater root exudation and improved nutrient mobilization, which support beneficial microbial proliferation and activity. Among the nutrient management treatments, M_6 recorded the highest microbial biomass carbon (230.4 mg kg^{-1}), dehydrogenase activity (2.73 mg TPF g^{-1} h^{-1}) and soil respiration (36.7 mg CO_2 kg^{-1} day^{-1}). This superior performance likely resulted from the combined application of FYM, NPK consortia and Nano-P, which improved soil organic matter, nutrient recycling, enzymatic activity and microbial proliferation (Table 3).

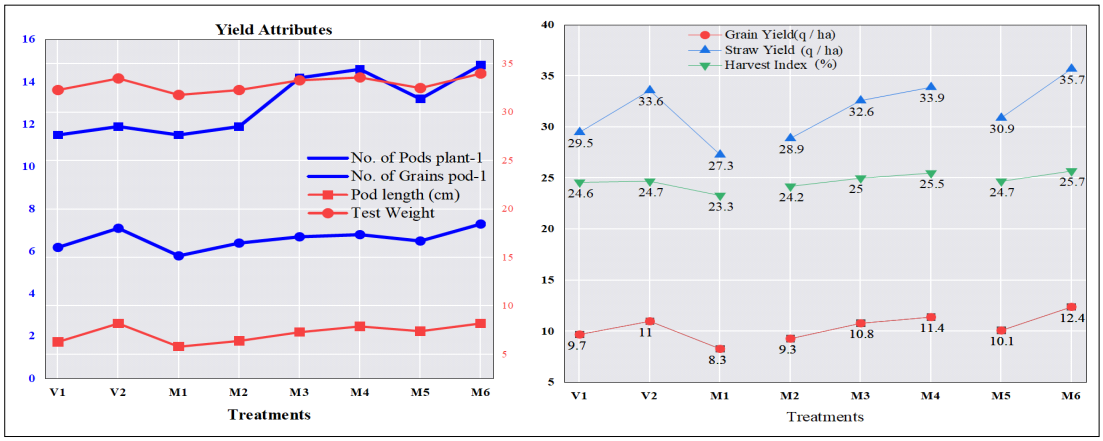


Fig 2: Effect of varieties and nutrient management practices on growth parameters, yield attributes, grain yield, straw yield and harvest index of mung bean (Pooled data).

Table 2: Effect of varieties and nutrient management practices on phosphorus content, uptake and benefit:cost ratio of mung bean (Pooled data).

		P content (%)		P uptake (Kg ha^{-1})		B:C
		Grain	Straw	Grain	Straw	ratio
A. Varieties						
V_1	Virat	0.39	0.24	3.84	6.59	1.95
V_2	PUSA-1431	0.41	0.26	4.56	8.13	2.18
	SEm+	0.003	0.002	0.07	0.23	0.03
	CD (P=0.05)	0.009	0.005	0.20	0.66	0.09
B. Nutrient management treatments						
M_1	100% NPK (20:40:20 N:P_2O_5:K_2O kg ha^{-1})	0.36	0.21	2.96	5.77	1.75
M_2	75% NPK + FYM @ 5 t ha^{-1}	0.38	0.22	3.53	6.28	1.84
M_3	75% NPK+ FYM @ 5 t ha^{-1} + NPK consortia	0.41	0.24	4.47	7.76	2.13
M_4	75% NPK + FYM @ 5 t ha^{-1} + nano-P spray at 25 DAS	0.42	0.25	4.80	8.36	2.25
M_5	75% NPK + NPK consortia + nano-P spray at 25 DAS	0.40	0.23	4.06	7.01	2.07
M_6	75% NPK + FYM @ 5 t ha^{-1} + NPK consortia + nano-P spray at 25 DAS	0.43	0.25	5.37	9.01	2.35
	SEm±	0.006	0.003	0.12	0.39	0.05
	CD (P=0.05)	0.016	0.01	0.34	1.15	0.16

Table 3: Effect of varieties and nutrient management practices on biological properties of soil (Pooled data).

		Microbial. biomass carbon. (mg kg^{-1} soil)	Dehydrogenase activity (mg TPF g^{-1} h^{-1})	Soil respiration. (mg CO_2 kg^{-1} day^{-1})
A. Varieties				
V_1	Virat	198.3	2.18	29.6
V_2	PUSA-1431	213.1	2.54	33.9
	SEm±	3.6	0.06	0.5
	CD (P=0.05)	10.8	0.19	1.6
B. Nutrient management treatments				
M_1	100% NPK (20:40:20 N:P_2O_5:K_2O kg ha^{-1})	173.4	1.68	25.2
M_2	75% NPK + FYM @ 5 t ha^{-1}	186.7	1.94	27.3
M_3	75% NPK+ FYM @ 5 t ha^{-1} + NPK consortia	208.6	2.44	31.4
M_4	75% NPK + FYM @ 5 t ha^{-1} + nano-P spray at 25 DAS	212.3	2.50	33.0
M_5	75% NPK + NPK consortia + nano-P spray at 25 DAS	205.5	2.36	30.8
M_6	75% NPK + FYM @ 5 t ha^{-1} + NPK consortia + nano-P spray at 25 DAS	230.4	2.73	36.7
	SEm±	4.4	0.07	0.6
	CD (P=0.05)	13.0	0.21	1.8

These results are consistent with earlier reports showing that integrated nutrient management enhances soil biological health and nutrient availability (Cathrine *et al*., 2024; Kumar *et al*., 2022; Khandare *et al*., 2025; Tiwari *et al*., 2024 and Rajitha *et al*., 2024).

CONCLUSION

The results showed that integrated nutrient management combining organic manure, reduced inorganic fertilizers, microbial consortia and nano-phosphorus significantly improved mungbean growth, yield, phosphorus uptake, economic returns and soil biological activity compared to sole chemical fertilization. The treatment with 75% recommended NPK + FYM @ 5 t ha^{-1} + NPK consortium + nano-P spray at 25 DAS was most effective in enhancing yield attributes, nutrient use efficiency (NUE) and soil enzyme activity. Among varieties, Pusa-1431 performed better than Virat under integrated nutrient treatments, indicating higher adaptability and nutrient efficiency. Overall, the study suggests that integration of organic, inorganic, bio-and nano-fertilizers can reduce dependence on full chemical fertilizer doses while sustaining soil health and productivity in mungbean. Integrated nutrient management thus offers a sustainable and economically viable approach for the Indo-Gangetic plains. Further long-term studies are needed to assess its impact on soil microbial diversity, nutrient cycling and carbon dynamics.

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Disclaimers

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Conflict of interest

The authors declare no conflict of interest.

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