



Impact of Fertilizer Combinations and Nano-phosphorus on the Growth, Yield, Nutrient Uptake and Soil Enzyme Activity in Dual Mungbean Varieties

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ABSTRACT

Background: Mungbean (*Vigna radiata* L.) productivity in the Indo-Gangetic plains is constrained by low nutrient use efficiency and declining soil biological activity. Conventional fertilizer practices often fail to supply phosphorus efficiently, while soil microbial functions essential for nutrient cycling continue to deteriorate. Nano-phosphorus (Nano-P), when combined with organic and microbial inputs, has the potential to improve phosphorus availability, enhance soil biological processes and increase crop productivity in a sustainable manner.

Methods: A field experiment was conducted at CSA University, Kanpur using a factorial randomized block design with two mungbean varieties (Pusa-1431 and Virat) and six nutrient management treatments, replicated three times. Treatments consisted of different combinations of NPK fertilizers, farmyard manure (5 t ha⁻¹), microbial consortia and Nano-P foliar spray applied at 25 days after sowing. Growth traits, yield, nitrogen content and uptake, partial factor productivity (PFP), protein content and soil biological parameters (AMF colonization, nitrogen-fixing bacteria and microbial diversity) were measured. Data were analyzed using ANOVA at p≤0.05.

Result: Integrated nutrient management significantly improved mungbean performance compared with conventional fertilizer use. The treatment 75% NPK + FYM + microbial consortia + Nano-P produced the highest grain yield (12.4 q ha⁻¹), nitrogen uptake, PFP and soil microbial activity (p≤0.05). Nano-P application enhanced phosphorus availability, AMF colonization and microbial diversity, leading to improved nutrient cycling. In terms of increasing nitrogen uptake, use efficiency, grain quality and soil biological activity across mungbean types, integrated fertilizer combinations (reduced NPK with FYM, nano-P and microbial consortia) consistently performed better than 100% NPK alone. Among the varieties, Pusa-1431 showed a stronger positive response to integrated nutrient management than Virat. These findings highlight the practical value of balanced nutrient integration for sustainable mungbean production and recommend adoption of such combined approaches to improve crop productivity and soil health.

Key words: AMF colonization, Integrated nutrient management, Microbial consortia, Mungbean, Nano-phosphorus, Nitrogen uptake, Partial factor productivity, Phosphorus use efficiency, Soil biological activity.

INTRODUCTION

Mungbean (*Vigna radiata* L.) is a protein-rich legume widely consumed in regions where intake of animal protein is low. It provides an important source of plant-based protein for human nutrition and helps address protein deficiency (Tarahi *et al.*, 2024; Navreet *et al.*, 2026). Mungbean is also proven to fix nitrogen making it an appealing intercrop. This natural fertilization process avails itself as sustainable soil fertility in rotational systems benefitting subsequent crops (Kumar *et al.*, 2023; Patel *et al.*, 2026). Although mungbean has many agronomic and nutritional benefits over other pulses in the region but its productivity is stagnated due to nutrient deficiencies (N, P, K) and deteriorating soil health that causing depletion of essential nutrients for maximum plant population growth potential (Ahmed *et al.*, 2023; Banotra *et al.*, 2023).

Mungbean is a protein-rich legume important for human nutrition and soil nitrogen enrichment, but its productivity is often limited by nutrient deficiencies and declining soil health. Integrated nutrient management, combining NPK fertilizers, organic manures and beneficial microbes, has been shown to enhance growth, yield and soil fertility, while emerging strategies such as nano-phosphorus (Nano-P) further improve phosphorus availability and uptake. Despite evidence of individual benefits, limited studies have evaluated the combined effects of NPK, FYM, microbial consortia and Nano-P on

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mungbean under field conditions (Diatta *et al.*, 2024; Fatima *et al.*, 2024; Sande *et al.*, 2024).

Therefore, the optimization of these strategies is a crucial area in agronomy, due to its built-in limitations. The responsible factors include fertilizer usage, which may be organic or inorganic/bio-based and results in enhancement of seed germination, mungbean seedling growth, root development and yield. The utilization of Manures, chemicals and biological sources of nutrient has been perceived as a very effective means of increasing crop yields in an environmentally sustainable way (Kumawat *et al.*, 2010; Gohain *et al.*, 2017). Soil textural amelioration, enhanced nutrient status of soil and improved soil health are the major determinants for the high production of leguminous crops e.g.; mungbean this could further be accomplished through INM practices (Kumari *et al.*, 2023; Choudhary *et al.*, 2025; Meena *et al.*, 2018; Patel *et al.*, 2026).

In recent years, using nano-fertilizer (especially Nano-P) as a new strategy due to the trend of improving nutrient in plants one of important phenomenon that has been considered as an emerging technique. A really high surface area and solubility also mean it can have a very large impact on the uptake of phosphorus - which is probably the most limiting nutrient in many soils for plants (Homeshwari-Devi *et al.*, 2024; Chang *et al.*, 2025). Nevertheless, foliar nanolized P application of this P has proved to enhance plant growth and yield with decreased rates of chemical fertilizer without collateral environmental pollution (Arora *et al.*, 2025). These are expected to be essential for the nutrient utilization management and further increase crop yield, actually in manner of sustainability (Tripathi *et al.*, 2024).

Soil microorganisms play a central role in nutrient cycling and plant nutrition through enzymatic processes such as urease, phosphatase and dehydrogenase activity, which regulate nitrogen and phosphorus availability in soil. The integration of organic manures, chemical fertilizers and beneficial microbes is therefore essential for maintaining soil fertility and crop productivity under intensive farming systems (Zhan, 2024; Yasir *et al.*, 2025). Recently, nano-fertilizers, particularly nano-phosphorus (Nano-P), have emerged as an efficient strategy to enhance phosphorus use efficiency because of their high surface area, solubility and controlled release properties. Nano-P has been shown to improve root growth, phosphorus uptake and microbial activity while reducing the need for conventional P fertilizers (Sharma *et al.*, 2024; Reddy *et al.*, 2025 and Gaylarde *et al.*, 2025).

Although individual effects of NPK fertilizers, organic manures and microbial inoculants on mungbean productivity have been reported, there is limited experimental evidence on their combined application with Nano-P under field conditions, particularly regarding soil biological activity and nutrient uptake. (Mishra *et al.*, 2025 and Subramanian *et al.*, 2025). Therefore, this study was undertaken to evaluate the synergistic effects of NPK fertilizer, FYM, microbial consortia and Nano-P on growth, yield, nutrient uptake and soil microbial parameters of two mungbean varieties.

MATERIALS AND METHODS

The experiment was conducted during the *kharif* season at the Crop Research Farm of Chandra Shekhar Azad University of Agriculture and Technology (CSAUAandT), Kanpur, Uttar Pradesh, India. The soil was sandy loam with medium fertility status. Two mungbean varieties, Pusa-1431 (V_1) and Virat (V_2), were evaluated under different nutrient management practices (Fig 1).

The experiment consists of two factors; factor A: mungbean varieties viz., Pusa-1431, Virat; factor B: Nutrient management treatments: M_1 - 100% NPK (20:40:20 kg ha⁻¹) (control), M_2 - 75% NPK + FYM (5 t ha⁻¹), M_3 - 75% NPK + FYM (5 t ha⁻¹) + microbial consortia, M_4 - 75% NPK + FYM (5 t ha⁻¹) + Nano-P spray (25 DAS), M_5 - 75% NPK + microbial consortia + Nano-P spray, M_6 - 75% NPK + FYM + microbial consortia + Nano-P spray. The experiment will be laid out in a factorial randomized block design (FRBD) with three replications.

Data were recorded on number of trifoliate leaves per plant, days to 50% flowering, days to maturity, root length (cm), grain and straw yield (q ha⁻¹), nitrogen content (%), nitrogen uptake (kg ha⁻¹), protein content (%) and partial factor productivity (PFP; kg grain kg⁻¹ nutrient applied). Nitrogen-fixing bacteria were estimated by serial dilution and plating (Collins *et al.*, 2004) and microbial diversity was calculated using Shannon's diversity index (Pielou, 1966).

Crop establishment and management

It was harrowed down, ploughed twice, after which it was prepared by levelling it to produce the experimental field. The applied rate of the application proposed was 20 kg N ha⁻¹, 40 kg P ha⁻¹, 20 kg K ha⁻¹. The urea (46N), D.A.P (46 P₂O₅) and M.O.P (60K₂O) were used as forms of the fertilizers. FYM was added and incorporated 15 days prior to planting and the soil was turned over. The application of Nano-P (30 nm particle size; 500 ppm concentration) on the plants was done with the use of a knapsack sprayer at 25 DAS. The amount of agronomics conducted, including irrigation, weeding, plant protection activities were also observed to have been performed as indicated under the package of activities to be practiced in that region.

Data analysis

The recorded data were compiled and tabulated for statistical analysis. The mean of all treatments was calculated and the analysis of variance for each of the characters under study was done. Data were analyzed using analysis of variance (ANOVA) in SPSS (Version 23) and treatment means were compared using the critical difference (CD) test at a significance level of $p \leq 0.05$ (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Growth and yield response

The analysis indicated that Pusa-1431 showed higher values at 20 and 40 DAS (not significant) and significantly

higher values at harvest ($p \leq 0.05$) compared with Virat with respect to growth parameters. Pusa-1431 also took 45.6 days to attain 50% flowering compared to Virat, which took 34.0 days, indicating a longer vegetative step. Pusa-1431 also showed significantly higher root growth ($p \leq 0.05$) with 17.14 per cent longer root length than Virat. This key aspect of root development is highly needed to enlarge the uptake of nutrients and water. In the present study, integrated nutrient management, particularly 75% NPK + FYM + Consortia + Nano-P (M_6), resulted in significantly higher ($p \leq 0.05$) leaf number and root length than the 100% NPK treatment, with differences of 10.9%, 33.3% and 39.2% at 20 DAS, 40 DAS and at harvest, respectively. The observed increases in leaf number and root length under integrated nutrient management may be related to the combined supply of nutrients from inorganic fertilizers and FYM, along with microbial consortia and nano-P application. This combination likely influenced nutrient availability and root-soil interactions at different growth stages, resulting in progressive differences between treatments from early growth to harvest. It was found that application of nano-fertilizers and NPK microbial consortia promoted nutrient uptake and FYM made the soil healthier (Kumar *et al.*, 2021). Nonetheless, the days to 50% flower was not affected significantly, which supports genetic factors as the major controlling force. The results reveal the relevance of variety selection and integrated nutrient management with special reference to the utilization of

nano-fertilizers and microbial consortia to enhance the growth and productivity of mung beans (Walling *et al.*, 2025; Kumar *et al.*, 2021) (Table 1).

Pusa-1431 recorded significantly higher grain and straw yield than Virat ($p \leq 0.05$). Pusa-1431 exhibited a grain yield of 11.0 q ha^{-1} , 11.8 per cent in comparison to Virat (9.7 q ha^{-1}) and a straw yield of 33.6 q ha^{-1} , 12.2 % higher than Virat (29.5 q ha^{-1}) in Table 2. It is not far off to state that the superior photosynthetic rate and plant root fitness of Pusa-1431 also lead to increased output due to increased production of leaves, increased nutrient uptake and condition of the plants. A mixture of 75 per cent NPK+ FYM@ 5 t ha^{-1} + NPK Consortia + Nano-P had produced significantly higher grain yield ($p \leq 0.05$) (12.4 q ha^{-1}) and Straw yield (35.7 q ha^{-1}), which was 33.06 percent more in the grain yield than at 100 per cent NPK. Nano-fertilizers, NPK microbial consortia, were used to probably increase the availability of nutrients and soil microbial biomass, thus promoting the uptake and growth of roots and this in turn led to the increase of the yield (Ali *et al.*, 2023; Sharma *et al.*, 2024; Reddy *et al.*, 2025). However, the magnitude of yield improvement was primarily driven by the nutrient management strategy, particularly the integration of Nano-P and microbial consortia, rather than the varietal effect alone.

Nutrient uptake and use efficiency

The research revealed that the Pusa-1431 mungbean variety contained more nitrogen in the grains (3.32) than Virat

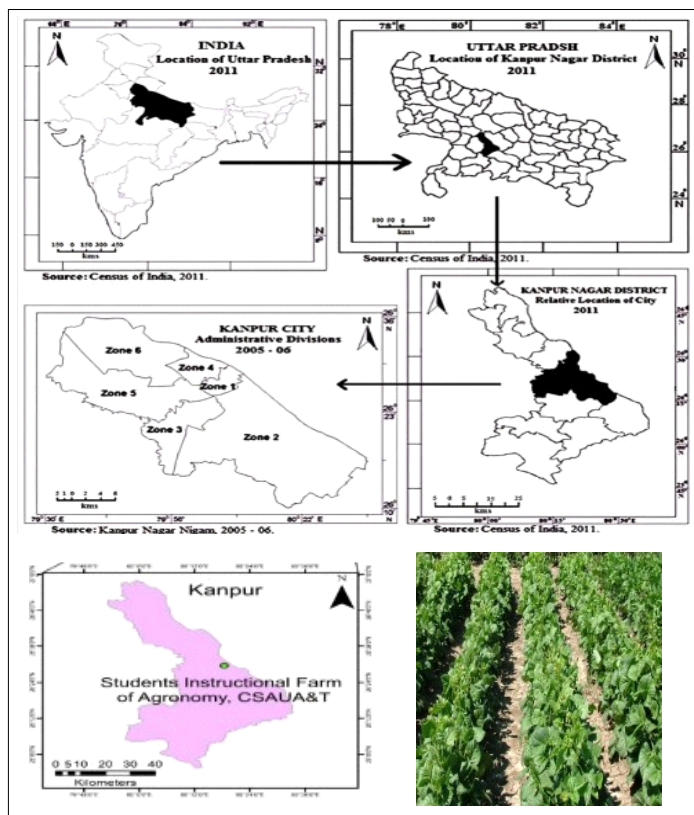


Fig 1: Layout of experimental position of moong-been varieties.

(3.07) as well as in straw (0.79) than Virat (0.68) in Table 2. Total uptake of nitrogen was also higher (64.27 kg ha⁻¹) in Pusa-1431 by 26.3 compared to Virat (50.87 kg ha⁻¹). The integrated nutrient management system, M₆ (75% NPK + FYM @ 5 t ha⁻¹ + NPK Consortia + Nano-P spray @ 25 DAS), provided significantly higher N concentration and uptake ($p \leq 0.05$) in grains (3.6%) as well as straw (0.88%) and total N uptake (76.8 kg ha⁻¹) by 38.5%, 46.7 and 100.5 percent, respectively, under the 100 per cent NPK treatment (M₁) in Table 2. The higher nitrogen concentration and uptake observed under M₆ may be attributed to the combined effect of organic and inorganic nutrient sources, along with bio-inoculants and nano-P application. Organic amendments such as FYM improve soil structure, moisture retention and microbial activity, enhancing nutrient availability. Simultaneously, NPK consortia and nano-P can improve

nutrient solubilization and uptake efficiency. Together, these factors likely contributed to greater N accumulation in both grain and straw, supporting improved overall nitrogen use efficiency. Better nitrogen nutrition in Pusa-1431 and M₆ underscores the relevance of choosing an appropriate variety and adopting a coordinated nutrient management approach such as a combination of organic manure, nano-fertilizer and microbial consortia as far as the concentration of nutrients, their uptake and the overall growth and yield of mungbean are concerned in a sustainable manner (Sharma *et al.*, 2024; Walling *et al.*, 2025).

The study showed that the mungbean cultivar Pusa-1431 recorded significantly higher partial factor productivity ($p \leq 0.05$) than Virat, producing 55.2 kg grain per kg N applied compared with 48.7 kg grain per kg N applied. Pusa-1431 also exhibited a higher grain protein content (20.8%) than

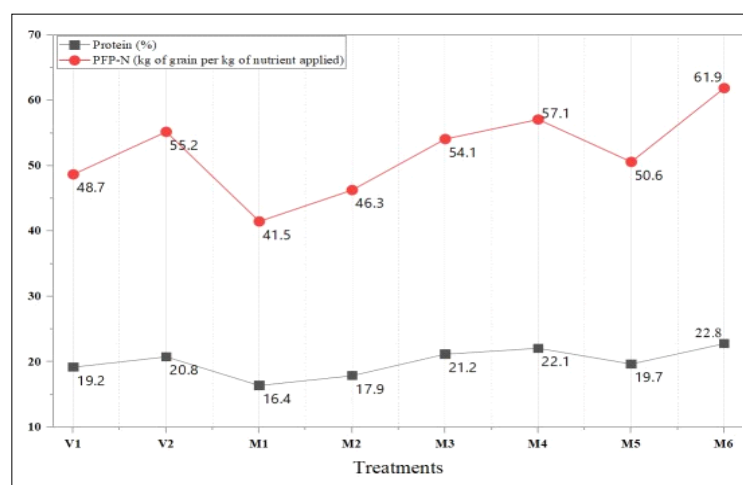


Fig 2: Effect of varieties and nutrient management practices on protein and PFP.

Table 1: Effect of varieties and nutrient management practices (pooled data at different stages).

Treatment combinations	No. of trifoliate leaves per plant			Number of days taken to 50% flowering	Root length
	20 DAS	40 DAS	At harvest		
A. Variety-wise data					
Virat (V ₁)	3.22	7.91	7.02	34.0	8.7
PUSA-1431 (V ₂)	3.30	8.23	7.40	45.6	10.5
SEm±	0.04	0.12	0.10	0.6	0.1
CD (P=0.05)	NS	NS	0.32	1.8	0.4
B. Nutriment management practices					
100% NPK (20 N, 40 P ₂ O ₅ , 20 K ₂ O kg ha ⁻¹) (M ₁)	3.12	6.25	5.07	37.5	7.8
75% NPK + FYM@ 5 t ha ⁻¹ (M ₂)	2.35	7.10	6.45	40.2	8.4
75% NPK + FYM @ 5 t ha ⁻¹ + NPK Consortia (M ₃)	3.22	8.85	7.82	39.7	9.8
75% NPK + FYM@ 5 t ha ⁻¹ + Nano-P Spray at 25 DAS (M ₄)	3.65	9.25	7.97	40.5	10.7
75% NPK + NPK Consortia + Nano-P Spray at 25 DAS (M ₅)	3.72	8.70	7.62	40.2	9.2
75% NPK + FYM@ 5 t ha ⁻¹ + NPK Consortia + Nano-P Spray at 25 DAS (M ₆)	3.50	9.35	8.35	41.8	11.6
SEm±	0.08	0.21	0.18	1.04	00.2
CD (P=0.05)	0.247	0.63	0.55	NS	0.9

Virat (19.2%) under the nutrient management strategies (Fig 2). The integrated practice M_6 (75% NPK + FYM @ 5 t ha⁻¹ + NPK consortia + nano-P spray at 25 DAS) produced significantly higher partial factor productivity (61.9 kg grain per kg N) and protein content (22.8%), which were 49.2% and 39.0% higher, respectively, than those obtained under the 100% NPK treatment (M_1) (Fig 2). The high-yielding

output of M_6 and Pusa-1431 mixture of organic manures, nano-fertilizers and microbial consortium in reduced concentration of chemical fertilisers coupled with selection of appropriate variety leads to increasing the nitrogen use efficiency, improving productivity and grain quality of mungbean crop in a sustainable way (Sharma *et al.*, 2024; Meel and Saharan 2024).

Table: 2 Effect of varieties and nutrient management practices (data pooled basis).

Varieties	Yield		Nitrogen content		Uptake of nitrogen	
	Grain	Straw	Grain	Straw	Grain	Straw
V ₁	9.7	29.5	3.07	0.68	30.3	20.57
V ₂	11.0	33.6	3.32	0.79	37.2	27.07
SEmt	0.1	0.4	0.2	0.006	0.2	0.14
CD (P=0.05)	0.5	1.4	0.07	0.018	0.63	0.4
Nutrient management practices						
M ₁	8.3	27.3	2.6	0.60	21.8	16.6
M ₂	9.3	28.9	2.9	0.65	26.5	19.0
M ₃	10.8	32.6	3.3	0.78	36.8	25.8
M ₄	11.4	33.9	3.5	0.84	40.6	28.8
M ₅	10.1	30.9	3.1	0.67	31.9	21.1
M ₆	12.4	35.7	3.6	0.88	45.2	31.6
SEmt	0.3	0.8	0.04	0.01	0.3	0.25
CD (P=0.05)	1.0	2.4	0.1	0.031	1.1	0.76

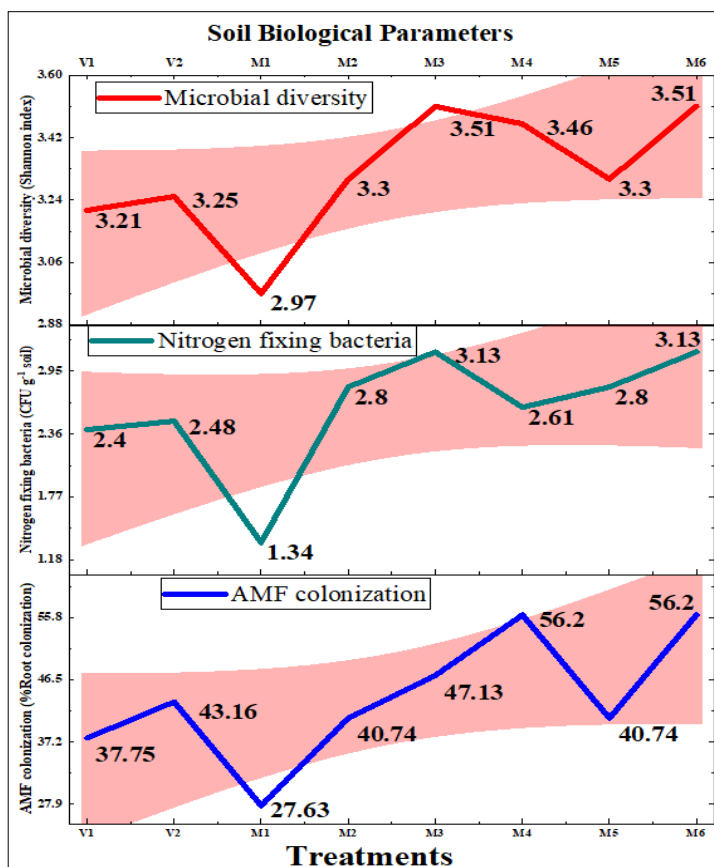


Fig 3: Effect of varieties and nutrient management practices on soil biological parameters.

Soil biological properties

Findings showed the notable impact of varieties and nutrient management on the degree of AMF colonization, presence of nitrogen-fixing bacteria (NFB) and microbial richness in mung bean (Fig 3). Pusa-1431 had greater AMF colonization (43.16%) than Virat (37.75%), implying that it is more capable of forming a beneficial association with the AMF, which increases phosphorus uptake. More so, a larger population of nitrogen-fixing bacteria (2.48 CFU g⁻¹) was also supported on Pusa-1431 than on Virat (2.40 CFU g⁻¹), which intensified nitrogen fixation and soil fertility. The microbial diversity showed the Shannon Diversity Index of Pusa-1431 to be 3.25, which was just a bit more than Virat (3.21). Treatment of nutrient management 75 % NPK + FYM @ 5 t ha⁻¹ + NPK Consortia + Nano-P Spray at 25 DAS significantly increased ($p \leq 0.05$) AMF colonization (56.20 %), NFB population (3.13 CFU g⁻¹) and microbial diversity (3.51) and proved the effectiveness of integrated nutrient practices. The input of nano-fertilizers and microbial consortia was probably the reason that encouraged microbial activity, enhancing nutrient cycling and crop growth (Pudhuvali *et al.*, 2024; Negi *et al.*, 2025). The results point out the need to integrate nutrient management, especially by using nano-fertilizers and microbial consortia, to sustain soil health, increase microbial diversity and the productivity of mung bean crops overall (Soni *et al.*, 2024; Meel *et al.*, 2024). The increase in AMF colonization and nitrogen-fixing bacterial population under integrated treatments also indicates higher soil enzymatic activity involved in phosphorus solubilization and nitrogen mineralization.

CONCLUSION

The current study demonstrated the possible beneficial impact of the combination of nutrient management (INM) and nano-fertilizer on growth, root length, nutrient concentration, nutrient use efficiency, protein, biological activities and productivity of mungbean. The variety Pusa-1431 had a vast extent of root development when compared to Virat and yielded a higher grain harvest (11.0 q ha⁻¹) than Virat (9.7 q ha⁻¹) (+11.8%). Pusa-1431 exceeded Virat in root development and yield. From these treatments, 75% NPK + FYM @ 5 t ha⁻¹ + Nano-P spray at 25 DAS produced the highest grain yield (12.4 q ha⁻¹), which was 33.06 per cent higher than applying the 100 per cent NPK formula. It also contributed significantly ($p \leq 0.05$) towards higher uptake of nitrogen via grain nitrogen, enhancing population abundance and diversity of microbial population, improving availability of nutrients and soil health over Pusa-1431. Conclusions of this study create the indication of the significance of incorporating organic-inorganic approaches, especially nano-fertilizers, in sustainable agriculture and long-term sustainability of soil fertility.

Conflict of interest

The authors have no conflict of interest to declare.

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