



RESEARCH ARTICLE

Comparative study of summer green gram (*Vigna radiata* L.) varieties under different nutrient regimes in irrigated subtropical conditions

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Abstract

A two-year field experiment (2024-2025) was conducted to assess the effect of integrated nutrient management for quality seed production of mungbean (*Vigna radiata* L.) varieties during the summer seasons at the Crop Research Farm, Faculty of Agriculture, Maharishi Markandeshwar (Deemed to be) University, Mullana, Ambala, Haryana. The experiment was laid out in a factorial randomized block design with three replications, comprising three varieties (MH 421, MH 1142 and MH 1762) and eight nutrient management treatments: N₁: 15 kg N + 40 kg P₂O₅, N₂: 15 kg N + 60 kg P₂O₅, N₃: 20 kg N + 60 kg P₂O₅, N₄: 15 kg N + 40 kg P₂O₅ + *Rhizobium*, N₅: 15 kg N + 60 kg P₂O₅ + *Rhizobium*, N₆: 20 kg N + 60 kg P₂O₅ + *Rhizobium*, N₇: RDF + 2 mL nano urea + nano DAP/ha + *Rhizobium* and N₈: RDF + 4 mL nano urea + nano DAP/ha + *Rhizobium*. Results revealed significant variations among varieties and nutrient combinations for all seed quality traits. MH 1142 (V₂) exhibited superior performance with the highest number of branches, pods per plant, pod length, seeds per pod and test weight, resulting in maximum seed yield (1068.65 and 1089.88 kg/ha in both years, respectively). Among nutrient treatments, N₆ (20 kg N + 60 kg P₂O₅ + *Rhizobium*) recorded the highest seed yield (1068.54 and 1089.88 kg/ha in 2024 and 2025, respectively), stover yield (2717.76 and 2739.10) and biological yield (3786.31 and 3828.97) in both years, respectively. Treatment N₅, the second- most effective nutrient regime, was found to be at par with treatment N₃, while the lowest yield was reported under N₁ (15 kg N + 40 kg P₂O₅). The improvement under N₆ was attributed to enhanced nodulation, nutrient uptake and assimilate partitioning. Overall, the variety MH 1142, combined with the application of treatment N₆, demonstrated the greatest efficacy due to enhanced nodulation for achieving higher and sustainable mungbean productivity under field conditions.

Keywords: integrated nutrient management; nano-fertilizers; quality seed; rhizobium; *Vigna radiata*; yield characters

Introduction

Mung bean (*Vigna radiata* L.), also known as green gram or golden bean, is one of the most important pulse crops. Cultivated extensively across tropical and subtropical regions of the world. It is a short-duration, warm-season legume belonging to the family Fabaceae, predominantly grown during the kharif and summer seasons. The crop is highly valued for its superior nutritional composition, early maturity and remarkable adaptability to diverse agro-climatic conditions (1). In India, mung beans rank third among major pulse crops after chickpea and pigeon pea and constitute a vital component of the vegetarian diet due to high protein content and excellent digestibility. The seeds contain approximately 24.50 % protein, enriched with essential amino acids such as lysine (460 mg/g N) and tryptophan (60 mg/g N), along with appreciable amounts of ascorbic acid (27.25 mg per 100 g) and riboflavin (0.21 mg/100 g). Despite its rich nutritional profile, mung beans also contain several anti-nutritional factors, such as tannins (366.6 mg/100 mg), phytic acid (441.5 mg/100 g), trypsin inhibitors, hemagglutinins, proteinase inhibitors and polyphenols (462.5 mg/100g), which may reduce nutrient digestibility and bioavailability (2).

In India, mung bean (*Vigna radiata* L.) was cultivated on an estimated 55.72 lakh ha during 2024-25, yielding approximately 38.19 lakh tonnes and achieving an average productivity of 685 kg/ha (3). During the kharif season, the crop covers about 33.91 lakh ha, producing 17.47 lakh tonnes at an average productivity of 515 kg/ha. According to the 3rd advance estimates of 2024-2025, the mung bean production in India stands at around 3.82 million tonnes, reaffirming the country's status as the world's largest producer (4). Owing to its short growth duration, low input requirement and capacity to fix atmospheric nitrogen, mung bean serves as an excellent component in crop diversification and sustainable intensification systems. It not only contributes to nutritional security but also enhances soil fertility and overall productivity in cereal-based cropping systems, thereby holding significant agronomic and economic importance in Indian agriculture (5).

Despite its multiple advantages, the productivity of mung beans in India remains far below its genetic potential, largely due to imbalanced fertiliser application, nutrient depletion and progressive soil fertility decline (6). The indiscriminate and prolonged use of chemical fertilisers without adopting integrated nutrient management

(INM) strategies has led to nutrient imbalances, soil degradation and reduced biological activity in the rhizosphere (7). Ensuring sustainable production, therefore, to ensure a sustainable production, a more balanced nutrient approach is required, which integrates organic, inorganic and biological sources to enhance soil fertility and improve crop productivity. Nitrogen and phosphorus are key macronutrients regulating mung bean growth, nodulation and yield (8). Nitrogen enhances vegetative development, chlorophyll content and photosynthesis, whereas phosphorus promotes root growth, energy metabolism and nodule function (9, 10).

Leguminous crops form symbiotic associations with *Rhizobium* spp., gram-negative nitrogen-fixing bacteria that induce root nodulation and convert atmospheric nitrogen into plant-available forms (11, 12). In mung bean (*Vigna radiata* L.), *Rhizobium* inoculation enhances biological nitrogen fixation (9–137 kg N/ha), leading to improved plant growth, leaf area and dry matter accumulation (13, 14). Nanotechnology enables manipulation of materials at the nanoscale, enhancing nutrient delivery and plant metabolism (15–17). Slow-release nanofertilizers improve root growth, nutrient uptake, photosynthesis and yield in mung bean (*Vigna radiata*), while promoting soil fertility and reducing agrochemical dependence (18–20).

Despite the significant nutritional, agronomic and ecological importance of mung bean (*Vigna radiata* L.), its productivity in India remains far below its genetic potential due to imbalanced fertiliser use, declining soil fertility and inadequate adoption of sustainable nutrient management practices. Although the individual roles of nitrogen, phosphorus and *Rhizobium* inoculation in improving crop growth and yield are well established, their integrated and efficient utilisation under diverse field conditions is still not adequately explored. Furthermore, the application of nanotechnology in the form of nanofertilizers has shown promising potential in enhancing nutrient use efficiency and crop performance; however, limited research is available on their synergistic interaction with conventional fertilisers and bio-inoculants in mung beans. In addition, comprehensive studies evaluating the combined effects of organic, inorganic and nano-based nutrient sources along with microbial inoculants on soil health, nutrient dynamics and long-term crop productivity are lacking. Considering these aspects, integration of organic, inorganic and biological nutrient sources offers a sustainable alternative to enhance mung bean productivity while maintaining soil fertility and environmental quality. Therefore, the present investigation was undertaken to evaluate the influence of different nutrient management strategies, including the use of fertilisers, *Rhizobium* inoculation and nanofertilisers, on growth attributes, dry matter accumulation, crop growth rate, nutrient uptake and yield of mung bean under the agro-climatic conditions of Ambala, Haryana.

Materials and Methods

A field experiment was conducted during the two consecutive summer seasons of 2024 and 2025 to study the effect of integrated nutrient management on the growth and yield of green gram (*Vigna radiata* L.) at the Crop Research Farm, Faculty of Agriculture, Maharishi Markandeshwar (Deemed to be) University, Mullana, Ambala, Haryana, India. The experimental site is situated at 30°17'0" N latitude and 77°3'0" E longitude at an altitude of 264 m above mean sea level. The soil of the experimental field was sandy clay loam with a pH ranging from 5.8 to 7.7.

The experiment was laid out in a factorial randomised block design (RBD) with three replications. Three green gram varieties procured from the Department of Agriculture, Maharishi Markandeshwar (Deemed to be) University, i.e., MH421, MH1142 and MH1762, were subjected to eight integrated nutrient management treatments, including chemical fertilisers, biofertilisers (*Rhizobium*) and nano-fertilisers. The treatments consisted of N1: 15 kg N + 40 kg P₂O₅, N2: 15 kg N + 60 kg P₂O₅, N3: 20 kg N + 60 kg P₂O₅, N4: 15 kg N + 40 kg P₂O₅ + *Rhizobium*, N5: 15 kg N + 60 kg P₂O₅ + *Rhizobium*, N6: 20 kg N + 60 kg P₂O₅ + *Rhizobium*, N7: RDF + 2 mL nano urea + nano DAP/ha + *Rhizobium* and N8: RDF + 4 mL nano urea + nano DAP/ha + *Rhizobium*. Each plot measured 3 × 2 m and seeds were sown at a rate of 25 kg/ha. For *Rhizobium*-inoculated treatments, seeds were divided into portions, mixed with 25 g inoculum per kg seed and shade-dried before sowing to ensure uniform coating and prevent contamination.

Seed inoculation and sowing

Green gram seeds were sown at a rate of 25 kg/ha. Seeds were divided into 21 portions and placed in small polythene bags. For *Rhizobium*-inoculated treatments, 25 g of inoculum per kg of seed was added and thoroughly mixed to ensure uniform coating. Care was taken to avoid contamination between treatments. Seeds were shade-dried before sowing in the field.

Crop management

Hand weeding was performed at 30 and 60 days after sowing (DAS) to control weeds. Fertilisers (urea, DAP and nano-fertilisers) were applied according to recommended doses at sowing. At 15DAS, surplus seedlings were thinned to maintain a spacing of 6-10cm between plants. All other intercultural operations, including irrigation and pest management, were carried out as needed. The crop was harvested at physiological maturity and grain and straw yields were recorded separately for each plot.

Data collection

Observations on growth, yield and quality parameters were recorded at 30 DAS intervals. From each plot, five tagged plants were selected for measurement of growth attributes, including plant height, dry matter accumulation, leaf area, crop growth rate (CGR) and relative growth rate (RGR). Yield-contributing traits such as seed yield, stover yield, biological yield and harvest index were measured. Quality parameters included nutrient content and nutrient uptake in the grain, which were calculated.

Statistical analysis

The recorded data were analysed using analysis of variance (ANOVA), appropriate for factorial randomised block design (21). The significance of treatment effects was tested using the 'F' test. Standard error of mean (SEM) was calculated and significant differences among treatment means were determined using the critical difference (CD) at 5 % probability level, where the 'F' test indicated significance:

$$CD = \sqrt{\frac{2 \times \text{error sum of square}}{N}} \times t (\text{error d.f. } 5 \%)$$

Eqn. 1

Results and Discussion

The data presented in Table 1 indicated significant variability among the evaluated mungbean varieties for various growth and physiological attributes, reflecting their differential genetic potential and adaptability under field conditions. The number of branches per plant varied significantly among varieties and nutrient management treatments during both years. The variety MH 1142 (V_2) produced the highest number of branches (5.90 and 6.25 in 2024 and 2025, respectively), closely followed by MH 1762 (V_3), while the lowest was recorded in MH 421 (V_1). Among nutrient treatments, N_6 (20 kg N + 60 kg P_2O_5 + Rhizobium) resulted in the highest number of branches (4.17 and 4.43), whereas the minimum was observed under N_1 (15 kg N + 40 kg P_2O_5). The increase under N_6 may be attributed to balanced N and P nutrition coupled with Rhizobium inoculation, which enhanced nodulation, nitrogen fixation and vegetative growth (22–24). The number of pods per plant was also significantly influenced by both varieties and nutrient management. Variety MH 1762 (V_3) produced the maximum pods (24.38 and 26.27 during 2024 and 2025), while MH 421 (V_1) recorded the minimum. Among the nutrient treatments, N_6 produced the highest pods per plant (16.51 and 17.69), whereas N_1 recorded the lowest. The increase in pod number under N_6 was due to optimum nutrient availability and improved reproductive efficiency.

Pod length differed significantly among treatments and varieties. The longest pods were recorded in MH 421 (V_1), i.e., 14.98 and 7.26 cm, followed by MH 1762 (V_3). Among treatments, N_6 recorded the longest pods (16.06 and 17.24 cm), while N_1 had the shortest. The improvement under N_6 may be attributed to higher phosphorus availability and better assimilate transport during pod development (25–27). The number of seeds per pod also showed similar trends. MH 1142 (V_2) produced the maximum seeds per pod (4.85 and 6.00), followed by MH 1762 (V_3), while MH 421 (V_1) recorded the minimum. Among the nutrient treatments, N_6 recorded the highest number of seeds per pod (6.06 and 7.23), whereas N_1 showed the lowest. The superior performance of N_6 could be attributed to improved pollination, fertilisation and nutrient uptake efficiency. Test weight showed no significant varietal difference but displayed minor variation across treatments. The highest values

were observed in MH 1142 (V_2) (34.23 and 35.40 g), while MH 421 (V_1) had the lowest. Among nutrient treatments, N_6 produced the heaviest seeds (34.90 g and 36.10 g in both years), while N_1 recorded the lowest. The increase in test weight under N_6 may be due to enhanced nutrient translocation and efficient grain filling supported by sustained nutrient availability through integrated fertilisation.

As indicated in Table 2, seed yield varied significantly among varieties and nutrient management treatments during both experimental years. Among the varieties, MH 1142 (V_2) produced the highest seed yield (996.52 and 1015.85 kg/ha during 2024 and 2025, respectively), closely followed by MH 1762 (V_3). The superiority of the performance of MH 1142 can be attributed to its better genetic potential, efficient assimilate translocation and greater sink capacity. Among nutrient management treatments, N_6 (20 kg N + 60 kg P_2O_5 + Rhizobium) recorded the maximum seed yield (1068.65 and 1089.88 kg/ha in 2024 and 2025, respectively), while N_1 (15 kg N + 40 kg P_2O_5) registered the minimum values (911.95 and 914.95 kg/ha). The higher seed yield under N_6 can be attributed to the combined effects of balanced nutrient supply and biological nitrogen fixation, which enhanced vegetative growth and reproductive efficiency, leading to improved pod and seed development (28–31).

Stover yield followed a pattern similar to seed yield. The maximum stover yield among varieties was recorded in MH 1142 (V_2) (2556.22 and 2514.78 kg/ha during 2024 and 2025). Among nutrient management practices, N_6 again recorded the highest stover yield (2717.76 and 2739.10 kg/ha during 2024 and 2025, respectively), whereas the lowest was obtained under N_1 (2387.83 and 2388.96 kg/ha). The enhanced stover yield under N_6 is likely a result of improved vegetative growth, enhanced root activity and nutrient uptake resulting from the synergistic effect of nitrogen, phosphorus and Rhizobium inoculation (32–34). Biological yield, being the sum of seed and stover yield, also showed significant differences across varieties and nutrient treatments. The highest biological yield was observed in MH 1142 (V_2) (3535.78 and 3572.06 kg/ha during 2024 and 2025). Among nutrient treatments, N_6 exhibited the maximum biological yield (3786.31 and 3828.97 kg/ha). The lowest biological yield was obtained under N_1 (3299.77 and 3303.91 kg/ha). The superior biological yield under N_6 indicates the positive influence of

Table 1. Effect of three mung bean varieties on the integrated application of chemical fertilisers, rhizobium inoculation and nano fertilisers

Treatments	Number of branches per plant		Number of pods per plant		Length of the pods (cm)		number of seeds per pod		Test weight (g)	
	2024	2025	2024	2025	2024	2025	2024	2025	2024	2025
Varieties										
V_1 (MH 421)	5.66	5.99	24.13	26.02	14.98	16.15	4.87	5.96	33.41	34.40
V_2 (MH 1142)	5.90	6.25	23.95	25.83	14.61	15.79	4.85	6.00	34.23	35.40
V_3 (MH 1762)	5.06	5.44	24.38	26.27	14.80	15.93	4.44	5.62	33.78	34.90
SEm ($\pm$)	0.09	0.08	0.21	0.21	0.12	0.11	0.11	0.10	0.36	0.34
CD (at 5 %)	0.17	0.16	NS	NS	0.24	0.23	0.21	0.21	NS	NS
Integrated nutrient management										
N_1 (15 kg N + 40 kg P_2O_5)	2.63	2.60	13.90	15.08	13.78	14.92	3.61	4.62	32.98	34.15
N_2 (15 kg N + 60 kg P_2O_5)	2.80	3.06	14.58	15.76	13.86	14.96	3.63	4.68	33.35	34.20
N_3 (20 kg N + 60 kg P_2O_5)	3.78	4.04	15.53	16.70	15.56	16.74	5.63	6.81	33.79	35.10
N_4 (15 kg N + 40 kg P_2O_5 + Rhizobium)	3.42	3.67	14.66	15.84	14.02	15.20	4.26	5.44	33.58	34.80
N_5 (15 kg N + 60 kg P_2O_5 + Rhizobium)	3.82	4.08	15.75	16.93	15.58	16.76	5.64	6.82	33.58	35.31
N_6 (20 kg N + 60 kg P_2O_5 + Rhizobium)	4.17	4.43	16.51	17.69	16.06	17.24	6.06	7.23	34.90	36.10
N_7 (RDF + 2 mL nano urea + 2 mL nano DAP/ha)	3.52	3.78	14.79	15.97	14.50	15.67	4.34	5.52	33.71	34.91
N_8 (RDF + 4 mL nano urea + 4 mL nano DAP/ha)	3.55	3.81	15.06	16.23	14.98	16.16	4.59	5.77	33.80	35.00
SEm ($\pm$)	0.14	0.13	0.34	0.34	0.19	0.19	0.17	0.17	0.60	0.56
CD (at 5 %)	0.28	0.27	0.69	0.69	0.39	0.37	0.35	0.34	NS	NS

Table 2. Effect of three mung bean varieties on the integrated application of chemical fertilisers, rhizobium inoculation and nano fertilisers

Treatments	Seed yield (kg/ha)		Stover yield (kg/ha)		Biological yield (kg/ha)		Harvest index (%)	
	2024	2025	2024	2025	2024	2025	2024	2025
Varieties								
V ₁ (MH 421)	968.52	993.52	2573.44	2585.28	3541.96	3578.80	27.40	27.75
V ₂ (MH 1142)	996.52	1015.85	2538.27	2556.22	3535.78	3572.06	28.48	28.53
V ₃ (MH 1762)	964.03	972.82	2496.78	2514.78	3460.81	3487.61	28.20	27.92
SEm(±)	15.05	14.01	23.63	22.38	25.55	26.13	0.35	0.34
CD (at 5 %)	NS	NS	47.56	40.05	51.42	52.59	NS	NS
Integrated nutrient management								
N ₁ (15 kg N + 40 kg P ₂ O ₅)	911.95	914.95	2387.83	2388.96	3299.77	3303.91	27.77	27.84
N ₂ (15 kg N + 60 kg P ₂ O ₅)	926.78	937.44	2429.18	2424.82	3355.96	3362.26	27.74	27.99
N ₃ (20 kg N + 60 kg P ₂ O ₅)	1013.39	1034.72	2610.26	2631.59	3623.64	3666.31	27.97	28.23
N ₄ (15 kg N + 40 kg P ₂ O ₅ + <i>Rhizobium</i>)	953.07	974.41	2471.38	2492.71	3424.45	3467.12	28.49	28.17
N ₅ (15 kg N + 60 kg P ₂ O ₅ + <i>Rhizobium</i>)	1017.22	1038.55	2621.83	2643.17	3639.05	3681.72	27.95	28.21
N ₆ (20 kg N + 60 kg P ₂ O ₅ + <i>Rhizobium</i>)	1068.65	1089.88	2717.76	2739.10	3786.31	3828.97	28.23	28.45
N ₇ (RDF + 2 mL nano urea + 2 mL nano DAP/ha)	956.15	977.48	2522.80	2544.13	3478.95	3521.61	28.09	27.81
N ₈ (RDF + 4 mL nano urea + 4 mL nano DAP/ha)	963.75	985.08	2530.93	2552.26	3494.67	3537.34	27.98	27.85
SEm(±)	24.57	22.87	38.59	36.55	41.72	42.66	0.58	0.55
CD (at 5 %)	49.46	46.04	77.67	73.57	83.97	85.88	NS	NS

integrated nutrient management in improving both vegetative and reproductive growth, thereby maximising overall biomass production (35–36). The harvest index remained statistically non-significant across varieties and nutrient management treatments during both years, ranging from 27.77 to 28.95 % in 2024 and 27.84 to 28.45 % in 2025. Among varieties, negligible numerical differences were observed, with MH 1142 (V₂) recording a slightly higher index (28.48 and 28.53 %) compared to MH 421 (V₁) and MH 1762 (V₃). The consistency in harvest index values indicates a stable partitioning of assimilates between economic (seed) and vegetative (stover) yields across all genotypes and nutrient management treatments (37).

Conclusion

The findings from the two-year study demonstrated that both varietal differences and nutrient management practices significantly influenced the growth and productivity of mungbean. Among the varieties, MH 1142 (V₂) consistently outperformed other varieties in growth and yield-attributing traits such as branches per plant, pods per plant, pod length and seed yield, reflecting its higher genetic potential and better nutrient use efficiency. Among the integrated nutrient management practices, the application of 20 kg N + 60 kg P₂O₅ + *Rhizobium* (N₆) recorded the maximum values for branches per plant, pods per plant, pod length, seed yield, as well as stover and biological yields, mainly due to enhanced nodulation, efficient nutrient uptake and improved assimilate partitioning. The results clearly indicate that the combined application of chemical fertilisers and biofertilisers significantly enhances crop growth, yield attributes and overall productivity of mungbean under field conditions. Hence, the integrated nutrient management approach involving N₆ along with the high-yielding variety MH 1142 can be recommended for achieving higher and sustainable mungbean yields in similar agro-ecological regions. Adoption of this recommendation can also provide substantial economic benefits to farmers by increasing seed and biomass yield, improving nutrient use efficiency, reducing dependence on excessive chemical fertilisers and ultimately enhancing net returns and benefit–cost ratio, thereby contributing to improved farm profitability and livelihood security in the region.

Authors' contributions

LK, IS and AB have contributed equally to designing the research problem, supervising the research, data analysis and writing the ms research paper. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

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