



RESEARCH ARTICLE

Performance of mungbean (*Vigna radiata* L.) in response to foliar application of nano and conventional fertilisers under reduced nitrogen, phosphorus and potassium levels in the indo-gangetic plain zone

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Abstract

Mungbean (*Vigna radiata*), an important pulse crop for nutritional security in India, often exhibits low productivity due to poor soil fertility and imbalanced nutrient management. A field experiment was conducted during the zaid season of 2024 at the Students Instructional Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, to evaluate the effect of foliar nutrition and nano-fertilisers on growth, yield and protein content. The experiment was laid out in a randomised block design with 8 treatments and 3 replications. Plant population remained non-significant across treatments, with the maximum values being recorded under the treatment comprising 75 % Nitrogen, phosphorus and potassium (NPK) + nano urea at 25 days after sowing (DAS) + nano diammonium phosphate (DAP) at 40 DAS (22.89 plants m⁻² at 30 DAS and 22.52 plants m⁻² at harvest). Growth parameters were significantly improved under the treatment involving 75 % NPK + nano urea at 25 DAS + nano DAP at 40 DAS, which recorded the highest plant height (49.87 cm), number of branches per plant (5.84), dry matter accumulation (14.62 g plant⁻¹), number of root nodules (18.76 plant⁻¹) and nodule dry weight (0.42 g plant⁻¹). Yield attributes were also maximised, including the number of pods per plant (14.58), seeds per pod (8.94), pod length (6.49 cm), seed weight per plant (3.98 g) and pod weight per plant (5.24 g), while test weight was non-significant but highest (41.17 g) under the treatment, comprising 75 % NPK + nano urea at 25 DAS + nano DAP at 40 DAS. Consequently, the same treatment produced the highest biological yield (1877.21 kg ha⁻¹), seed yield (713.14 kg ha⁻¹), protein content (24.07 %) and protein yield (204.51 kg ha⁻¹). These findings suggest that integrating 75 % of the recommended NPK dose with the foliar application of nano urea and nano DAP enhances nutrient use efficiency, improves growth and yield attributes and offers a sustainable strategy for increasing mungbean productivity and quality.

Keywords: nano di-ammonium phosphate; nano urea; nutrient; nutritional; protein; sustainability

Introduction

Pulses, a crucial member of the legume family, provide essential nutrition for billions of people globally (1, 2). Pulses are a fundamental protein-rich food staple for India's vegetarian and rural communities, ensuring nutritional security. These edible legumes offer a unique combination of lysine-rich, high-protein, low-fat and high-fibre content, making them an increasingly preferred choice over non-vegetarian options. As the world's largest producer, processor and consumer of pulses, India remains significant contributor to the global pulse market (3). The states of Rajasthan, Maharashtra and Karnataka are the top mungbean producing states according to the Indian Ministry of Agriculture. Pulses contribute approximately 14 % of the total protein in the average Indian diet, serving as a primary source of dietary protein, particularly for the poorest segments of the population. Mungbean (*Vigna radiata*) is a prominent food legume in India that thrives in arid and semi-arid regions. It ranks third among pulse crops, after chickpea and pigeonpea and ahead of other pulses grown in India (3). Mungbean or green gram belongs to the family Fabaceae (Leguminosae). It is a self-pollinated, short-duration crop that exhibits tolerance to drought and flourishes in well-drained loamy to sandy loam soils, making it ideal for areas with unpredictable rainfall (4, 5).

India's agricultural system is highly dependent on imported fertilisers, which have resulted in increasing input costs, especially with the gradual reduction in government subsidies (6, 7). Fertilisers contribute significantly accounting for approximately 35–40 % of agricultural productivity by directly influencing plant growth and development. However, the excessive and imbalanced use of inorganic fertilisers has led to serious concerns, including soil degradation, declining soil fertility, reduced factor productivity and adverse effects on human health (8). These challenges emphasise the urgent need to adopt balanced and sustainable nutrient management practices, along with the exploration of eco-friendly alternatives to ensure long-term productivity and environmental sustainability.

Green gram or mungbean productivity in India has remained low and stagnant in recent years, primarily because it is cultivated on marginal and sub-marginal lands with poor soil fertility. Inadequate and improper fertilisation practices further limit its yield potential (3). Foliar nutrition is an efficient approach for supplying essential nutrients directly to plants during critical growth stages. It enables the rapid absorption of nutrients such as nitrogen, phosphorus, potassium (NPK) and micronutrients through the leaf surface, bypassing soil-related limitations like poor moisture availability, temperature fluctuations and nutrient imbalances. Foliar feeding ensures the rapid correction of deficiencies, enhances plant health, maintains nutrient balance and improves yield potential while minimising nutrient losses. Common foliar fertilisers include urea (2 %), containing 46 % nitrogen and diammonium phosphate (DAP) (2 %), which supplies both nitrogen (18 %) and phosphorus (46 % P_2O_5). These are typically applied as dilute solutions for effective nutrient delivery.

In addition to conventional foliar feeding, nanotechnology offers promising solutions for modern agriculture. Nano-fertilisers are developed by encapsulating nutrients within nanoscale materials, enabling controlled and slow nutrient release (9). Their high surface area and small particle size enhance nutrient use efficiency, reduce nutrient losses and improve plant nutrient uptake.

These fertilisers are specifically designed to meet crop nutrient requirements more precisely than conventional fertilisers. Foliar application of nano-fertilisers has been shown to improve plant growth parameters, such as plant height, leaf area, chlorophyll content and dry matter accumulation (10). It also enhances photosynthesis, the translocation of assimilates and ultimately, crop yield. Nano-urea, with particle sizes of 20–50 nm, significantly improves nitrogen use efficiency (over 80 %) compared with conventional urea. Similarly, nano-DAP provides readily available nitrogen and phosphorus and enhances seed vigour, chlorophyll content and photosynthetic efficiency.

Overall, integrating foliar nutrition with nano-fertilisers presents a sustainable strategy to improve nutrient use efficiency, reduce environmental impact and enhance productivity in green gram cultivation.

Materials and Methods

Experimental site

The current study was conducted during the zaid season of the cropping year 2024 at Student's Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh. Kanpur is located between 25°56' and 28°58' N latitude and 79°31' and 80°34' E longitude, with a mean sea level of 125.9 m. The city lies in India's upper Indo-Gangetic plain region, located in the Central Plain Zone of Uttar Pradesh, on the right bank of the Ganga River.

Soil characteristics

The physico-chemical properties of the experimental soil were analysed using standard procedures. The soil was classified as sandy loam based on the triangular method of soil textural classification. The soil pH was 7.5, determined using a glass electrode pH meter (11), indicating a neutral to slightly alkaline reaction. Electrical conductivity (EC) was 0.33 deciSiemens per metre ($dS\ m^{-1}$), measured as per United States Department of Agriculture (USDA) Handbook No. 60 (12), suggesting that the soil is non-saline. The organic carbon content was 0.42 %, estimated by the Walkley and Black method (13), indicating a low organic matter status. The available nitrogen content was 181.20 $kg\ ha^{-1}$, determined by the alkaline potassium permanganate method (14), which falls within the low category. The available phosphorus content was 16.00 $kg\ ha^{-1}$, analysed using Olsen's method (15), indicating medium availability. The available potassium content was 149.30 $kg\ ha^{-1}$, determined by the modified sodium tetraphenylboron method (16) and was categorised as medium.

Experimental design and treatment details

The experiment was conducted in a randomised block design (RBD) with 3 replications. Eight treatments were included in the study and their details are as follows: T₁: control; T₂: 100 % NPK (20 kg N + 40 kg P + 20 kg K); T₃: 75 % NPK + foliar spray of nano urea at 25 days after sowing (DAS); T₄: 75 % NPK + foliar spray of nano urea at 25 DAS and diammonium phosphate (DAP) (2 %) at 25 DAS; T₅: 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS; T₆: 75 % NPK + foliar spray of nano DAP at 25 DAS; T₇: 75 % NPK + foliar spray of DAP (2 %) at 40 DAS and T₈: 75 % NPK + foliar spray of urea (2 %) and DAP (2 %) at 40 DAS.

Fertiliser application

Treatments receiving 100 % NPK were supplied with 20 kg N, 40 kg P and 20 kg K ha⁻¹, while treatments under 75 % NPK received proportionately reduced quantities of these nutrients. Foliar application of nutrients was carried out as per the treatment details using a knapsack sprayer. Nano urea, nano DAP, urea (2 %) and DAP (2 %) solutions were sprayed at the specified growth stages, i.e. 25 and/or 40 DAS, depending on the treatment. Care was taken to ensure uniform spray coverage of the crop canopy during application.

Grain protein content (%)

The study used Kjeldahl's method to determine the nitrogen content in green gram seeds and the grain protein content was then calculated using the following formula (FAO):

Grain protein content (%) = Nitrogen content in grains (%) × 6.25

Protein yield

Protein yield was determined by calculating the product of seed yield and protein content and then dividing by 100. This calculation provides a measure of the total protein produced per unit area.

$$\text{Protein yield} = \frac{\text{Seed yield} \times \text{Protein content (\%)}}{100}$$

Statistical analysis

The data were statistically analysed using the OPSTAT web server. Statistical significance was tested at the 5 % ($p=0.05$) level.

Results and Discussion

Growth parameters

The observations on plant population indicated non-significant variation among the treatments at different growth stages (Table 1). At 30 DAS, the highest plant population was recorded under 75 % NPK + foliar spray of nano urea at 25 DAS along with nano DAP at 40 DAS (22.89 plants m⁻²), closely followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS (22.86 plants m⁻²). At harvest, a similar trend was observed, with values of 22.52 and 22.37 plants m⁻², respectively, whereas the lowest population occurred under control (Fig. 1). The non-significant differences suggest that the plant stand was mainly governed by initial germination and establishment rather than by nutrient treatments, which is in agreement with earlier findings (17, 18).

Plant height was significantly influenced by nutrient management practices (Table 1, Fig. 2). The tallest plants were recorded with 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS, followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS. Enhanced plant height under these treatments may be attributed to better nitrogen availability and improved nutrient uptake efficiency, leading to increased cell elongation and vegetative growth (19, 20). The lowest plant height was observed under the control due to nutrient deficiency.

The number of branches per plant showed a significant response to the treatments (Table 1, Fig. 3). The highest number of branches per plant was observed with 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS, followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS. Increased branching might be due to improved nitrogen and

Table 1. Effect of treatments on plant population, plant height, number of branches per plant, dry weight, number of root nodules per plant and dry weight of root nodules per plant

Treatment	Plant population (m ⁻²)		Plant height (cm)		Number of branches per plant		Dry weight (g)		Number of root nodules per plant		Dry weight of root nodules per plant (g)	
	30 DAS	At harvest	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
T ₁	22.57	22.05	14.67	34.12	35.23	34.2	2.18	10.02	10.46	11.05	18.87	9.47
T ₂	22.63	22.09	14.98	35.24	36.68	3.91	2.29	10.33	10.74	11.96	21.23	10.25
T ₃	22.78	22.21	15.22	37.37	38.09	4.43	2.37	10.71	11.13	12.5	22.03	12.08
T ₄	22.86	22.37	15.37	37.95	38.64	4.69	2.41	10.92	11.29	12.72	22.46	12.41
T ₅	22.89	22.52	15.63	39.26	40.59	4.77	2.47	11.14	11.52	12.98	22.82	12.65
T ₆	22.75	22.18	15.14	36.53	37.84	4.31	2.35	10.63	11.05	12.41	21.81	11.64
T ₇	22.69	22.13	15.05	35.78	37.16	4.09	2.32	10.56	10.91	12.19	21.55	11.37
T ₈	22.81	22.29	15.29	37.45	38.37	4.56	2.41	10.78	11.17	12.56	22.17	12.2
SE (m ±)	0.401	0.394	0.203	0.514	0.428	0.036	0.037	0.192	0.164	0.154	0.355	0.130
CD (5 %)	NS	NS	NS	1.559	1.297	0.112	0.114	0.584	0.497	0.465	1.076	0.396
											0.634	0.403

DAS: days after sowing; CD: critical difference; NS: non-significant.

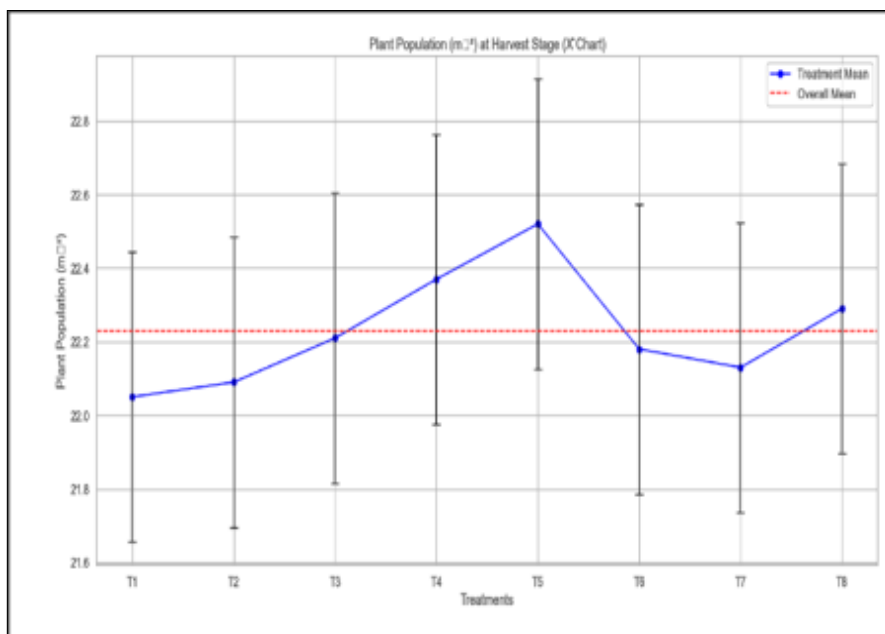


Fig. 1. Plant population at harvest (m⁻²).

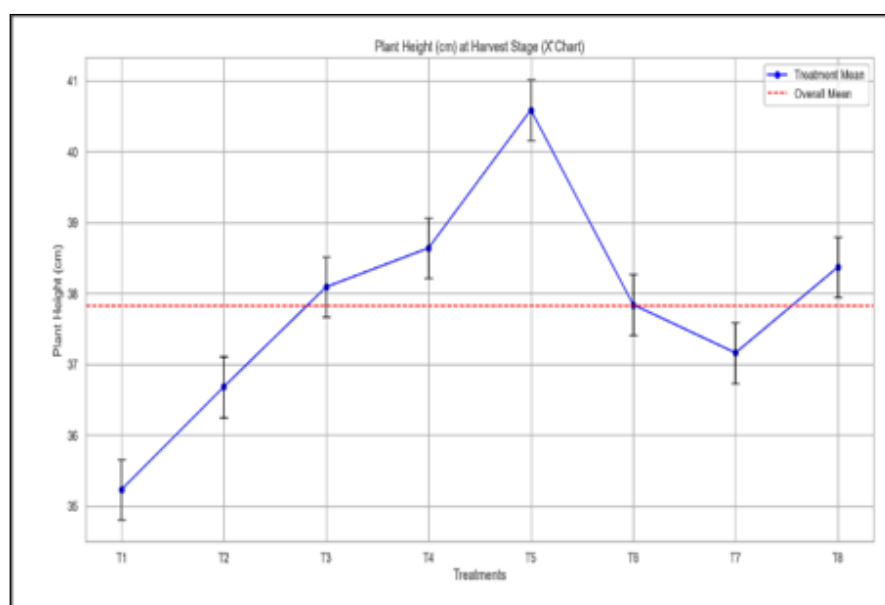


Fig. 2. Plant height at harvest (cm).

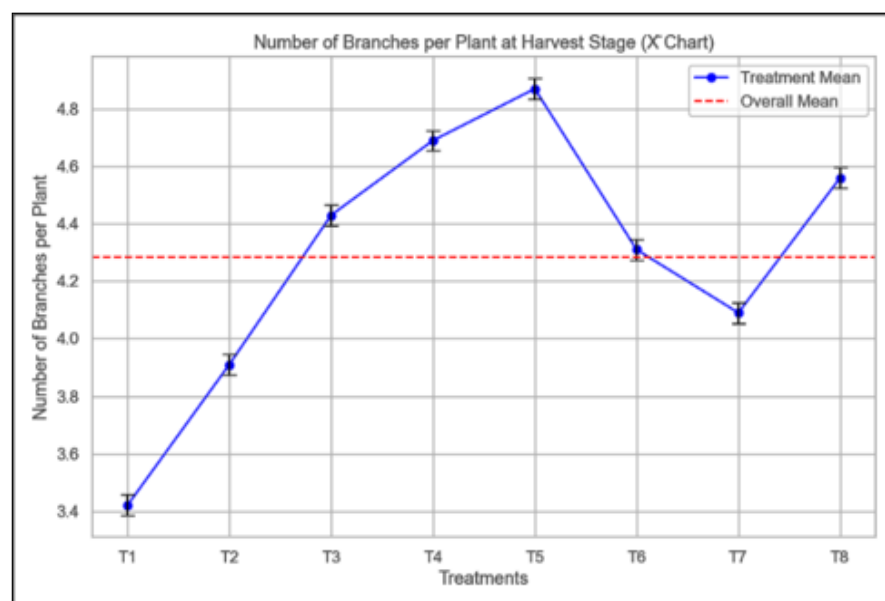


Fig. 3. Number of branches per plant (at harvest).

phosphorus nutrition, which enhances meristematic activity and lateral growth (21, 22).

Dry matter accumulation per plant increased significantly with improved nutrient supply (Table 1, Fig. 4). The maximum dry weight was recorded under 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS, followed by the combined application of nano urea and DAP spray at 25 DAS. Higher dry matter production could be due to increased photosynthetic activity and better translocation of assimilates under balanced fertilisation (23, 24).

The number of root nodules per plant was also significantly affected (Table 1, Fig. 5). The highest nodulation was recorded with 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS, followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS. Improved nodulation may be due to enhanced phosphorus availability and better root development, which favours symbiotic activity (18, 25).

The dry weight of root nodules per plant followed a trend similar to that of nodulation (Table 1, Fig. 6). The highest value was

recorded under 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS, followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS. Increased nodule biomass indicates higher nitrogen fixation efficiency, which ultimately supports plant growth (22, 26).

Yield attributes

The number of pods per plant varied significantly among the treatments (Table 2, Fig. 7). The maximum number of pods per plant (14.58) was recorded under 75 % NPK + foliar spray of nano urea at 25 DAS and Nano DAP at 40 DAS, followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS (14.15), whereas the minimum was observed under the control (11.72). Increased pod formation may be attributed to better nutrient availability during the reproductive stages (27, 28).

The number of seeds per pod showed a similar trend (Fig. 8), with the highest value recorded under 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS (8.94), followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS (8.62). Improved seed set may be due to better nutrient

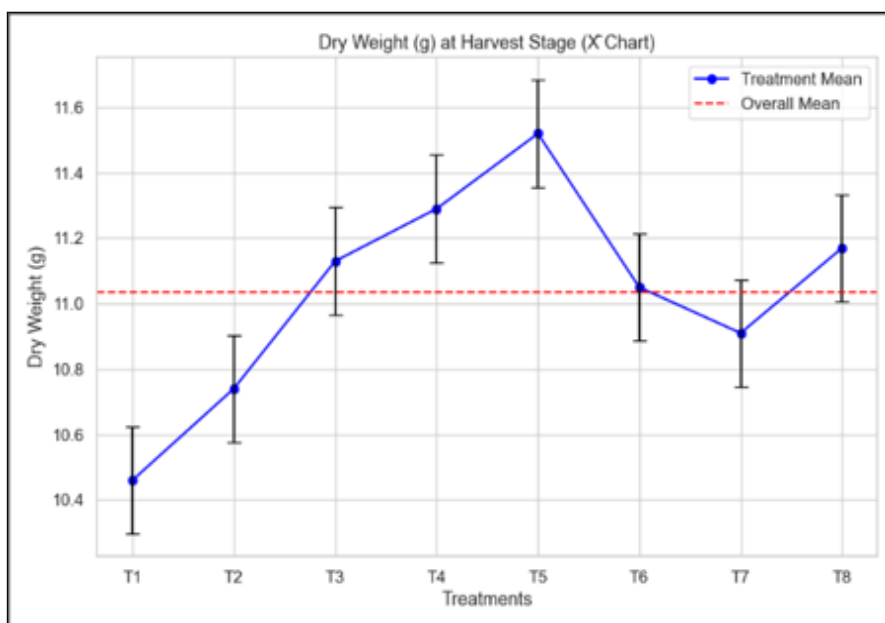


Fig. 4. Dry weight at harvest (g).

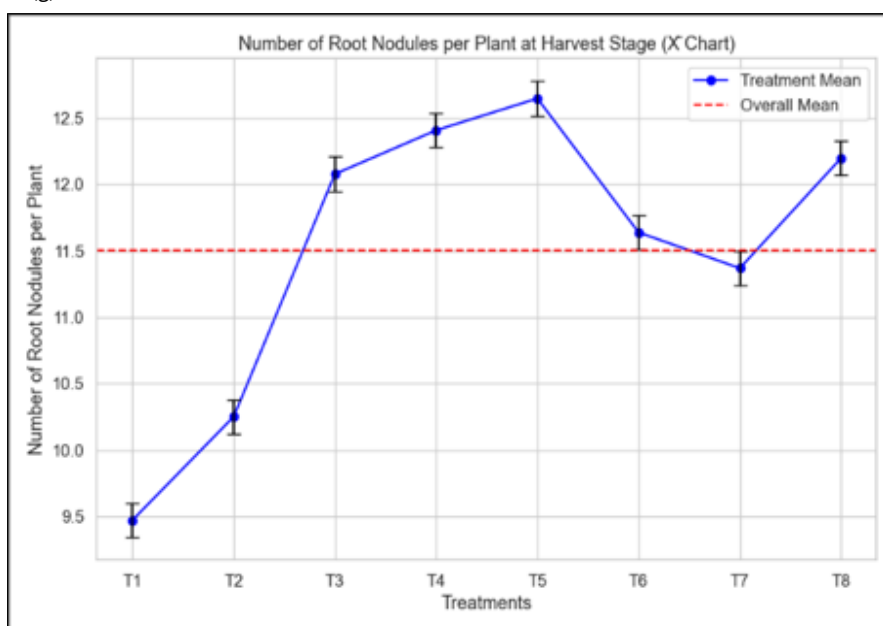


Fig. 5. Root nodules per plant at harvest.

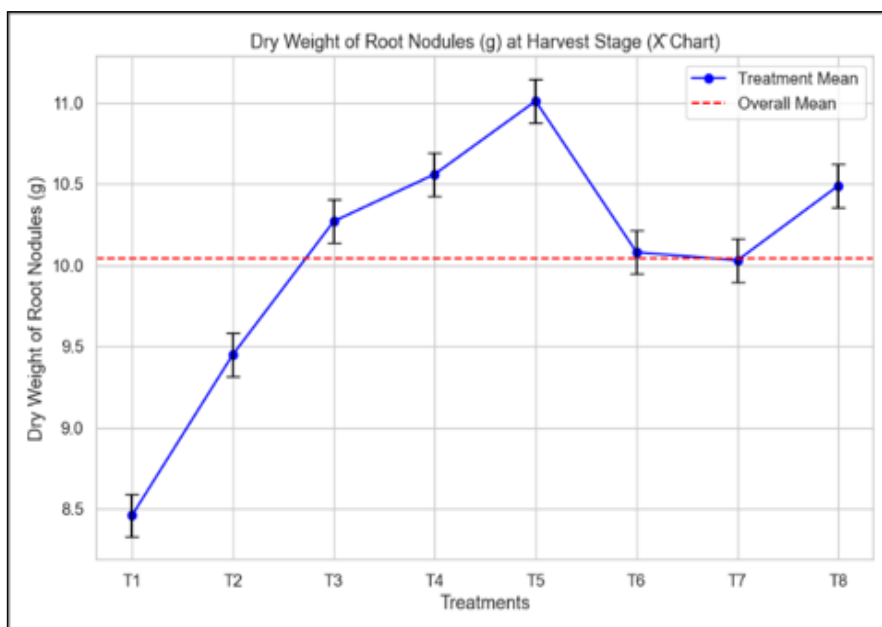


Fig. 6. Dry weight of root nodules at harvest (g).

Table 2. Effect of treatments on number of pods plant⁻¹, weight of pod plant⁻¹(g), pod length (cm), number of seeds pod⁻¹, weight of seeds plant⁻¹ (g), test weight (g) at harvest

Treatments	Number of pods plant ⁻¹	Number of seed pod ⁻¹	Pod length (cm)	Weight of seed plant ⁻¹ (g)	Weight of pod plant ⁻¹ (g)	Test weight (g)
Control	11.72	7.52	5.74	2.73	3.57	40.16
100 % NPK (20kg N + 40 kg P + 20 kg K)	12.97	7.89	5.86	2.95	3.89	40.28
75 % NPK + Foliar spray nano urea at 25 DAS	13.86	8.37	6.15	3.43	4.41	40.56
75 % NPK + Foliar spray nano urea at 25 DAS and DAP (2 %) at 25 DAS	14.15	8.62	6.36	3.61	4.75	40.73
75 % NPK + Foliar spray nano urea at 25 DAS and nano DAP at 40 DAS	14.58	8.94	6.49	3.98	5.24	41.17
75 % NPK + Foliar spray nano DAP at 25 DAS	13.67	8.26	6.07	3.26	4.28	40.39
75 % NPK + Foliar spray DAP (2 %) at 40 DAS	13.53	8.04	5.93	3.12	4.15	40.32
75 % NPK + Foliar spray urea (2 %) at 40 DAS and DAP (2 %) at 40 DAS	14.09	8.52	6.25	3.57	4.63	40.64
SE(m ±)	0.179	0.115	0.834	0.579	0.087	0.624
CD at 5 %	0.545	0.348	0.253	0.176	0.264	NS

NPK: nitrogen, phosphorus and potassium; DAS: days after sowing; NS: non-significant.

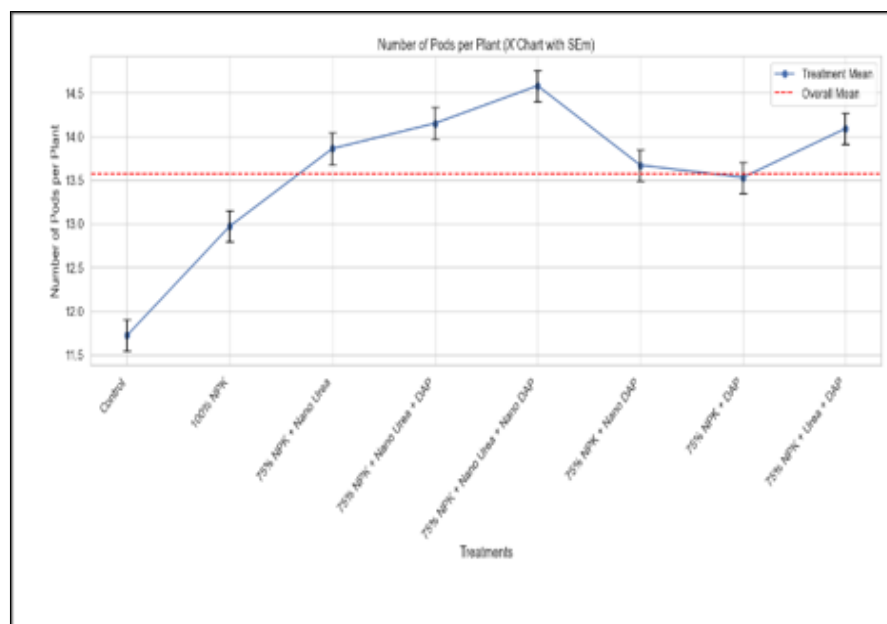


Fig. 7. Number of pods per plant.

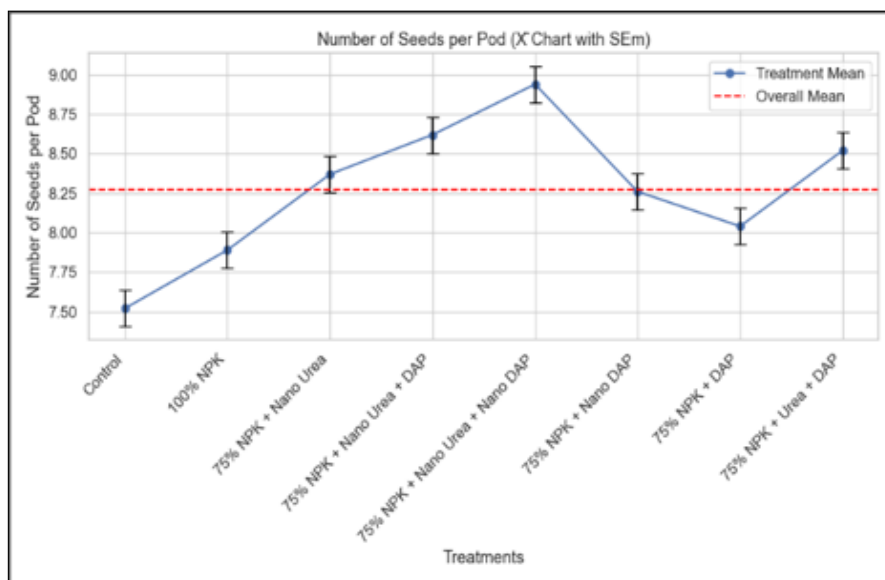


Fig. 8. Number of seeds per pod.

translocation and enhanced reproductive efficiency (21, 29).

The pod length was significantly influenced, with the highest value observed under 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS (6.49 cm), followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS (6.36 cm) (Fig. 9). Adequate phosphorus and nitrogen supply likely enhanced cell division and elongation in the pods (20, 23).

The weight of seeds per plant (Fig. 10) was highest under 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS (3.98 g), followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS (3.61 g), while the lowest was recorded under the control (2.73 g). This increase may be due to improved assimilate partitioning towards the seeds (30, 31).

The weight of pods per plant (Fig. 11) was also highest under 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS (5.24 g), followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS (4.75 g). Better nutrient supply during pod development likely enhanced pod filling (32, 33).

The differences in test weight were non-significant (Fig. 12); however, the highest value was recorded under 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS (41.17 g), followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS (40.73 g), which is consistent with findings reported earlier (34, 35).

Yield

Biological yield (Table 3, Fig. 13) was significantly higher under 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS (1877.21 kg ha⁻¹), followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS (1851.66 kg ha⁻¹), whereas the lowest was recorded under the control (1431.78 kg ha⁻¹). Increased biomass production is attributed to improved nutrient uptake and enhanced photosynthesis (24, 36).

Seed yield (Table 3, Fig. 14) was highest under 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS (713.14

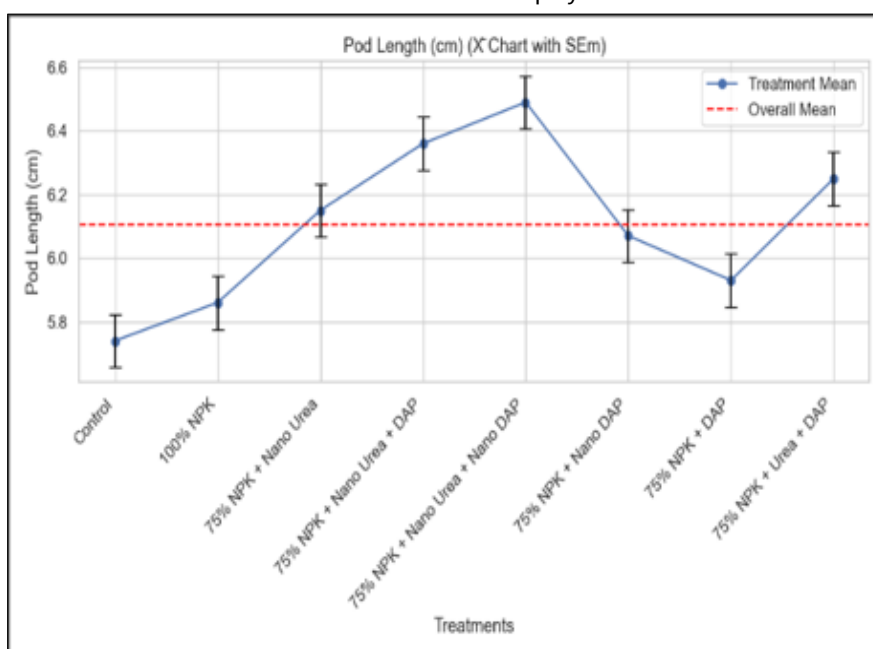


Fig. 9. Pod length (cm).



Fig. 10. Seed weight per plant (g).

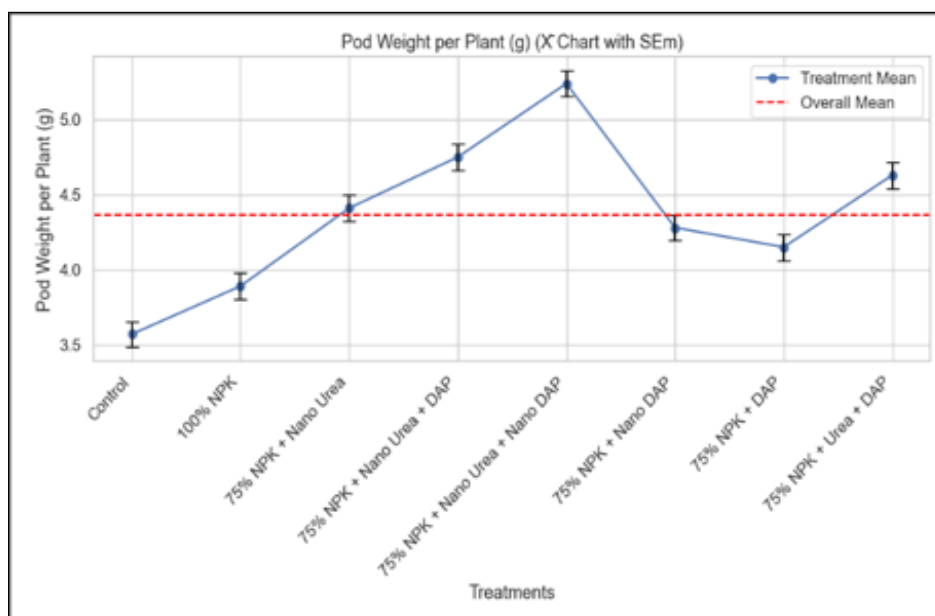


Fig. 11. Pod weight per plant (g).

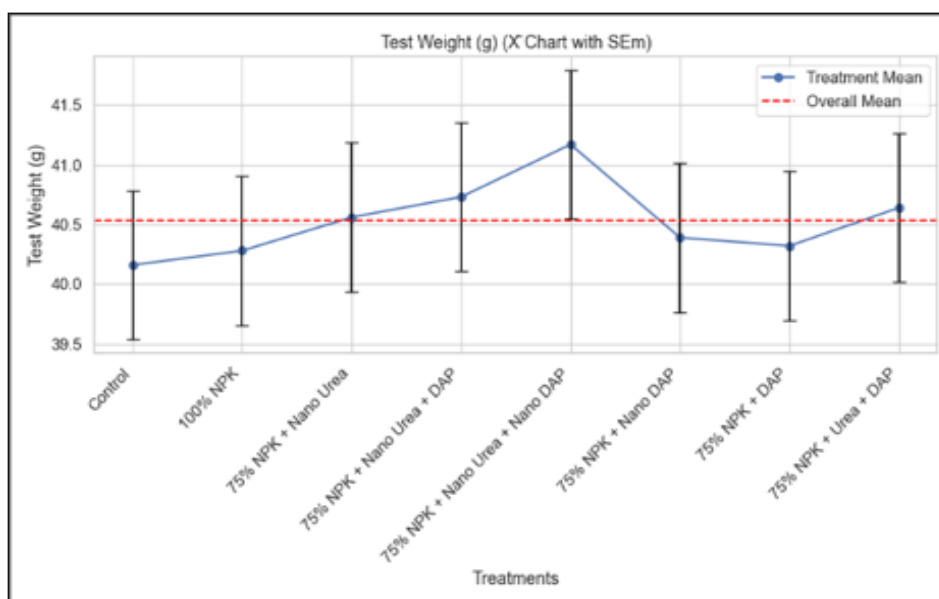
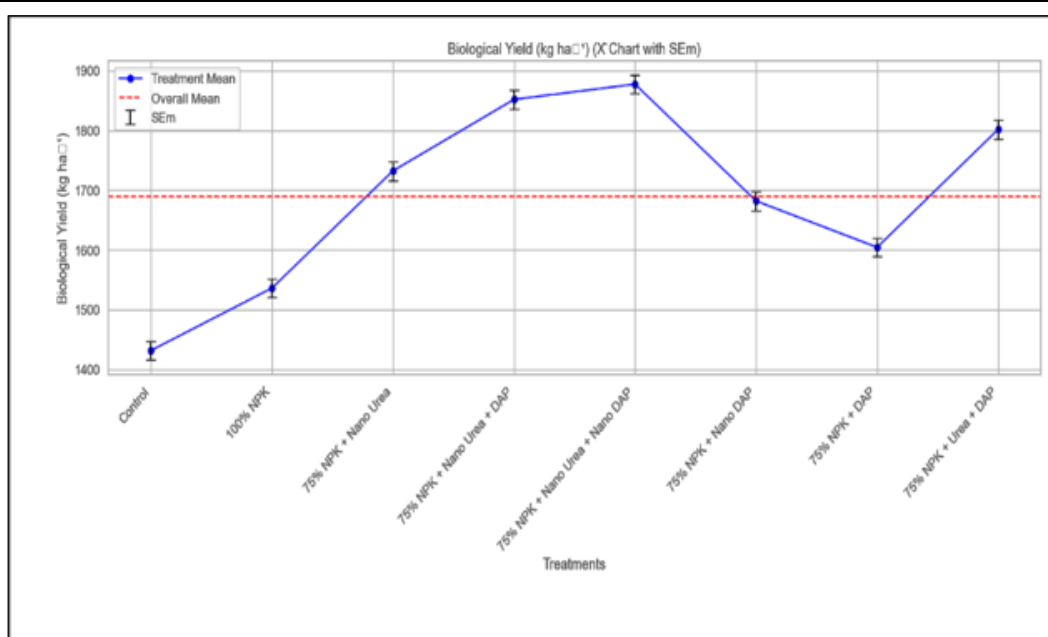
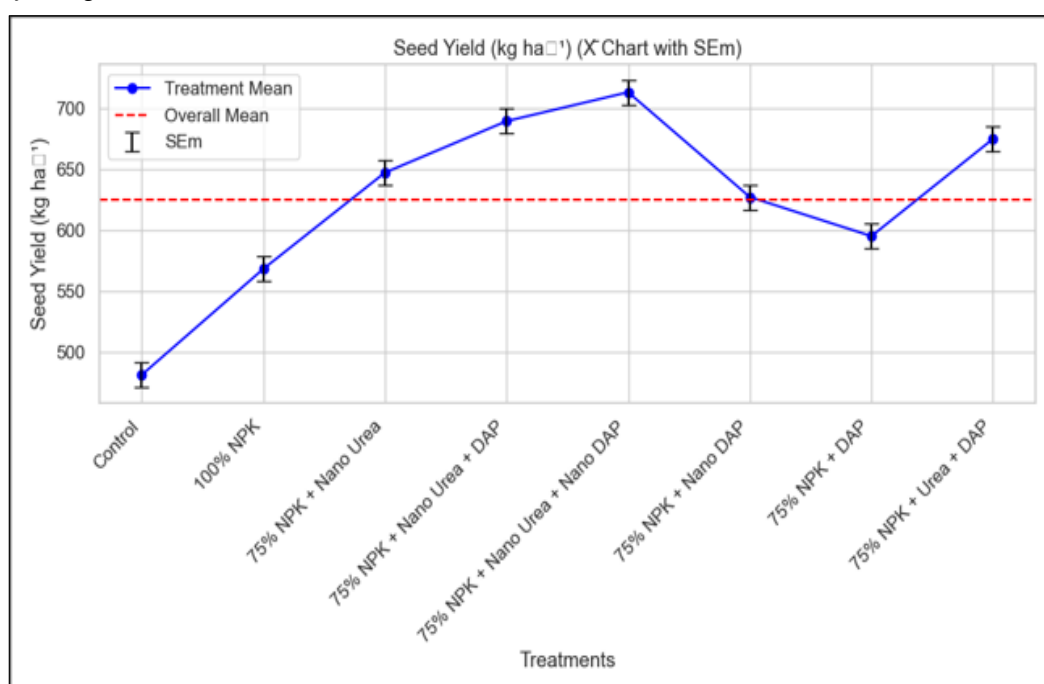


Fig. 12. Test Weight (g).

Table 3. Effect of treatments on biological yield (kg ha^{-1}), seed yield (kg ha^{-1}), stover yield (kg ha^{-1}), harvest index (%) at harvest

Treatments	Biological yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Grain protein content (%)	Protein yield (kg ha^{-1})
Control	1431.78	481.24	22.35	145.37
100 % NPK (20kg N + 40 kg P + 20 kg K)	1536.16	568.18	22.64	157.25
75 % NPK + Foliar spray nano urea at 25 DAS	1732.25	647.19	23.25	182.84
75 % NPK + Foliar spray nano urea at 25 DAS and DAP (2 %) at 25 DAS	1851.66	689.43	23.73	196.48
75 % NPK + Foliar spray nano urea at 25 DAS and nano DAP at 40 DAS	1877.21	713.14	24.07	204.51
75 % NPK + Foliar spray nano DAP at 25 DAS	1681.82	627.21	23.11	175.13
75 % NPK + Foliar spray DAP (2 %) at 40 DAS	1604.41	595.13	22.75	166.92
75 % NPK + Foliar spray urea (2 %) at 40 DAS and DAP (2 %) at 40 DAS	1801.57	674.92	23.48	187.29
SE(m ±)	15.784	10.207	0.302	2.151
CD at 5 %	47.875	30.959	0.915	6.526

**Fig. 13.** Biological yield (kg ha^{-1}).**Fig. 14.** Seed yield (kg ha^{-1}).

kg ha⁻¹), followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS (689.43 kg ha⁻¹). The enhanced yield may be due to improved growth and yield attributes (37, 38).

Grain protein content (Fig. 15) was highest under 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS (24.07 %), followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS (23.73 %). Improved nitrogen availability likely enhanced protein synthesis (19, 39).

Protein yield (Fig. 16) was also highest under 75 % NPK + foliar spray of nano urea at 25 DAS and nano DAP at 40 DAS (204.51 kg ha⁻¹), followed by 75 % NPK + foliar spray of nano urea at 25 DAS and DAP (2 %) at 25 DAS (196.48 kg ha⁻¹), which corroborates earlier reports (40, 41).

Conclusion

In terms of practical agricultural application, the results of this study clearly indicate that reducing basal fertiliser application to 75 % of the recommended NPK dose, combined with foliar sprays of nano urea at 25 days after sowing (DAS) and nano diammonium phosphate (DAP) at 40 DAS, is an efficient and economical practice

for mungbean cultivation. This approach improved plant growth, nodulation and yield attributes and resulted in a higher seed yield (713.14 kg ha⁻¹) and protein yield (204.51 kg ha⁻¹) compared with conventional practices. Therefore, adopting this integrated nutrient management strategy can help farmers achieve higher productivity, better grain quality and improved profitability while maintaining soil health and promoting sustainable agriculture

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Authors' contributions

AS¹ conducted the investigation, laboratory analysis and led the methodology. AS¹, DSS, NT, RKP, SKS¹ and SM contributed to conceptualisation of the study. AS¹ and PS were responsible for data curation. AS¹, DKM, DKR, PKJ, SKS² and AS² developed the methodology. AS¹, DSS, PS, DS¹ and DS² provided resources. AS¹,

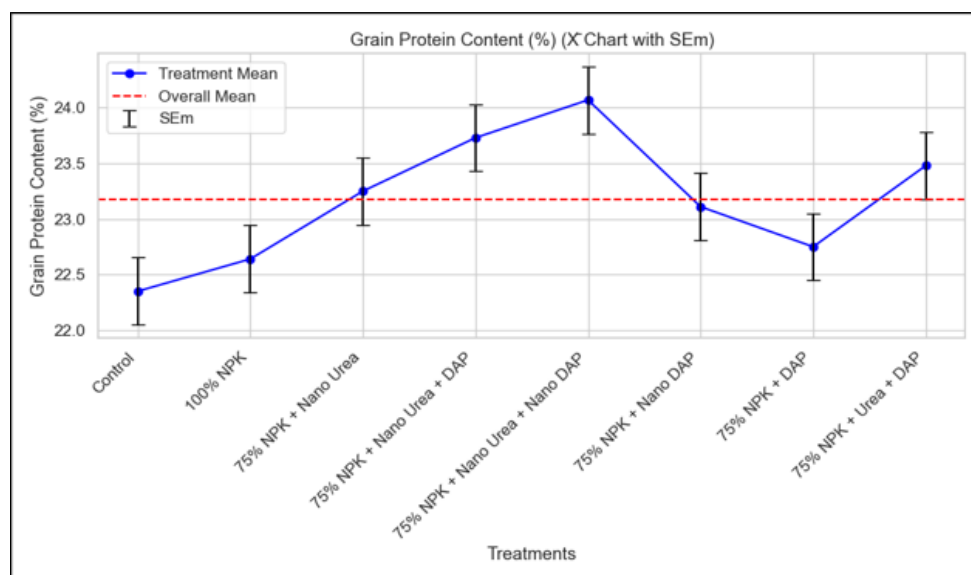


Fig. 15. Grain protein content (%).

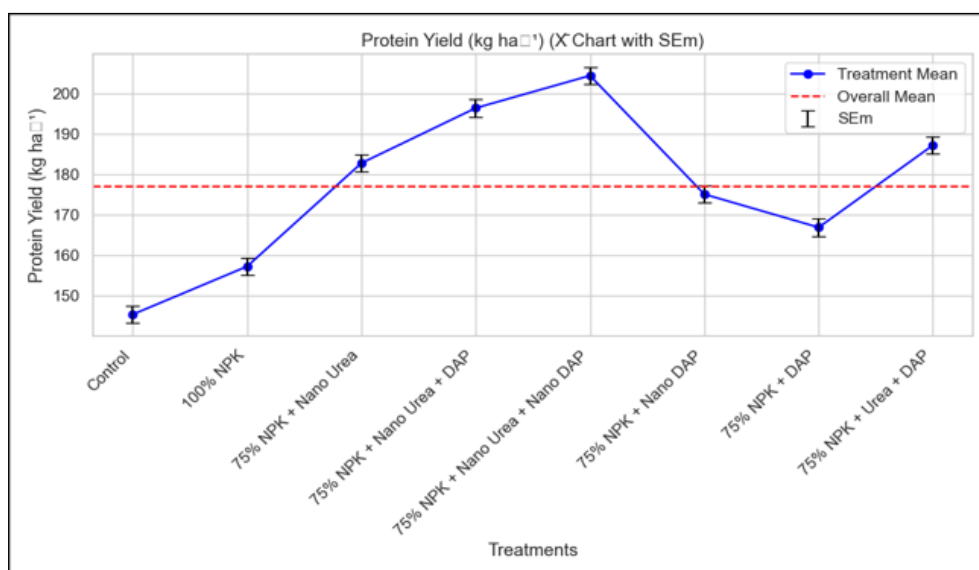


Fig. 16. Protein yield (kg ha⁻¹).

DSS, SS and UP prepared the manuscript. DSS and PS reviewed and edited the manuscript. All authors read and approved the final manuscript. [AS¹ - Anuraj Sachan and AS² - Anurag Singh; SKS¹ - Shivendra Kumar Singh and SKS² - Shani Kumar Singh; DS¹ - Dheeraj Singh and DS² - Dushyant Singh]

Compliance with ethical standards

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

Ethical issues: None

References

- Singh N. Pulses: an overview. *J Food Sci Technol*. 2017;54(4):853–7. <https://doi.org/10.1007/s13197-017-2537-4>
- Kurdekar AK, Ashoka P, Sachan DS, Reddy KJ, Jena P, Saryam M, et al. Optimising water utilisation to enhance pulse production: a review. *Int J Plant Soil Sci*. 2023;35(15):365–75. <https://doi.org/10.9734/IJPSS/2023/v35i153117>
- Sachan DS, Siddiqui MZ, Singh S. Global perspective of grain legume production, trade and policy imperatives. In: *Grain legumes towards sustainable agrifood systems*. New Delhi: NIPA; 2025. p. 141–53.
- Mishra GP, Dikshit HK, Tripathi K, Aski MS, Pratap A, Dasgupta U, et al. Mungbean breeding. In: *Fundamentals of field crop breeding*. Singapore: Springer Nature; 2022. p. 1097–149.
- Silva Volpato ND, Gomez FM, Giménez VD, Ciampitti IA. A global dataset on mungbean for managing seed yield and quality. *Sci Data*. 2025;12(1):658. <https://doi.org/10.1038/s41597-025-05016-6>
- Singhaal R. Sowing dependency: unravelling the rational addiction of agricultural fertiliser subsidies in India. *Agric Econ Res Rev*. 2025;38(1):61–70. <https://doi.org/10.1177/09713441251389413>
- Khan S, Khan AT, Tiwari MS. Counter strategies for solving import dependency and developing India into a self-reliant nation. *Eur Econ Lett*. 2025;15(2):1718–1728.
- Xing Y, Xie Y, Wang X. Enhancing soil health through balanced fertilization: a pathway to sustainable agriculture and food security. *Front Microbiol*. 2025;16:1536524. <https://doi.org/10.3389/fmicb.2025.1536524>
- Gupta P, Dhar H, Bagal YS, Jaglan S. Smart nano-fertilisers: a path to sustainable agriculture. *Environ Geochem Health*. 2025;47(10):443. <https://doi.org/10.1007/s10653-025-02749-6>
- Ding M, Tang L, Zhang L, Yang Y, Li H, Ma Q, et al. Balanced application of nano-macronutrients promotes growth, productivity and quality through modulation of antioxidative activities in wheat. *Plant Sci*. 2025;112807. <https://doi.org/10.1016/j.plantsci.2025.112807>
- Jackson ML. *Soil chemical analysis*-Prentice Hall of India Pvt. Ltd., New Delhi. 1973; pp. 98.
- Richards LA, editor. *Diagnosis and improvement of saline and alkali soils*. US Government Printing Office; 1954.
- Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*. 1934;37(1):29–38.
- Subbaiah BV, Asija GL. A rapid procedure for estimation of available nitrogen in soil. *Curr. Sci.* 1956; 25:259–60.
- Olsen SR. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Department of Agriculture; 1954.
- Cox AE, Joern BC, Brouder SM, Gao D. Plant-available potassium assessment with a modified sodium tetraphenylboron method. *Soil Science Society of America Journal*. 1999;63(4):902–11.
- Ahmad J, Anwar S, Shad AA, Marwat FY, Bibi H, Ahmad F, et al. Yield and nutritional status of mungbean as influenced by molybdenum and phosphorus. *Pak. J. Agric. Res*. 2021;34(1):144–53. <https://doi.org/10.17582/journal.pjar/2021/34.1.144.153>
- Amin MR, Karim MA, Khaliq QA, Islam MR, Aktar S. Effect of nitrogen and potassium on the root growth, nutrient content and yield of mungbean (*Vigna radiata* L. Wilczek) under waterlogged condition. *Agric. Res*. 2015;13(1):67–78. <https://doi.org/10.3329/agric.v13i1.26549>
- Rajput A, Memon M. Phosphorus application on grain yield, uptake and P utilisation efficiency of mungbean (*Vigna radiata* L.). *Sarhad J. Agric*. 2023;39(1):256. <https://doi.org/10.17582/journal.sja/2023/39.1.256.268>
- Amanullah M, Muhammad A, Nawab K, Ali A. Effect of tillage and phosphorus interaction on yield of mungbean (*Vigna radiata* L. Wilczek) with and without moisture stress condition. *Ponte Acad. J*. 2016;72:114–39.
- Ali MA, Abbas G, Mohy-ud-Din Q, Abbas KUG, Aslam M. Response of mungbean (*Vigna radiata*) to phosphatic fertiliser under arid climate. *J. Anim. Plant Sci*. 2010;20(2):83–6.
- Quddus MA, Hossain MA, Naser HM, Anwar B, Siddiky MA, Ali MR. Influence of potassium addition on productivity, quality and nutrient uptake of mungbean (*Vigna radiata* L.). *J. Agric. Stud*. 2019;7(1):21–40. <https://doi.org/10.5296/jas.v7i1.14269>
- Yin Z, Guo W, Xiao H, Liang J, Hao X, Dong N, et al. Nitrogen, phosphorus and potassium fertilization to achieve expected yield and improve yield components of mung bean. *PLoS One*. 2018;13(10):e0206285.
- Sangakkara R, Amarasekera P, Stamp P. Growth, yields and nitrogen-use efficiency of maize (*Zea mays* L.) and mungbean (*Vigna radiata* L. Wilczek) as affected by potassium fertiliser in tropical South Asia. *Commun. Soil Sci. Plant Anal*. 2011;42(7):832–43. <https://doi.org/10.1080/00103624.2011.552663>
- Ja RL, Rolaniya LK, Kumar N, Choudhary RR, Punia M, Kumar S, et al. Strategic scheduling of urea foliar application and irrigation for moth bean: a path to improve Productivity, profitability and quality in Western dry region of India. *Cogent Food Agric*. 2024;10(1):2368269. <https://doi.org/10.1080/23311932.2024.2368269>
- Islam MR, Sarker U, Azam MG, Hossain J, Alam MA, Ullah R, et al. Potassium augments growth, yield, nutrient content and drought tolerance in mung bean (*Vigna radiata* L. Wilczek.). *Sci. Rep*. 2024 Apr 23;14(1):9378. <https://doi.org/10.1038/s41598-024-60129-z>
- Jamil M, Abbasi GH, Hussain A, Malik Z, Sufyan A. Response of mungbean (*Vigna radiata* L.) to potassium application rates under desert climate. *Adv. Agric. Anim. Sci*. 2018;34(1):10–21.
- Hussain F, Malik AU, Haji MA, Malghani AL. Growth and yield response of two cultivars of mungbean (*Vigna radiata* L.) to different potassium levels. *J. Anim. Plant Sci*. 2011;21(3):622–5.
- Sartaj M, Pandey V, Tripathi SS, Diwakar SK, Kumar S, Mohan S. Impact of different nutrient management practices on kharif mung bean (*Vigna radiata* L.). *J. Adv. Biol. Biotechnol*. 2025;28(8):745–51. <https://doi.org/10.9734/jabb/2025/v28i82748>
- Nawab K, Iqbal A, Fahad S, Khan MJ, Akbar H, Hussain I, et al. Response of summer pulses (mung bean vs. mash bean) to integrated use of organic carbon sources and phosphorus in dry lands. *Afr. J. Agric. Res*. 2017;12(50):3470–90.
- Mondal MM, Rahman MA, Akter MB, Fakir MS. Effect of foliar application of nitrogen and micronutrients on growth and yield in mungbean. *Legume Res.: An International Journal*. 2011;34(3).
- DeRosa MC, Monreal C, Schnitzer M, Walsh R, Sultan Y. Nanotechnology in fertilisers. *J Agric Food Chem*. 2010;58(11):641–651.
- Tarafdar JC, Raliya R, Mahawar H, Rathore I. Development of zinc nano fertiliser to enhance crop production in pearl millet (*Pennisetum americanum*). *Agric. Res*. 2014;3:257–262. <https://doi.org/10.1007/s40003-014-0113-y>

34. Raliya R, Tarafdar JC. ZnO nanoparticle biosynthesis and its effect on phosphorous-mobilizing enzyme secretion and gum contents in clusterbean (*Cyamopsis tetragonoloba* L.). *Agric Res.* 2013;2, 48–57. <https://doi.org/10.1007/s40003-012-0049-z>
35. Oad FC, Shah AN, Jamro GH, Ghaloo SH. Phosphorus and potassium requirements of mungbean (*Vigna radiata*). *Applied Sci.* 2003;3(6):428–31. <https://doi.org/10.3923/jas.2003.428.431>
36. Liu R, Lal R. Potentials of engineered nanoparticles as fertilisers for increasing agronomic productions. *Sci Total Environ.* 2015;514:131–139. <https://doi.org/10.1016/j.scitotenv.2015.01.104>
37. Prasad R, Bhattacharyya A, Nguyen QD. Nanotechnology in sustainable agriculture. *J Plant Nutr.* 2017;40(9):1231–45.
38. Magar PS, Gadade GD, Shelke VR, Mane BM, Mali NS, Kausalye SP. Effect of foliar application of nano urea and nano-dap on growth, yield attributes and yield of green gram (*Vigna radiata* L.). *International Journal of Research in Agronomy.* 2025; 8(8): 1109–12. <https://doi.org/10.33545/2618060X.2025.v8.i8p.3704>
39. Subramanian KS, Manikandan A, Thirunavukkarasu M, Rahale CS. Nano-fertilisers for balanced crop nutrition. *Adv Agron.* 2015;132:1–47. https://doi.org/10.1007/978-3-319-14024-7_3
40. Ge J, Du Y, Wang Q, Xu X, Li J, Tao J, et al. Effects of nitrogen fertiliser on the physicochemical, structural, functional, thermal and rheological properties of mung bean (*Vigna radiata*) protein. *International Journal of Biological Macromolecules.* 2024;260:129616. <https://doi.org/10.1016/j.ijbiomac.2024.129616>
41. Pandey KP, Kalhapure A, Mishra S, Chaubey AK, Kumar A, Gautam B, et al. Influence of nano urea and nano DAP on crop nutrient content, uptake and soil fertility status in black gram (*Vigna mungo*). *Plant Archives.* 2025;25(1):2799–806. <https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.1.405>

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