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Influence of fertilizer levels and nano-fertilizer applications on vegetative growth of green gram (*Vigna radiata* L.)

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Abstract

A field study entitled “Effect of fertilizer levels and foliar application of Nano-fertilizers on growth of green gram” was conducted during the summer seasons of 2024 and 2025 at the Instructional Farm, College of Agriculture, Dapoli, Dist. Ratnagiri (M.S.). The experiment was laid out in a split-plot design with three replications, comprising 21 treatment combinations. The main plot included three fertilizer levels viz., F₁: Absolute control, F₂ -100% RDF (100:50:50 kg N:P₂O₅:K₂O ha⁻¹), F₃ - 80% RDF(80:40:40 kg N:P₂O₅:K₂O ha⁻¹ and sub plot treatment of comprised of seven nano fertilizer treatments viz., N₁ -Absolute control, N₂ - Nano N @ 50 ppm + Nano P @ 100 ppm, N₃ - Nano N @ 50 ppm + Nano P @ 200 ppm, N₄ - Nano N @ 50 ppm + Nano P @ 300 ppm, N₅ - Nano N conjugate @ 50 ppm + Nano P conjugate @ 100 ppm, N₆ - Nano N conjugate @ 50 ppm + Nano P conjugate @ 200 ppm, N₇ - Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm. Two foliar sprays are given at 20 DAS and 40 DAS. The experimental findings revealed that the application of 100% recommended dose of fertilizers (F₂) significantly enhanced the vegetative growth of green gram, as indicated by increased plant height and a higher number of functional leaves per plant. Among the nano fertilizer treatments, the combined foliar application of Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm (N₇) resulted in the highest plant height and maximum number of functional leaves per plant, outperforming other nano fertilizer treatments. The superior performance of these treatments can be attributed to improved nutrient availability, enhanced physiological activity, and greater nutrient use efficiency, which collectively promoted vegetative growth and plant vigor throughout the crop cycle. These results suggest that the integration of full RDF with chitosan-based nano fertilizers can effectively optimize the growth potential of green gram.

Keywords: green gram, fertilizers, nano fertilizers, nitrogen, phosphorous

1. Introduction

India is the largest producer and consumer of pulses in the world, contributing around 25-28% of total global production. The country cultivates a variety of pulse crops, including chickpea, pigeonpea, greengram, blackgram, dry peas, and lentils, across a wide range of agro-climatic conditions. As the majority of the Indian population is vegetarian, pulses serve as an affordable and excellent source of protein in the diet. Pulses typically contain 22–24% protein, compared to 8–10% in cereals (Kharadi *et al.*, 2023) [7]. Not only are pulses valuable for human nutrition, but they are also important for animal feed due to their high protein content. To achieve sustainable crop production and meet the demand for essential nutrients such as proteins, carbohydrates, and minerals, restoring soil fertility has become crucial in modern agriculture. Leguminous crops that fix atmospheric nitrogen play a significant role in this process. Green gram (*Vigna radiata*), originating from Central Asia and commonly referred to as mung or mug, is one such legume. Renowned as the “Golden Bean” for its high nutritional content and nitrogen-fixing ability, green gram has been extensively studied for its agronomic and ecological benefits (Muchomba *et al.*, 2023; Choudhary *et al.*, 2025) [8, 5].

Green gram serves as a source of animal fodder, and its crop residues improve the physical, chemical, and biological properties of the soil, enhancing land productivity. Through a symbiotic association with *Rhizobium* bacteria, mungbean fixes atmospheric nitrogen, thereby enriching soil fertility and reducing the need for synthetic nitrogen fertilizers.

Incorporating green gram into rice-based cropping systems diversifies and strengthens the rotation, mitigating the drawbacks of continuous cereal-cereal cultivation. Studies have shown that such rotations not only improve soil health but also increase the yield of subsequent crops, including paddy, thereby raising farmer income (Weinberger, 2003) ^[16].

Fertilizers are vital in modern agriculture for supplying essential nutrients that may be deficient in the soil, ensuring optimal plant growth, enhancing crop yield, and improving the quality of agricultural produce. They provide macro- and micronutrients required for various physiological and biochemical processes in plants and help sustain soil fertility for long-term productivity. Among these nutrients, nitrogen is one of the most important for achieving high crop performance. Nitrogen (N) is essential for plant growth and development. It is a key component of amino acids, the building blocks of proteins, and is also part of nucleic acids such as DNA and RNA, which are crucial for genetic processes (Ali *et al.*, 2019) ^[2]. Many plant enzymes are proteinaceous, so nitrogen plays a central role in various metabolic reactions. Additionally, nitrogen is a component of chlorophyll; its deficiency causes chlorosis, reducing photosynthesis and the quality of plant products. Nitrogen also contributes to the structural integrity of cell walls, improving the quality of digestible fiber in crops.

Phosphorus (P) is another essential nutrient for pulse production. Although required in smaller amounts than nitrogen, phosphorus is critical for green gram yield due to its multiple effects on nutrition. It regulates physiological processes such as root growth, dry matter accumulation, nodulation, nitrogen fixation, and metabolic activities, particularly protein synthesis (Patel *et al.*, 2019) ^[11].

Improving agricultural productivity while minimizing environmental impact is a key goal of modern farming systems (Pramanick *et al.*, 2013) ^[13]. One approach to achieve this is through nanotechnology, which enhances the efficiency of conventional fertilizers. Nano-fertilizers improve nutrient uptake, reduce fertilizer losses, and lower cultivation costs. Their large surface area, high sorption capacity, and controlled-release properties allow for targeted nutrient delivery, improving crop growth, yield, and quality (Banotra *et al.*, 2023; Patel & Gangwar, 2023) ^[4, 10]. Nanotechnology-based fertilizers can help mitigate the problems associated with excessive or unbalanced chemical fertilizer use, supporting more sustainable and environmentally friendly agricultural practices.

2. Material and Methods

The experiment was conducted at the Instructional Farm, Department of Agronomy, College of Agriculture, Dapoli, located in the subtropical zone at 17 °45'57" N latitude and 73 °10'29" E longitude, with an elevation of approximately 157.8 meters above mean sea level. The region experiences a warm and humid subtropical climate, and the experimental soil was sandy clay loam in texture. The study was laid out in a split-plot design with three main treatments and seven sub-plot treatments; each replicated three times. Planting spacing was maintained at 30 cm × 15 cm, with a gross plot size of 3.60 m × 3.75 m and a net plot size of 3.00 m × 3.45 m. The main plot treatments consisted of conventional fertilizer regimes: F₁ - absolute control, F₂ - 100% Recommended Dose of Fertilizer (RDF) through straight fertilizers, and F₃ - 80% RDF through straight fertilizers. The sub-plot treatments for green gram included N₁ - absolute control, N₂ - Nano N @ 50 ppm + Nano P @ 100 ppm, N₃ - Nano N @ 50 ppm + Nano P @ 200 ppm, N₄ - Nano N @ 50 ppm + Nano P @ 300 ppm, N₅ - Nano N conjugate @ 50 ppm + Nano P conjugate @ 100 ppm, N₆ - Nano N conjugate @ 50 ppm + Nano P conjugate @ 200 ppm, and N₇ - Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm. This experimental setup was designed to evaluate the effects of conventional and nano-fertilizer treatments on growth of green gram under subtropical conditions.

3. Results and Discussion

3.1 Plant Height

3.1.1 Effect of Fertilizer Levels

The data presented in Table 1 indicated that among the different fertilizer treatments application of 100% Recommended Dose of Fertilizer (RDF) through straight fertilizers (F₂) resulted in significantly taller plants compared to 80% RDF through straight fertilizers (F₃). The lowest mean plant height at all growth stages was consistently observed in the absolute control (F₁) during the years 2024 and 2025, as well as in the pooled mean. Adequate nutrient supply through 100% RDF enhanced photosynthetic efficiency and assimilate production, resulting in greater biomass accumulation and taller green gram plants. In contrast, 80% RDF limited physiological activities, leading to reduced plant height, while the absolute control exhibited the lowest growth due to nutrient deficiency. These results indicate that full recommended fertilization is crucial for optimum vegetative growth. Similar trends have been reported in previous studies, where 100% RDF improved plant height and growth attributes in green gram and other pulse crops by ensuring proper nutrient availability and utilization during early growth stages Arunraj *et al.*, 2018) ^[3].

Table 1: Plant height (cm) of green gram as influenced by different treatments during 2024, 2025 and in the pooled data

Treatment	Plant height (cm)		
	2024	2025	Pooled data
Main plot			
F ₁ -Absolute Control	37.86	39.54	38.70
F ₂ -100% RDF through straight fertilizer	45.25	47.34	46.30
F ₃ - 80% RDF through straight fertilizer	43.01	45.05	44.03
S.E.(m)±	0.19	0.16	0.15
C.D. at 5%	0.75	0.62	0.60
Sub plot			
N ₁ -Absolute Control	38.88	40.71	39.80
N ₂ - Nano N @ 50 ppm + Nano P @ 100 ppm	40.34	42.51	41.43
N ₃ - Nano N @ 50 ppm + Nano P @ 200 ppm	41.15	43.36	42.25
N ₄ - Nano N @ 50 ppm + Nano P @ 300 ppm	42.01	44.13	43.07
N ₅ - Nano N conjugate @ 50 ppm + Nano P conjugate @ 100 ppm	42.90	44.94	43.92
N ₆ - Nano N conjugate @ 50 ppm + Nano P conjugate @ 200 ppm	44.00	45.69	44.85
N ₇ - Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm	45.02	46.51	45.76
S.E.(m)±	0.27	0.28	0.31
C.D. at 5%	0.79	0.81	0.88
Interaction effects			
S.E.(m)±	0.48	0.49	0.53
C.D. at 5%	1.36	1.40	1.52
General mean	42.04	43.98	43.01

3.1.2 Effect of Nano fertilizers

Different nano fertilizers significantly affected the mean plant height of green gram at harvest. The highest plant height was recorded with Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm (N₇), followed by Nano N conjugate @ 50 ppm + Nano P conjugate @ 200 ppm (N₆), while the lowest height was observed in the absolute control (N₁) in both years and the pooled analysis. Chitosan-based nano fertilizers function as both nutrient carriers and bio-stimulants, enhancing nutrient use efficiency,

root and shoot development, and overall plant vigor. The small size and high surface area of nitrogen- and phosphorus-bound chitosan nanoparticles enable rapid foliar absorption and translocation, ensuring macronutrient availability during critical vegetative stages. Additionally, chitosan improves water and nutrient uptake by modulating osmotic potential and stimulating growth-related enzymatic activity, thereby promoting increased plant height (Abou El-Enin *et al.*, 2023; Surendra *et al.*, 2025) ^[1, 15].

Table 2: Interaction effects between fertilizer levels and nano fertilizers on plant height (cm) of green gram at harvest during 2024, 2025 and in the pooled data

Nano fertilizers	Fertilizer levels											
	Plant height (cm) at harvest											
	2024				2025				Pooled data			
	F ₁	F ₂	F ₃	Mean	F ₁	F ₂	F ₃	Mean	F ₁	F ₂	F ₃	Mean
N ₁	35.22	41.90	39.51	38.88	37.33	43.94	40.87	40.71	36.28	42.92	40.19	39.80
N ₂	36.16	44.12	40.75	40.34	38.93	45.29	43.31	42.51	37.54	44.70	42.03	41.43
N ₃	37.21	44.47	41.77	41.15	39.39	46.58	44.10	43.36	38.30	45.53	42.93	42.25
N ₄	38.44	45.39	42.19	42.01	39.91	47.95	44.53	44.13	39.17	46.67	43.36	43.07
N ₅	38.57	46.26	43.86	42.90	39.92	48.39	46.50	44.94	39.24	47.33	45.18	43.92
N ₆	39.17	46.91	45.93	44.00	39.92	49.22	47.94	45.69	39.55	48.07	46.93	44.85
N ₇	40.28	47.73	47.06	45.02	41.37	50.01	48.14	46.51	40.83	48.87	47.60	45.76
Mean	37.12	44.43	41.62	41.05	39.10	46.43	43.86	43.13	38.70	46.30	44.03	43.01
S.E.(m)±	0.48				0.49				0.53			
C.D. at 5%	1.36				1.40				1.52			

3.2 Interaction effect (fertilizer levels and nano fertilizers)

The interaction effect between fertilizer levels and nano fertilizers was significant at harvest. The highest plant height was observed with F₂N₇ (100% RDF through straight fertilizer combined with Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm), which was statistically at par with F₂N₆ (100% RDF + Nano N @

50 ppm + Nano P @ 200 ppm) and F₃N₇ (80% RDF + Nano N @ 50 ppm + Nano P @ 300 ppm) during 2024, and with F₂N₆ during 2025 and in the pooled data. The lowest plant height was consistently recorded in F₁N₁ (absolute control) during 2024, 2025, and in the pooled analysis.

Table 3: Number of leaves plant⁻¹ as influenced by different treatments during 2024, 2025 and in the pooled data

Treatment	Number of leaves plant ⁻¹		
	2024	2025	Pooled data
A) Main plot			
F ₁ -Absolute Control	12.29	12.79	12.54
F ₂ -100% RDF through straight fertilizer	16.21	16.42	16.31
F ₃ - 80% RDF through straight fertilizer	14.90	15.02	14.96
S.E.(m)±	0.15	0.11	0.13
C.D. at 5%	0.58	0.45	0.51
B) Sub plot			
N ₁ -Absolute Control	12.04	12.26	12.15
N ₂ - Nano N @ 50 ppm + Nano P @ 100 ppm	13.18	13.42	13.30
N ₃ - Nano N @ 50 ppm + Nano P @ 200 ppm	13.85	14.12	13.98
N ₄ - Nano N @ 50 ppm + Nano P @ 300 ppm	14.49	14.78	14.63
N ₅ - Nano N conjugate @ 50 ppm + Nano P conjugate @ 100 ppm	15.24	15.53	15.39
N ₆ - Nano N conjugate @ 50 ppm + Nano P conjugate @ 200 ppm	15.91	16.21	16.06
N ₇ - Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm	16.55	16.89	16.72
S.E.(m)±	0.21	0.18	0.27
C.D. at 5%	0.59	0.53	0.78
Interaction effects			
S.E.(m)±	0.36	0.32	0.47
C.D. at 5%	1.02	0.92	1.35
General mean	14.47	14.74	14.61

3.3 Number of leaves plant⁻¹

3.3.1 Effect of fertilizer levels

The number of leaves per plant was significantly influenced by fertilizer levels at harvest during 2024, 2025, and in the pooled mean. Across both years and in the pooled data, 100% RDF through straight fertilizer (F₂) consistently produced the highest number of leaves per plant at harvest, followed by 80% RDF through straight fertilizer (F₃). The absolute control (F₁) recorded the lowest leaf count at all growth stages in both years and in the

pooled analysis. The increase in the number of leaves per plant under higher fertilizer levels may be attributed to enhanced root and shoot growth during the early growth phase, which improved nutrient absorption and promoted leaf production. Adequate supplies of nitrogen, phosphorus, and potassium likely stimulated meristematic activity and cell division, resulting in greater vegetative growth. These findings are consistent with reports by Nettikantaiah (2008) and similar observations by Singh *et al.*

(2017), Kalsaria *et al.* (2017), and Arunraj *et al.* (2018) ^[9, 14, 6, 3], who noted that optimal fertilization enhances vegetative growth by improving nutrient availability and physiological efficiency.

3.3.2 Effect of nano fertilizers

Nano fertilizer treatments significantly affected the number of functional leaves per plant at harvest during 2024, 2025, and in the pooled mean. Among the treatments, Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm (N₇) produced the highest number of leaves per plant, while the absolute control (N₁) consistently recorded the lowest leaf count across both years and in the pooled analysis. Nano-formulated fertilizers also provide a

controlled release and slow-release profile, maintaining nutrient supply over an extended period and reducing losses compared to conventional fertilization, thereby supporting sustained growth throughout the crop cycle. These mechanisms collectively contribute to greater cell division, elongation, and biomass accumulation, resulting in significantly taller plants under N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm (N₇) compared to other nano fertilizer treatments in both individual years and pooled data. Similar results were reported by Pisal *et al.* (2024) ^[12], who found that the nano phosphorus conjugate @ 100 ppm recorded significantly higher plant height, number of branches per plant, and dry matter production in mustard crop.

Table 4: Interaction effects between fertilizer levels and nano fertilizers on number of leaves plant⁻¹ of green gram at harvest during 2024, 2025 and in the pooled data

Nano fertilizers	Fertilizer levels											
	Number of leaves plant ⁻¹ at harvest											
	2024				2025				Pooled data			
	F ₁	F ₂	F ₃	Mean	F ₁	F ₂	F ₃	Mean	F ₁	F ₂	F ₃	Mean
N ₁	9.52	14.05	12.54	12.04	9.92	14.27	12.60	12.26	9.72	14.16	12.57	12.15
N ₂	11.28	15.11	13.16	13.18	11.80	15.18	13.28	13.42	11.54	15.15	13.22	13.30
N ₃	12.20	15.36	13.99	13.85	12.73	15.61	14.01	14.12	12.47	15.48	14.00	13.98
N ₄	12.93	15.51	15.03	14.49	13.44	15.75	15.14	14.78	13.19	15.63	15.09	14.63
N ₅	12.98	16.60	16.15	15.24	13.49	16.85	16.26	15.53	13.24	16.72	16.21	15.39
N ₆	13.32	18.16	16.25	15.91	13.83	18.40	16.41	16.21	13.57	18.28	16.33	16.06
N ₇	13.81	18.65	17.18	16.55	14.33	18.89	17.44	16.89	14.07	18.77	17.31	16.72
Mean	11.78	15.33	14.17	13.76	12.28	15.53	14.26	14.02	12.54	16.31	14.96	14.61
S.E.(m)±	0.36				0.32				0.47			
C.D. at 5%	1.02				0.92				1.35			

3.3.3 Interaction effect (fertilizer levels and nano fertilizers)

A significant interaction between fertilizer levels and nano fertilizers was observed for the number of functional leaves per plant at harvest during 2024, 2025, and in the pooled data (Table 4). The highest number of leaves per plant was recorded under F₂N₇ (100% RDF + Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm), which was statistically at par with F₂N₆ (100% RDF + Nano N conjugate @ 50 ppm + Nano P conjugate @ 200 ppm) in both years and in the pooled mean. In contrast, the lowest leaf count was consistently observed in the absolute control combination (F₁N₁) across both years and pooled analysis.

4. Conclusion

The application of 100% recommended dose of fertilizers (RDF) through straight fertilizers significantly improved vegetative growth in green gram, resulting in increased plant height and number of leaves per plant. Among nano fertilizer treatments, the combined application of Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm consistently recorded the highest plant height and functional leaf number. These results suggest that integrating full RDF with properly formulated nano fertilizers can effectively enhance nutrient use efficiency and optimize vegetative growth in green gram.

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