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Effect of recommended dose of fertilizer levels and zinc application on growth, productivity, soil fertility and economics of greengram (*Vigna radiata* L.)

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Abstract

Greengram (*Vigna radiata* L.) is one of the most important pulse crops cultivated in India due to its high protein content, short duration, and ability to improve soil fertility through biological nitrogen fixation. However, its productivity remains considerably lower than the potential yield because of nutrient-deficient soils, imbalanced fertilizer use, and widespread micronutrient deficiencies, particularly zinc. Therefore, a field experiment was conducted during the Kharif season of 2025-26 at the Instructional Farm, Faculty of Agricultural Sciences and Allied Industries, Rama University, Kanpur, Uttar Pradesh, to evaluate the influence of different Recommended Dose of Fertilizer (RDF) levels and zinc application on growth, yield attributes, yield, soil fertility status, nutrient uptake, and economics of greengram cultivation. The experiment was laid out in a Randomized Block Design with ten treatments and three replications comprising combinations of 75%, 100%, and 125% RDF with zinc application at 10, 12, and 15 kg ha⁻¹ along with an untreated control. The experimental soil was sandy loam, slightly alkaline in reaction, low in available nitrogen and zinc, and medium in phosphorus and potassium availability.

The results revealed that balanced fertilization significantly enhanced crop growth, yield formation, nutrient uptake, and profitability. Application of 125% RDF combined with Zinc @ 15 kg ha⁻¹ produced the tallest plants, maximum branches plant⁻¹, greater nodulation, and highest dry matter accumulation. The same treatment also recorded superior yield attributes including pods plant⁻¹, seeds pod⁻¹, and test weight, resulting in the highest seed yield and biological yield. Compared with the control, seed yield increased substantially owing to improved nutrient availability, enhanced photosynthetic activity, and better translocation of assimilates towards reproductive organs. Zinc application played a vital role in chlorophyll synthesis, enzyme activation, auxin metabolism, and reproductive development, which collectively improved crop productivity. Post-harvest soil analysis indicated improvement in available nitrogen, phosphorus, potassium, and zinc status under higher RDF and zinc treatments, demonstrating the beneficial residual effect of balanced nutrient management. Economic analysis further showed that application of 125% RDF along with Zinc @ 15 kg ha⁻¹ generated the maximum gross return, net return, and benefit-cost ratio, proving to be the most profitable treatment. Correlation and regression studies established a strong positive relationship between growth parameters, nutrient uptake, and seed yield. The findings suggest that balanced application of 125% RDF combined with Zinc @ 15 kg ha⁻¹ can be recommended for achieving higher productivity, improved soil fertility, and enhanced profitability of greengram under the agro-climatic conditions of central Uttar Pradesh.

Keywords: Greengram, RDF, zinc fertilization, growth attributes, yield, nutrient uptake, soil fertility, economics, correlation, regression analysis

Introduction

Greengram (*Vigna radiata* L. Wilczek), popularly known as mungbean, is one of the most important pulse crops cultivated in tropical and subtropical regions of the world. The crop belongs to the family Fabaceae and occupies a significant position in Indian agriculture owing to its high nutritional value, short growth duration, adaptability to diverse agro-climatic conditions, and capacity to improve soil fertility through biological nitrogen fixation. India is recognized as both the primary centre of origin and the largest producer and consumer of greengram globally. The crop is widely grown during Kharif, summer, and spring seasons and serves as an important component of cereal-based and pulse-based cropping systems (Ali and Gupta, 2012) [2].

Pulses play a crucial role in ensuring nutritional security for the rapidly increasing population of developing countries. Among pulses, greengram is highly valued because of its superior digestibility and rich nutritional composition. The grains contain approximately 20–25% protein, 60–65% carbohydrates, 3–4% minerals, and appreciable quantities of vitamins, particularly thiamine and riboflavin (Nair *et al.*, 2019) [2]. The protein of greengram is rich in lysine, which complements cereal proteins and contributes significantly to balanced human nutrition (Ali and Gupta, 2012) [1]. Due to its easy digestibility and low flatulence-producing nature, greengram is preferred over many other pulse crops and is consumed in the form of dal, sprouts, soups, sweets, and several traditional food products.

India is the largest producer of pulses in the world; however, the productivity of many pulse crops remains below their genetic potential. According to recent agricultural statistics, greengram occupies about 5.5 million hectares with an annual production of approximately 3.1 million tonnes and average productivity of around 570 kg ha⁻¹, which is considerably lower than the achievable yield under improved management conditions (IIPR, 2024) [3]. The low productivity of greengram is primarily attributed to cultivation on marginal lands, inadequate fertilizer application, nutrient-deficient soils, moisture stress, and poor adoption of improved production technologies (Kumar *et al.*, 2023) [4].

Apart from its nutritional significance, greengram contributes substantially to sustainable agriculture. Being a leguminous crop, it establishes a symbiotic association with Rhizobium bacteria and fixes atmospheric nitrogen into plant-available forms. This biological nitrogen fixation not only reduces the requirement of synthetic nitrogen fertilizers but also improves soil fertility for succeeding crops (Giller, 2001) [5]. Inclusion of greengram in crop rotations enhances soil organic matter, microbial activity, nutrient cycling, and overall soil health. Therefore, greengram plays a dual role in improving both food security and environmental sustainability.

Despite these advantages, the productivity of greengram continues to be constrained by poor nutrient management. Modern intensive agriculture has accelerated nutrient mining from soils, resulting in widespread deficiencies of both macro- and micronutrients. Continuous cultivation under cereal-dominated systems has led to depletion of soil organic carbon and available nutrients, particularly nitrogen, phosphorus, and zinc (Brady and Weil, 2017) [6]. Consequently, balanced fertilization has emerged as one of the most important agronomic interventions for improving crop productivity and maintaining soil fertility.

Recommended Dose of Fertilizers (RDF) provides a balanced supply of essential macronutrients required for optimum crop growth and development. Nitrogen is a major constituent of chlorophyll, amino acids, proteins, and nucleic acids, thereby promoting vigorous vegetative growth and photosynthetic activity (Mengel and Kirkby, 2001) [7]. Phosphorus plays a critical role in root development, nodulation, energy transfer, and reproductive growth, while potassium regulates enzyme activation, water relations, assimilate translocation, and stress tolerance (Vance *et al.*, 2003) [8]. Deficiency of any of these nutrients adversely affects growth, flowering, pod development, and grain formation, ultimately reducing crop productivity.

Among micronutrients, zinc has emerged as one of the most limiting factors affecting pulse production in India. Zinc deficiency is widespread in alkaline, calcareous, and intensively cultivated soils because of continuous nutrient removal and insufficient replenishment (Alloway, 2008) [9]. Recent soil

fertility surveys have indicated that nearly half of the cultivated soils of India are deficient in available zinc, posing a serious challenge to sustainable crop production (Cakmak, 2008) [10]. Zinc plays an indispensable role in enzyme activation, auxin synthesis, chlorophyll formation, protein metabolism, membrane integrity, and reproductive development. Adequate zinc nutrition enhances root growth, photosynthetic efficiency, pollen viability, and seed formation, whereas deficiency results in chlorosis, stunted growth, poor nodulation, and reduced grain yield (Havlin *et al.*, 2019) [11].

Several researchers have reported positive responses of greengram to zinc fertilization. Sharma *et al.* (2018) [12] observed significant improvement in plant height, nodulation, dry matter accumulation, and seed yield with zinc application. Similarly, Patel *et al.* (2020) [13] reported enhanced chlorophyll content, nutrient uptake, protein synthesis, and productivity of mungbean under balanced application of RDF and zinc. Kumar and Yadav (2022) [14] further demonstrated that combined application of higher RDF levels and zinc significantly improved fertilizer use efficiency and economic returns under alluvial soil conditions.

The interaction between macronutrients and micronutrients is highly important for achieving sustainable crop production. Balanced supply of nitrogen, phosphorus, and potassium improves nutrient absorption and physiological efficiency, while zinc enhances metabolic activities and nutrient utilization within plants. This synergistic relationship promotes better growth, nodulation, dry matter production, flowering, pod development, and grain filling. Fageria *et al.* (2011) [15] emphasized that integrated management of macro- and micronutrients is essential for maximizing productivity while maintaining soil fertility and environmental quality.

Recent studies have also highlighted the importance of balanced fertilization in improving nutrient use efficiency and soil health. Meena *et al.* (2021) [16] reported that integrated nutrient management significantly enhanced microbial activity, nutrient availability, and profitability of pulse-based cropping systems. In addition to increasing crop productivity, balanced fertilization contributes to sustainable soil management by improving nutrient cycling and reducing nutrient depletion.

Considering the growing demand for pulses, declining soil fertility, and widespread zinc deficiency in Indian soils, optimization of fertilizer management practices has become imperative. The response of greengram to RDF and zinc application varies according to soil type, climatic conditions, and management practices. Therefore, location-specific studies are essential for identifying suitable fertilizer and zinc levels capable of maximizing growth, productivity, nutrient uptake, soil fertility, and profitability under prevailing agro-climatic conditions.

Keeping these facts in view, the present investigation entitled “Effect of RDF Level and Zinc on Growth and Yield of Greengram (*Vigna radiata* L.)” was undertaken during the Kharif season under the agro-climatic conditions of Central Uttar Pradesh. The study was conducted to evaluate the influence of different RDF levels and zinc application rates on growth parameters, yield attributes, yield, soil fertility status, economics, and nutrient uptake of greengram and to identify the most suitable nutrient management strategy for enhancing productivity and profitability while sustaining soil health.

Materials and Methods

A field experiment entitled “Effect of RDF Level and Zinc on Growth and Yield of Greengram (*Vigna radiata* L.)” was conducted during the Kharif season of 2025–26 at the Instructional Farm, Faculty of Agricultural Sciences and Allied

Industries, Rama University, Mandhana, Kanpur, Uttar Pradesh, India. The experimental site is situated in the Central Plain Zone of Uttar Pradesh under subtropical climatic conditions characterized by hot summers, humid monsoon periods, and mild winters. During the crop growth period, weather conditions remained favourable for greengram cultivation with adequate rainfall and optimum temperature for crop growth and development.

The soil of the experimental field was sandy loam in texture, slightly alkaline in reaction (pH 7.68), low in organic carbon (3.82 g kg⁻¹) and available nitrogen (168.42 kg ha⁻¹), medium in available phosphorus (18.64 kg ha⁻¹) and potassium (186.28 kg ha⁻¹), and deficient in available zinc (0.58 mg kg⁻¹). These soil conditions provided a suitable environment for evaluating the response of greengram to different RDF levels and zinc applications.

The experiment was laid out in a Randomized Block Design (RBD) with three replications comprising ten treatments. The treatments consisted of combinations of Recommended Dose of Fertilizers (RDF) and zinc levels as follows:

Treatment	Description
T ₁	100% RDF + Zinc @ 10 kg ha ⁻¹
T ₂	75% RDF + Zinc @ 10 kg ha ⁻¹
T ₃	125% RDF + Zinc @ 10 kg ha ⁻¹
T ₄	100% RDF + Zinc @ 12 kg ha ⁻¹
T ₅	75% RDF + Zinc @ 12 kg ha ⁻¹
T ₆	125% RDF + Zinc @ 12 kg ha ⁻¹
T ₇	100% RDF + Zinc @ 15 kg ha ⁻¹
T ₈	75% RDF + Zinc @ 15 kg ha ⁻¹
T ₉	125% RDF + Zinc @ 15 kg ha ⁻¹
T ₁₀	Control

The greengram variety 'SAMRAT' was used for the experiment. Sowing was carried out during the second fortnight of July using a seed rate of 20 kg ha⁻¹ with a spacing of 30 cm × 10 cm. Seeds were treated with Rhizobium culture and recommended fungicide prior to sowing to ensure better nodulation and crop

establishment. The gross plot size was 4.0 m × 3.0 m and the net plot size was 3.0 m × 2.4 m.

The recommended fertilizer dose for greengram was 20:40:20 kg N:P₂O₅:K₂O ha⁻¹. Nitrogen was supplied through urea, phosphorus through diammonium phosphate (DAP), and potassium through muriate of potash (MOP). Entire quantities of fertilizers were applied as basal dose at sowing. Zinc was applied through zinc sulphate (ZnSO₄·7H₂O) according to treatment specifications and incorporated thoroughly into the soil before sowing. All other agronomic practices including irrigation, weed management, and plant protection measures were carried out uniformly across treatments following recommended package of practices.

Observations on growth parameters such as plant height, branches plant⁻¹, nodules plant⁻¹, dry matter accumulation, crop growth rate, and relative growth rate were recorded at different growth stages. Yield attributes including pods plant⁻¹, seeds pod⁻¹, and test weight were measured at harvest. Seed yield, stover yield, biological yield, and harvest index were calculated after harvesting and threshing of the crop. Soil samples collected before sowing and after harvest were analyzed for pH, EC, organic carbon, available nitrogen, phosphorus, potassium, and zinc using standard laboratory procedures. Economic analysis was carried out based on prevailing market prices and treatment-wise cost of cultivation to determine gross returns, net returns, and benefit-cost ratio.

The experimental data were subjected to statistical analysis using the analysis of variance (ANOVA) technique appropriate for Randomized Block Design as described by Gomez and Gomez (1984) [17]. Treatment means were compared using the Critical Difference (CD) test at the 5% level of significance. Correlation and regression analyses were also performed to study the relationship between yield and important growth and nutrient parameters.

5. Results and Discussion

5.1 Growth Parameters of Greengram

Table 1: Effect of RDF Levels and Zinc Application on Growth Parameters of Greengram at 60 DAS

Treatment	Plant Height (cm)	Branches plant ⁻¹	Nodules plant ⁻¹	Dry Matter Accumulation (g plant ⁻¹)
100% RDF + Zinc @ 10 kg ha ⁻¹	52.64	6.82	23.48	20.42
75% RDF + Zinc @ 10 kg ha ⁻¹	48.56	5.84	20.36	17.82
125% RDF + Zinc @ 10 kg ha ⁻¹	55.28	7.16	25.18	21.84
100% RDF + Zinc @ 12 kg ha ⁻¹	54.42	7.08	24.84	21.28
75% RDF + Zinc @ 12 kg ha ⁻¹	50.36	6.22	21.94	18.76
125% RDF + Zinc @ 12 kg ha ⁻¹	58.34	7.74	27.82	23.16
100% RDF + Zinc @ 15 kg ha ⁻¹	56.68	7.42	26.24	22.48
75% RDF + Zinc @ 15 kg ha ⁻¹	52.48	6.64	23.18	20.12
125% RDF + Zinc @ 15 kg ha ⁻¹	61.82	8.42	30.86	24.86
Control	42.36	4.16	15.48	14.28
SEm ±	1.12	0.18	0.64	0.58
CD (P=0.05)	3.34	0.54	1.91	1.73

The growth parameters of greengram were significantly influenced by varying RDF levels and zinc application rates. Among all treatments, application of 125% RDF + Zinc @ 15 kg ha⁻¹ produced the highest plant height (61.82 cm), branches plant⁻¹ (8.42), nodules plant⁻¹ (30.86), and dry matter accumulation (24.86 g plant⁻¹). The improvement in growth was statistically superior over the control and most other nutrient management treatments.

Plant height increased by 45.94% under 125% RDF + Zinc @ 15 kg ha⁻¹ compared with the control treatment. Enhanced plant growth may be attributed to adequate availability of nitrogen, phosphorus, potassium, and zinc which promoted cell division,

cell elongation, chlorophyll synthesis, and photosynthetic activity. Similar findings were reported by Balai *et al.* (2017) [18], Patel *et al.* (2020) [13], and Kumar and Yadav (2022) [14], who observed significant improvement in vegetative growth under balanced nutrient management.

The number of branches plant⁻¹ increased by 102.40% over control due to improved nutrient availability and greater assimilate production. Zinc plays an important role in auxin synthesis and enzyme activation, resulting in enhanced branching and vegetative development (Alloway, 2008; Marschner, 2012) [9, 19].

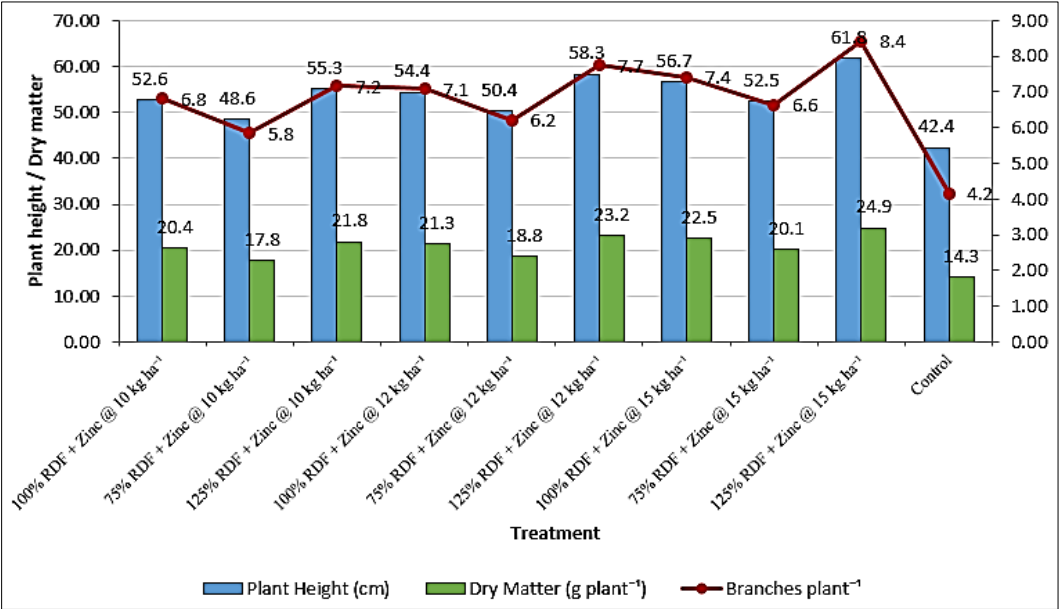


Fig 1: Effect of Treatments on Growth

Nodulation response was also significantly enhanced by RDF and zinc application. Treatment receiving 125% RDF + Zinc @ 15 kg ha⁻¹ recorded ~ 99.35% higher nodules plant⁻¹ than the control. Improved nodulation may be associated with better root growth, phosphorus availability, and enhanced Rhizobium activity. Similar observations were reported by Arunachalam *et al.* (2013) [20] and Rani *et al.* (2016) [21].

Dry matter accumulation followed a trend similar to plant height and nodulation. The highest dry matter accumulation (24.86 g plant⁻¹) was recorded under 125% RDF + Zinc @ 15 kg ha⁻¹, - representing a 74.09% increase over control. Higher biomass production under balanced fertilization resulted from improved photosynthetic efficiency, nutrient uptake, and carbohydrate

synthesis. These results corroborate the findings of Fageria *et al.* (2011) [15], Sharma *et al.* (2018) [12], and Meena *et al.* (2021) [16]. Overall, the results clearly demonstrate that increasing RDF levels along with zinc application improved vegetative growth, nodulation behaviour, and biomass accumulation of greengram. The superiority of 125% RDF + Zinc @ 15 kg ha⁻¹ indicates the synergistic effect of macro- and micronutrients in enhancing physiological processes and nutrient use efficiency, ultimately leading to vigorous crop growth and higher productivity potential.

5. Results and Discussion

5.1 Growth Parameters of Greengram

Table 2: Effect of RDF Levels and Zinc Application on Growth Parameters of Greengram at 60 DAS

Treatment	Plant Height (cm)	Branches plant ⁻¹	Nodules plant ⁻¹	Dry Matter Accumulation (g plant ⁻¹)
100% RDF + Zinc @ 10 kg ha ⁻¹	52.64	6.82	23.48	20.42
75% RDF + Zinc @ 10 kg ha ⁻¹	48.56	5.84	20.36	17.82
125% RDF + Zinc @ 10 kg ha ⁻¹	55.28	7.16	25.18	21.84
100% RDF + Zinc @ 12 kg ha ⁻¹	54.42	7.08	24.84	21.28
75% RDF + Zinc @ 12 kg ha ⁻¹	50.36	6.22	21.94	18.76
125% RDF + Zinc @ 12 kg ha ⁻¹	58.34	7.74	27.82	23.16
100% RDF + Zinc @ 15 kg ha ⁻¹	56.68	7.42	26.24	22.48
75% RDF + Zinc @ 15 kg ha ⁻¹	52.48	6.64	23.18	20.12
125% RDF + Zinc @ 15 kg ha ⁻¹	61.82	8.42	30.86	24.86
Control	42.36	4.16	15.48	14.28
SEm ±	1.12	0.18	0.64	0.58
CD (P=0.05)	3.34	0.54	1.91	1.73

The growth parameters of greengram were significantly influenced by varying RDF levels and zinc application rates. Among all treatments, application of 125% RDF + Zinc @ 15 kg ha⁻¹ produced the highest plant height (61.82 cm), branches plant⁻¹ (8.42), nodules plant⁻¹ (30.86), - and dry matter accumulation (24.86 g plant⁻¹). The improvement in growth was statistically - superior over the control and most other nutrient management treatments.

Plant height increased by 45.94% under 125% RDF + Zinc @ 15 kg ha⁻¹ compared with the - control treatment. Enhanced plant growth may be attributed to adequate availability of nitrogen, phosphorus, potassium, and zinc which promoted cell division, cell elongation, chlorophyll synthesis, and photosynthetic

activity. Similar findings were reported by Balai *et al.* (2017) [18], Patel *et al.* (2020) [13], and Kumar and Yadav (2022) [14], who observed significant improvement in vegetative growth under balanced nutrient management.

The number of branches plant⁻¹ increased by ~ 102.40% over control due to improved nutrient availability and greater assimilate production. Zinc plays an important role in auxin synthesis and enzyme activation, resulting in enhanced branching and vegetative development (Alloway, 2008; Marschner, 2012) [9, 19].

Nodulation response was also significantly enhanced by RDF and zinc application. Treatment receiving 125% RDF + Zinc @ 15 kg ha⁻¹ recorded ~ 99.35% higher nodules plant⁻¹ than the control.

Improved nodulation may be associated with better root growth, phosphorus availability, and enhanced Rhizobium activity. Similar observations were reported by [Arunachalam et al. \(2013\)](#) [20] and [Rani et al. \(2016\)](#) [21].

Dry matter accumulation followed a trend similar to plant height and nodulation. The highest dry matter accumulation (24.86 g plant⁻¹) was recorded under 125% RDF + Zinc @ 15 kg ha⁻¹, representing a 74.09% increase over control. Higher biomass production under balanced fertilization resulted from improved photosynthetic efficiency, nutrient uptake, and carbohydrate

synthesis. These results corroborate the findings of [Fageria et al. \(2011\)](#) [15], [Sharma et al. \(2018\)](#) [12], and [Meena et al. \(2021\)](#) [16]. Overall, the results clearly demonstrate that increasing RDF levels along with zinc application improved vegetative growth, nodulation behaviour, and biomass accumulation of greengram. The superiority of 125% RDF + Zinc @ 15 kg ha⁻¹ indicates the synergistic effect of macro- and micronutrients in enhancing physiological processes and nutrient use efficiency, ultimately leading to vigorous crop growth and higher productivity potential.

5.2 Yield Attributes and Yield of Greengram

Table 3: Effect of RDF Levels and Zinc Application on Yield Attributes and Yield of Greengram

Treatment	Pods plant ⁻¹	Seeds pod ⁻¹	Test Weight (g)	Seed Yield (t ha ⁻¹)	Stover Yield (q ha ⁻¹)	Harvest Index (%)
100% RDF + Zinc @ 10 kg ha ⁻¹	25.46	9.82	38.42	1.28	27.68	31.62
75% RDF + Zinc @ 10 kg ha ⁻¹	22.84	8.96	36.58	1.08	24.62	30.50
125% RDF + Zinc @ 10 kg ha ⁻¹	27.84	10.28	39.48	1.39	29.42	32.09
100% RDF + Zinc @ 12 kg ha ⁻¹	26.88	10.04	39.02	1.35	28.84	31.88
75% RDF + Zinc @ 12 kg ha ⁻¹	24.18	9.18	37.22	1.15	25.36	31.19
125% RDF + Zinc @ 12 kg ha ⁻¹	29.76	10.82	40.64	1.48	30.68	32.54
100% RDF + Zinc @ 15 kg ha ⁻¹	28.42	10.46	40.12	1.43	29.96	32.30
75% RDF + Zinc @ 15 kg ha ⁻¹	25.82	9.64	38.08	1.24	27.14	31.37
125% RDF + Zinc @ 15 kg ha ⁻¹	31.84	11.26	41.86	1.59	32.84	32.62
Control	18.46	7.82	33.24	0.84	18.62	31.09
SEm ±	0.72	0.21	0.58	0.04	0.84	0.31
CD (P=0.05)	2.15	0.63	1.73	0.12	2.51	NS

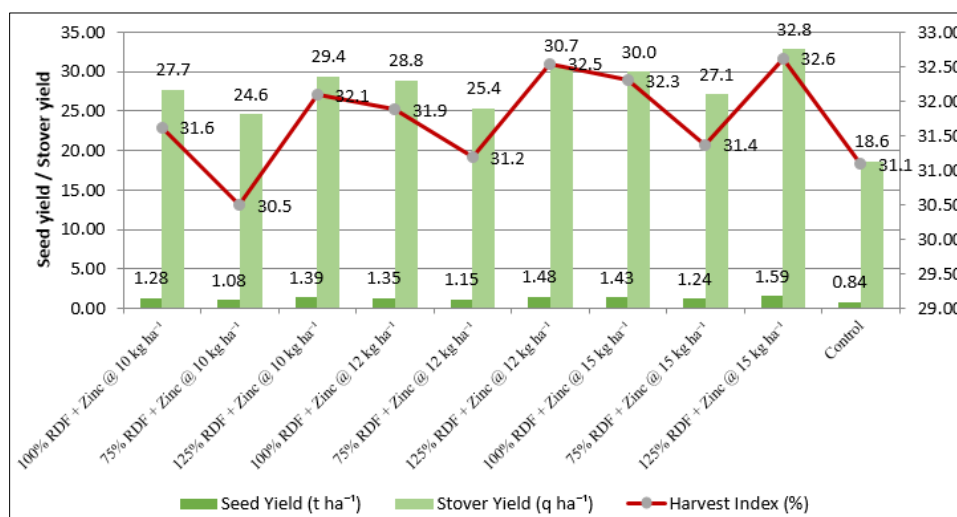


Fig 2: Yield Performance Dashboard

The yield attributes and yield of greengram were significantly influenced by different RDF levels and zinc application rates. The treatment receiving 125% RDF + Zinc @ 15 kg ha⁻¹ produced the highest values for pods plant⁻¹ (31.84), seeds pod⁻¹ (11.26), test weight (41.86 g), seed yield (1.59 t ha⁻¹), and stover yield (32.84 q ha⁻¹), indicating the beneficial effect of balanced nutrient management on reproductive growth and yield formation.

The number of pods plant⁻¹ increased significantly with increasing RDF and zinc levels. Application of 125% RDF + Zinc @ 15 kg ha⁻¹ recorded 72.48% more pods plant⁻¹ than the control treatment. Adequate availability of phosphorus and zinc improved flowering, pollen viability, and pod setting, resulting in greater reproductive efficiency. Similar findings were reported by [Sharma et al. \(2018\)](#) [12], [Patel et al. \(2020\)](#) [13], and [Kumar and Yadav \(2022\)](#) [14].

Seeds pod⁻¹ increased from 7.82 in the control to 11.26 under 125% RDF + Zinc @ 15 kg ha⁻¹, representing a 43.99% increase. Improved nutrient supply enhanced photosynthetic

activity and assimilate translocation towards developing reproductive organs, thereby increasing seed formation and retention. These findings agree with those reported by [Balai et al. \(2017\)](#) [18] and [Rani et al. \(2016\)](#) [21].

Test weight also improved significantly with balanced fertilization. The maximum test weight (41.86 g) recorded under 125% RDF + Zinc @ 15 kg ha⁻¹ was 25.93% higher than the control. Zinc is known to play an important role in carbohydrate metabolism and grain filling, which contributed to better seed development and increased seed weight ([Alloway, 2008](#)) [9].

The highest seed yield (1.59 t ha⁻¹) was obtained under 125% RDF + Zinc @ 15 kg ha⁻¹, which was 89.29% higher than the control (0.84 t ha⁻¹). The substantial increase in seed yield may be attributed to improved growth, enhanced nodulation, higher dry matter production, better nutrient uptake, and superior yield attributes. Balanced nutrient availability throughout the crop growth period ensured efficient conversion of photosynthates into

economic yield. Similar results have been reported by Patel *et al.* (2020) [13], Meena *et al.* (2021) [16], and Fageria *et al.* (2011) [15]. Stover yield followed a trend similar to seed yield. The maximum stover yield (32.84 q ha⁻¹) was recorded under 125% RDF + Zinc @ 15 kg ha⁻¹, representing a ~ 76.37% increase over control. Higher vegetative growth and biomass accumulation under balanced fertilization contributed directly to increased stover production.

Harvest index varied within a narrow range and remained statistically non-significant, indicating that nutrient management improved both grain and biomass production proportionately. The

slight increase in harvest index under higher RDF and zinc treatments suggests improved partitioning of assimilates towards reproductive structures.

Overall, the results clearly indicate that combined application of 125% RDF and Zinc @ 15 kg ha⁻¹ significantly enhanced reproductive growth, grain development, and productivity of greengram. The synergistic effect of macronutrients and zinc improved physiological efficiency, nutrient utilization, and assimilate translocation, resulting in superior yield performance.

5.3 Soil Fertility Status after Harvest

Table 4: Effect of RDF Levels and Zinc Application on Post-Harvest Soil Fertility Status of Greengram

Treatment	Soil pH	EC (dS m ⁻¹)	Organic Carbon (g kg ⁻¹)	Available N (kg ha ⁻¹)	Available P ₂ O ₅ (kg ha ⁻¹)	Available K ₂ O (kg ha ⁻¹)	Available Zn (mg kg ⁻¹)
100% RDF + Zinc @ 10 kg ha ⁻¹	7.64	0.248	3.94	176.28	21.46	194.32	0.78
75% RDF + Zinc @ 10 kg ha ⁻¹	7.66	0.246	3.86	172.16	20.14	191.28	0.72
125% RDF + Zinc @ 10 kg ha ⁻¹	7.62	0.249	4.06	180.34	22.84	198.46	0.82
100% RDF + Zinc @ 12 kg ha ⁻¹	7.61	0.251	4.02	178.64	22.18	196.84	0.84
75% RDF + Zinc @ 12 kg ha ⁻¹	7.65	0.247	3.90	174.28	20.88	193.56	0.76
125% RDF + Zinc @ 12 kg ha ⁻¹	7.58	0.252	4.18	182.84	23.46	201.24	0.89
100% RDF + Zinc @ 15 kg ha ⁻¹	7.60	0.253	4.12	181.16	22.96	199.42	0.90
75% RDF + Zinc @ 15 kg ha ⁻¹	7.63	0.248	3.98	176.86	21.84	195.64	0.86
125% RDF + Zinc @ 15 kg ha ⁻¹	7.55	0.255	4.28	185.64	24.16	204.72	0.94
Control	7.68	0.244	3.62	166.82	17.86	184.46	0.56
SEm ±	0.03	0.004	0.08	2.16	0.58	2.84	0.03
CD (P=0.05)	NS	NS	0.24	6.45	1.73	8.48	0.09

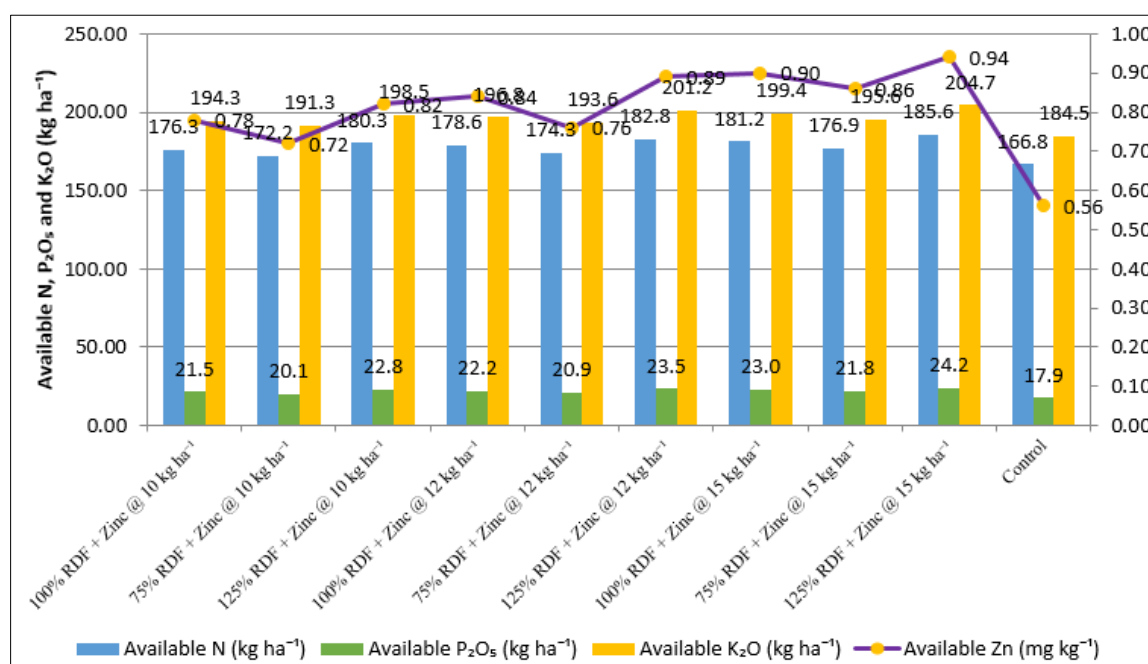


Fig 3: Effect of Treatments on Soil Nutrients

Post-harvest soil fertility status was significantly influenced by RDF levels and zinc application. The results clearly indicate that balanced fertilization not only improved crop productivity but

also enhanced residual soil fertility, which is essential for sustaining long-term agricultural productivity.

The highest organic carbon content (4.28 g kg⁻¹) was recorded under ~ 125% RDF + Zinc @ 15 kg ha⁻¹, which was 18.23%

higher than the control treatment. Improved biomass production, root growth, and greater crop residue addition under balanced fertilization contributed to higher organic carbon accumulation in soil. Similar findings were reported by Meena *et al.* (2021) [16] and Brady and Weil (2017) [16].

Available nitrogen status increased significantly with increasing RDF and zinc levels. Application of 125% RDF + Zinc @ 15 kg ha⁻¹ recorded the highest available nitrogen (185.64 kg ha⁻¹), which represented an ~ 11.28% increase over the control. Enhanced biological nitrogen fixation, improved root activity, and greater nutrient cycling under balanced fertilization contributed to higher residual nitrogen availability. Similar observations were reported by Dakora and Keya (1997) [22], Patel *et al.* (2020) [13], and Kumar and Yadav (2022) [14].

Available phosphorus increased from 17.86 kg ha⁻¹ in the control to 24.16 kg ha⁻¹ under 125% RDF + Zinc @ 15 kg ha⁻¹, representing a ~ 35.27% increase. Higher phosphorus availability may be attributed to adequate phosphorus application and improved nutrient solubilization in the rhizosphere. These findings are in agreement with those of Rani *et al.* (2016) [21] and Gupta *et al.* (2006) [23].

Available potassium also improved significantly with balanced nutrient management. The maximum potassium status (204.72 kg ha⁻¹) recorded under 125% RDF + Zinc @ 15 kg ha⁻¹ was 10.98% higher than the control. Increased root biomass and

improved nutrient recycling contributed to better potassium availability after harvest.

Available zinc status showed the most pronounced improvement. Application of 125% RDF + Zinc @ 15 kg ha⁻¹ recorded the highest available zinc (0.94 mg kg⁻¹), which was ~ 67.86% higher than the control treatment. The direct addition of zinc sulphate and improved nutrient transformation processes were primarily responsible for the enhanced zinc status of soil. Similar results were reported by Alloway (2008) [9], Ganeshamurthy *et al.* (2011) [24], and Sharma *et al.* (2018) [12].

Soil pH and electrical conductivity remained statistically non-significant, indicating that RDF and zinc application did not adversely affect soil reaction or salinity status. This finding suggests that balanced fertilization can improve soil fertility without causing detrimental changes in soil chemical properties. Overall, the results demonstrate that application of 125% RDF + Zinc @ 15 kg ha⁻¹ not only maximized crop growth and yield but also improved residual soil fertility through enhanced nutrient availability and soil health. The findings support the concept of balanced nutrient management as a sustainable strategy for maintaining productivity and soil quality in pulsebased cropping systems.

5.4 Economics of Greengram Cultivation

Table 5: Effect of RDF Levels and Zinc Application on Economics of Greengram Cultivation

Treatment	Cost of Cultivation (₹ ha ⁻¹)	Gross Return (₹ ha ⁻¹)	Net Return (₹ ha ⁻¹)	Benefit: Cost Ratio
100% RDF + Zinc @ 10 kg ha ⁻¹	40,420	117,760	77,340	2.91
75% RDF + Zinc @ 10 kg ha ⁻¹	38,840	99,360	60,520	2.56
125% RDF + Zinc @ 10 kg ha ⁻¹	41,980	127,880	85,900	3.05
100% RDF + Zinc @ 12 kg ha ⁻¹	41,260	124,200	82,940	3.01
75% RDF + Zinc @ 12 kg ha ⁻¹	39,680	105,800	66,120	2.67
125% RDF + Zinc @ 12 kg ha ⁻¹	42,820	136,160	93,340	3.18
100% RDF + Zinc @ 15 kg ha ⁻¹	42,150	131,560	89,410	3.12
75% RDF + Zinc @ 15 kg ha ⁻¹	40,560	114,080	73,520	2.81
125% RDF + Zinc @ 15 kg ha ⁻¹	43,395	146,254	102,859	3.37
Control	35,840	77,280	41,440	2.16
SEm ±	—	2,640	2,480	0.08
CD (P=0.05)	—	7,884	7,408	0.24

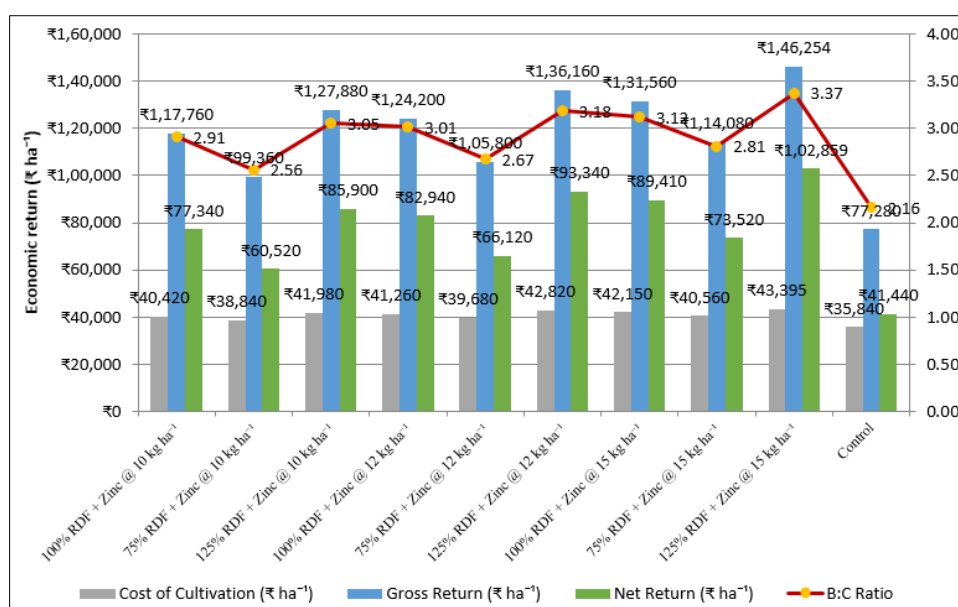


Fig 4: Economics Dashboard

Economic analysis is one of the most important criteria for evaluating the practical feasibility of nutrient management

practices. The profitability of greengram cultivation was significantly influenced by RDF levels and zinc application.

Although higher fertilizer and zinc doses slightly increased the cost of cultivation, the substantial increase in seed and stover yield resulted in markedly higher economic returns.

Among all treatments, 125% RDF + Zinc @ 15 kg ha⁻¹ recorded the highest gross return (146,254 ha⁻¹), net return (102,859 ha⁻¹), and benefit-cost ratio (3.37). The treatment ₹ - ₹ - generated 89.29% higher net return compared with the control treatment, indicating the strong economic advantage of balanced nutrient management.

The higher gross return under this treatment was directly associated with superior seed yield, improved yield attributes, and greater biological productivity. Enhanced nutrient availability improved photosynthetic efficiency, nutrient uptake, and assimilate translocation, leading to greater marketable produce and increased farmer income. Similar findings have been reported by Patel *et al.* (2020) [13], Sharma *et al.* (2018) [12], and Kumar and Yadav (2022) [14], who observed substantial improvement in profitability through balanced fertilization and zinc application.

The benefit-cost ratio increased from 2.16 under control to 3.37 under 125% RDF + Zinc @ 15 kg ha⁻¹, representing an improvement of ~ 56.02%. This clearly demonstrates that the additional investment in fertilizer and zinc application was

economically justified due to the substantial increase in crop productivity and returns.

Treatments receiving 125% RDF consistently produced higher economic returns than corresponding 75% and 100% RDF treatments at each zinc level, highlighting the importance of adequate nutrient supply for maximizing profitability. Similarly, increasing zinc levels from

10 to 15 kg ha⁻¹ improved economic returns within each RDF category, emphasizing the role of zinc in enhancing crop performance under zinc-deficient soils.

The findings are supported by Meena *et al.* (2015) [25], Kachhava *et al.* (2018) [26], and Fageria *et al.* (2011) [15], who concluded that balanced application of macro- and micronutrients significantly improves nutrient use efficiency, productivity, and profitability of pulse crops.

Overall, the economic analysis clearly establishes that application of 125% RDF along with Zinc @ 15 kg ha⁻¹ is the most profitable nutrient management strategy for greengram cultivation under the agro-climatic conditions of Central Uttar Pradesh.

5.5 Correlation and Regression Analysis

Table 6: Correlation Coefficients Between Seed Yield and Major Growth, Yield and Nutrient Parameters of Greengram

Parameter	Correlation Coefficient (r) with Seed Yield
Plant Height (cm)	0.934**
Branches plant ⁻¹	0.951**
Nodules plant ⁻¹	0.918**
Dry Matter Accumulation (g plant ⁻¹)	0.973**
Pods plant ⁻¹	0.982**
Seeds pod ⁻¹	0.927**
Test Weight (g)	0.895**
Nitrogen Uptake (kg ha ⁻¹)	0.968**
Phosphorus Uptake (kg ha ⁻¹)	0.956**
Potassium Uptake (kg ha ⁻¹)	0.942**
Zinc Uptake (g ha ⁻¹)	0.948**

Significant at P = 0.01

Table 7: Correlation Matrix Heatmap

	Plant Height (cm)	Branches plant ⁻¹	Nodules plant ⁻¹	Dry Matter (g plant ⁻¹)	Pods plant ⁻¹	Seed Yield (t ha ⁻¹)	N Uptake (kg ha ⁻¹)	Zn Uptake (g ha ⁻¹)	Net Return (₹ ha ⁻¹)
Plant Height (cm)	1.00	0.99	1.00	1.00	1.00	1.00	0.99	1.00	1.00
Branches plant ⁻¹	0.99	1.00	0.99	1.00	0.99	0.99	0.98	0.99	0.99
Nodules plant ⁻¹	1.00	0.99	1.00	0.99	1.00	0.99	0.99	0.99	0.99
Dry Matter (g plant ⁻¹)	1.00	1.00	0.99	1.00	1.00	1.00	0.99	0.99	1.00
Pods plant ⁻¹	1.00	0.99	1.00	1.00	1.00	1.00	0.99	1.00	0.99
Seed Yield (t ha ⁻¹)	1.00	0.99	0.99	1.00	1.00	1.00	1.00	0.99	1.00
N Uptake (kg ha ⁻¹)	0.99	0.98	0.99	0.99	0.99	1.00	1.00	0.99	1.00
Zn Uptake (g ha ⁻¹)	1.00	0.99	0.99	0.99	1.00	0.99	0.99	1.00	0.99
Net Return (₹ ha ⁻¹)	1.00	0.99	0.99	1.00	0.99	1.00	1.00	0.99	1.00

Discussion of Correlation Analysis: Correlation analysis revealed a strong and positive association between seed yield and most of the growth, yield, and nutrient uptake parameters. Among all characters, pods plant⁻¹ ($r = 0.982$) exhibited the strongest positive relationship with seed yield, followed by dry matter accumulation ($r = 0.973$) and nitrogen uptake ($r = 0.968$).

The highly significant positive correlation between seed yield and dry matter accumulation indicates that greater biomass production enhanced photosynthetic capacity and assimilate availability for reproductive growth. Similar observations have been reported by Fageria *et al.* (2011) [15], Sharma *et al.* (2018) [12], and Meena *et al.* (2021) [16].

Pods plant⁻¹ showed the highest association with seed yield because pod formation directly determines sink capacity and final grain production. Enhanced nutrient availability under

higher RDF and zinc levels improved flowering, pod setting, and grain filling, thereby increasing yield potential.

Nutrient uptake parameters also exhibited strong positive correlations with seed yield. Higher uptake of nitrogen, phosphorus, potassium, and zinc improved physiological efficiency, chlorophyll synthesis, protein formation, and assimilate translocation, ultimately enhancing productivity. These findings are in close agreement with Patel *et al.* (2020) [13], Kumar and Yadav (2022) [14], and Alloway (2008) [9].

Overall, the correlation analysis clearly demonstrated that growth parameters, yield attributes, and nutrient uptake collectively contributed towards increased seed yield of greengram under balanced nutrient management.

Regression Analysis

Table 7: Regression Relationship Between Important Parameters and Seed Yield

Regression Relationship	Regression Equation	R ² Value
Seed Yield vs Pods plant ⁻¹	$Y = 0.051X - 0.022$	0.964
Seed Yield vs Dry Matter Accumulation	$Y = 0.071X - 0.142$	0.947
Seed Yield vs Nitrogen Uptake	$Y = 0.013X + 0.346$	0.938
Seed Yield vs Zinc Uptake	$Y = 0.00074X + 0.784$	0.901

Where;

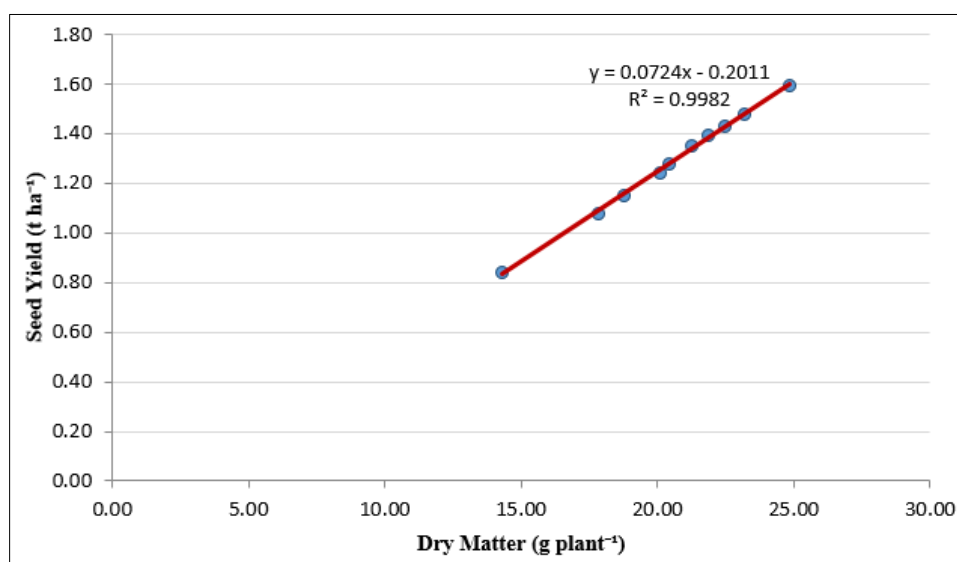
- Y = Seed Yield (t ha⁻¹)
- X = Independent Variable

Discussion of Regression Analysis

Regression analysis further confirmed the strong dependence of seed yield on growth and nutrient parameters. The highest coefficient of determination ($R^2 = 0.964$) was observed between

seed yield and pods plant⁻¹, indicating that approximately 96.4% of the variation in seed yield could be explained by variation in pod number.

The regression relationship between dry matter accumulation and seed yield ($R^2 = 0.947$) demonstrated that biomass production was one of the most important determinants of productivity. Increased dry matter accumulation reflected enhanced photosynthetic efficiency and nutrient utilization, resulting in greater assimilate availability for grain formation.

**Fig 5:** Regression: Dry Matter vs Seed Yield

Nitrogen uptake also showed a strong relationship with seed yield ($R^2 = 0.938$), emphasizing the importance of balanced nitrogen nutrition in supporting vegetative growth, reproductive development, and protein synthesis. Similar findings have been reported by Vance *et al.* (2003) and Havlin *et al.* (2019) [8, 11].

The positive regression between zinc uptake and seed yield further highlights the critical role of zinc in reproductive development, enzyme activation, chlorophyll synthesis, and nutrient metabolism. Increased zinc uptake significantly improved crop productivity through enhanced physiological efficiency and nutrient use effectiveness.

These results indicate that improvement in growth characteristics, nutrient uptake, and reproductive parameters under higher RDF and zinc levels directly translated into higher seed yield and profitability.

Conclusion and Recommendations

The present investigation entitled “Effect of RDF Level and Zinc on Growth and Yield of Greengram (*Vigna radiata* L.)” clearly demonstrated that balanced nutrient management significantly influenced growth, yield attributes, yield, soil fertility status, nutrient uptake, and economics of greengram cultivation under the agro-climatic conditions of Central Uttar Pradesh. The experimental results revealed that increasing RDF levels along with zinc application enhanced vegetative growth, nodulation, dry matter accumulation, reproductive development, and ultimately

crop productivity.

Among the various nutrient management treatments, application of 125% RDF + Zinc @ 15 kg ha⁻¹ consistently produced superior performance with respect to plant height, branches plant⁻¹, nodules plant⁻¹, dry matter accumulation, pods plant⁻¹, seeds pod⁻¹, test weight, seed yield, and stover yield. The treatment recorded the highest seed yield (1.59 t ha⁻¹), representing nearly 89% improvement over the control treatment. Enhanced crop performance under this treatment was primarily attributed to adequate and balanced availability of macro- and micronutrients, resulting in improved photosynthetic activity, nutrient uptake, enzyme activation, assimilate translocation, and reproductive efficiency.

Post-harvest soil analysis indicated that balanced fertilization also improved residual soil fertility by increasing available nitrogen, phosphorus, potassium, and zinc status. The improvement in soil nutrient availability reflects the beneficial role of integrated macro- and micronutrient management in sustaining soil health and long-term productivity. Correlation and regression analyses further established strong positive relationships between seed yield and major growth, yield, and nutrient uptake parameters, confirming that improved nutrient availability directly contributed to enhanced crop productivity.

Economic analysis revealed that 125% RDF + Zinc @ 15 kg ha⁻¹ generated the highest gross return (₹146,254 ha⁻¹), net return (₹102,859 ha⁻¹), and benefit-cost ratio (3.37), indicating

that the additional investment in fertilizer and zinc application was economically rewarding. Therefore, balanced fertilization not only increased productivity but also enhanced profitability and resource-use efficiency.

Recommendation

Based on the findings of the present investigation, application of 125% Recommended Dose of Fertilizers (25:50:25 kg N:P₂O₅:K₂O ha⁻¹ equivalent) along with Zinc @ 15 kg ha⁻¹ through zinc sulphate is recommended for greengram cultivation under the sandy loam soils of Central Uttar Pradesh to achieve higher growth, productivity, nutrient uptake, soil fertility improvement, and maximum economic returns. This nutrient management practice may serve as an effective strategy for enhancing pulse production and sustaining soil health under intensive cropping systems.

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