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Effect of different levels of zinc and rhizobium inoculation conjugated with recommended NPK on soil properties, growth and yield of green gram (*Vigna radiata* L.)

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Abstract

The field experiment was conducted on effect of different levels of zinc and rhizobium inoculation conjugated with recommended NPK on soil properties, growth and yield of green gram in *kharif* season, 2024 at the Crop Research Farm of Department of Soil Science and Agricultural Chemistry, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj. The experiment was laid out in a randomized block design (RBD) with three replications consisting of 8 treatment combinations (NPK_{100%}+Zn₀+Rh₀, NPK_{100%}+Zn₀+Rh₁₀₀, NPK_{100%}+Zn₃+Rh₀, NPK_{100%}+Zn₃+Rh₁₀₀, NPK_{100%}+Zn₆+Rh₀, NPK_{100%}+Zn₆+Rh₁₀₀, NPK_{100%}+Zn₉+Rh₀ and NPK_{100%}+Zn₉+Rh₁₀₀), the treatment includes four zinc levels (control, @3 kg/ha, @6 kg/ha, @9 kg/ha) and two rhizobium levels (Rh₀ and Rh₁₀₀). The results experiment depict that application of 9 kg Zn/ha with rhizobium inoculation significantly improved soil properties. The maximum percent organic carbon (0.44 %), available nitrogen (244.40 kg/ha), available phosphorous (24.30 kg/ha), available potassium (235.86 kg/ha) and extractable zinc (0.97 mg/kg) were recorded in treatment T₈ (NPK_{100%}+Zn₉+Rh₁₀₀). Notably, 6 kg Zn/ha with rhizobium boosted plant growth and yield parameters. The maximum plant height (43.19 cm), number of nodules (12.56/plant), number of pods (23.30 pods/plant), test weight (39.62 g), grain yield (20.94 Q/ha) and stover yield (24.15 Q/ha) were recorded in treatment T₆ (NPK_{100%}+Zn₆+Rh₁₀₀).

Keywords: Green gram, zinc, rhizobium, soil property, growth, yield

1. Introduction

Soil is the topmost layer of the earth, composed of minerals, organic matter, water, air and living organisms. It supports plant growth, regulates water flow, recycles nutrients and sustains ecosystems. Its formation is influenced by parent material, climate, organisms, topography and time, resulting in diverse soil types. Understanding soil properties is essential for sustainable agriculture and land management (Brady and Weil, 2016) [2]. Eastern Uttar Pradesh has fertile alluvial soils but suffers from zinc deficiency, organic carbon loss and poor nutrient management demanding sustainable interventions (ICAR-IISS, 2021; FAO, 2023) [12, 5]. Indian agriculture is a key sector, supporting over 50% of the population and contributing to food security and economic growth. (Department of Agriculture, 2022; GOI, 2024) [3, 8]

Green gram (*Vigna radiata* L.), or moong, is a short-duration legume crop known for its high protein (24-28%), micronutrients and BNF (Mehandhi *et al.* 2019) [16]. India is the world's top producer, contributing over 70% of global output with key states including Rajasthan (39.06%), followed by Madhya Pradesh (11.57%), Maharashtra (8.57%), Bihar (5.54%), Karnataka (5.05%), Tamil Nadu (5.02%), Gujarat (4.63%) and Andhra Pradesh (4.31%) (Gavali *et al.*, 2022) [7].

This crop grows well in well-drained loamy to sandy loam soils with pH of 6.0-7.5. It prefers warm climates (25-35 °C) and performs best under rainfed conditions in the *kharif* or summer season. (IIPR, 2021) [11]. Low productivity is due to poor soils, outdated varieties, pest pressures, and imbalanced fertilization (Singh and Kumar, 2020) [27]. Green gram thrives with integrated nutrient management involving zinc and rhizobium, which enhance nodulation, nitrogen

fixation, biomass and yield (Bhardwaj and Singh, 2018) ^[1].

In 2024-25, India produced 1.3 million tonnes of green gram, up from 1.1 million tonnes in 2023-24, cultivated over 33.24 lakh hectares (PJ TSAU, 2024) ^[19]. Indian agriculture supports over 40% of the population and contributes 15-18% to GDP (FAO, 2022) ^[4], yet faces challenges like soil degradation, low productivity, and dependence on monsoons (NITI Aayog, 2020) ^[17]. As compared to the other countries Indonesia (13% GDP, 29% workforce) excels in palm oil and rice. China (7-8% GDP) and Brazil (6-7%) benefit from better tech and exports. USA (1% GDP, <2% workforce) leads in mechanized farming. India has high output but lags in efficiency and modernization (Purba *et al.*, 2023; OECD, 2018; USDA, 2023; Shelare, 2015) ^[21, 18, 32, 24].

Zinc is one of the seventh plant micronutrient. It is vital for enzyme activity, growth and nodulation, deficiency impairs crop performance, while optimal levels improve productivity (Kumar and Singh, 2021) ^[14]. Zinc deficiency in plants typically occurs when soil zinc levels drop below 20 ppm, whereas concentrations exceeding 400 ppm in plant tissues can lead to zinc toxicity. (Tisdale *et al.*, 1993) ^[31].

Rhizobium inoculation enhances nitrogen fixation (20-40 kg/ha), boosts yield by up to 30%, and improves soil fertility, making it essential for sustainable pulse production (Wani *et al.*, 2022) ^[33]. In summary, rhizobium inoculation during the *kharif* season is crucial for optimizing green gram production. It enhances plant growth, increases yield and improves soil fertility, thereby supporting sustainable agriculture (Singh *et al.*, 2018) ^[28].

PDM-139 (Samrat) is an early-maturing green gram (*Vigna radiata* L.) variety developed by the Indian Institute of Pulses Research and released in 2001 for cultivation in Uttar Pradesh. It matures in about 58-62 days and produces attractive, bold and shiny green seeds. The variety is moderately resistant to Yellow Mosaic Virus (YMV) and leaf crinkle disease. It has a yield potential of 15-20 quintals per hectare under optimal conditions (Mastkar and Kushwaha, 2016) ^[10].

2. Materials and Methods

2.1 Experimental site

The field experiment was conducted at the Crop Research Farm of Department of Soil Science and Agricultural Chemistry, NAI, SHUATS, Naini, Prayagraj, U.P. situated at 25°27' N latitude and 81°51' E longitude at an elevation of 98 m from the mean sea level. This region has a sub-tropical climate prevailing in the South-East part of UP. The soil of the experimental site is alluvial and falls under Inceptisol order. Prayagraj has a semi-arid to sub-humid climate with a moisture deficit index of 20-40. It receives 1100 mm annual rainfall, mainly during the *kharif* season (June-September). Summers (April-July) are hot (40-48 °C), while winters (December-February) can drop to 3-5 °C. During *Kharif* 2024, warm temperatures and ample rainfall supported crop growth. During the greengram cultivation period (July-October) temperature ranged from a maximum 39.6-33.6°C to minimum 24.6-28°C. Relative humidity ranged from a maximum 100-82 % to minimum 59-34%.

2.2 Experimental setup

The experiment consist of eight treatments (NPK_{100%}+Zn₀+Rh₀, NPK_{100%}+Zn₀+Rh₁₀₀, NPK_{100%}+Zn₃+Rh₀, NPK_{100%}+Zn₃+Rh₁₀₀, NPK_{100%}+Zn₆+Rh₀, NPK_{100%}+Zn₆+Rh₁₀₀, NPK_{100%}+Zn₉+Rh₀ and NPK_{100%}+Zn₉+Rh₁₀₀). Which were laid out in randomized block design and replicated thrice.

Soil samples were collected randomly from five locations within the experimental plot before tillage and treatment wise after crop

harvest at 0-15 cm depth. The collected samples were air-dried, crushed with wooden hammer and passed through 2 mm sieve to prepare them for analysis (organic carbon %, available N, P, K kg/ha and extractable Zinc mg/kg of soil) following standard procedure (Walkley and Black method, Alkaline Potassium Permanganate method, Olsen's Colorimetric method, Neutral Ammonium Acetate method and DTPA extraction method).

The seeds were sowing on 29th July, 2024 in each row at the spacing of 30 x 10 cm. Recommended dose of NPK (20:40:20) were applied through urea, single super phosphate and muriate of potash, respectively. Nitrogen was applied in three split doses, 40% of the nitrogen and full dose of phosphorous and potassium (basal dose) were applied at the time of sowing and remaining nitrogen was applied as top dressed in two equal split parts at 20 DAS (days after sowing) and 40 DAS. Two manual weeding were carried out during the crop season first at 25 DAS and the second at 45 DAS to control weed competition during the critical early growth stages and to promote better crop establishment and yield. Irrigation was applied at critical growth stages to support crop establishment, development and yield, with flowering and pod filling identified as the most moisture-sensitive phases.

Growth parameters such as plant height (cm/plant) and number of nodules (per plant) were recorded at different physiological growth stages 15, 30, 45 and 60 days after sowing (DAS). Five plants were randomly selected and tagged was used to measure plant height with a meter scale. Yield parameters such as number of pods (per plant), test weight (g), grain yield (Q/ha) and stover yield (Q/ha). The recorded data were statistically analysed following the method described by Ronald A. Fisher (1935) ^[6] to ensure valid interpretation. Treatment means were compared using the critical difference (CD) at the 5% level of significance ($P=0.05$).

3. Result and Discussion

3.1 Effect of different level of zinc and rhizobium inoculation conjugated with recommended dose of NPK on Chemical properties soil

The effect of different level of zinc and rhizobium inoculation conjugated with recommended dose of NPK on percent organic carbon, available nitrogen, phosphorous and potassium kg/ha and extractable zinc mg/kg of soil were found significant at 5% critical difference are presented in (Table 1). The maximum organic carbon 0.44%, nitrogen 244.40 kg ha⁻¹, phosphorous 24.30 kg ha⁻¹, potassium 235.86 kg ha⁻¹ and extractable zinc 0.97 mg kg⁻¹ of soil was observed in treatment T₈ [NPK_{100%}+Zn₉+Rh₁₀₀] and minimum organic carbon 0.35%, nitrogen 237.17 kg ha⁻¹, phosphorous 19.92 kg ha⁻¹, potassium 197.91 kg ha⁻¹ and extractable zinc 0.66 mg kg⁻¹ of soil was recorded in treatment T₁ [NPK_{100%}+Zn₀+Rh₀]. The combined application of zinc (9 kg/ha), rhizobium and NPK improves soil fertility by enhancing nutrient availability and microbial activity. Rhizobium boosts nitrogen fixation and microbial biomass, while zinc promotes root growth and nutrient metabolism. Together with NPK, they increase biomass return and residue decomposition, enriching soil organic carbon. Zinc enhances uptake of N, P, K, and Zn; Rhizobium mobilizes nutrients through microbial action and NPK supports nutrient cycling collectively improving soil N, P, K and extractable Zn levels. Meena *et al.* (2018) ^[15] also reported that application of 6-9 kg Zn/ha with rhizobium in legumes enhanced soil health indicators including organic carbon, due to improved microbial activity and rhizosphere enrichment. Sankhla *et al.* (2019) ^[23] observed that combined use of zinc and rhizobium significantly increased

available nitrogen in green gram by enhancing nodulation and rhizosphere microbial activity. Kumar *et al.* (2018) ^[13] reported that application of zinc with rhizobium in green gram increased available phosphorus through improved root activity and microbial P solubilization. Rathore *et al.* (2014) ^[22] observed enhanced potassium availability in mungbean was observed with biofertilizers and micronutrients, due to increased microbial activity and nutrient cycling. Takkar and Walker (1993) ^[30] reported that zinc availability increases when zinc fertilizers are applied with legumes due to root-induced pH changes and organic acid production.

3.2 Effect of different level of zinc and rhizobium inoculation conjugated with recommended dose of NPK on growth parameters

The effect of different level of zinc and rhizobium inoculation conjugated with recommended dose of NPK on plant height (cm) and number of nodules of green gram at 15, 30, 45 and 60 DAS were found significant at 5% critical difference are presented in (Table 2). The maximum plant height 9.20, 26.00, 33.99 and 43.19 cm and number of nodules 9.75, 19.82, 26.42 and 12.56 was observed in treatment T₆ [NPK_{100%}+Zn₆+Rh₁₀₀] and minimum plant height 6.57, 17.23, 23.87 and 30.49 cm and number of nodules 5.17, 13.26, 18.49 and 8.67 was recorded in treatment T₁ [NPK_{100%}+Zn₀+Rh₀]. The combined application of 6 kg Zn, 100% rhizobium and NPK enhances root growth, nodulation. Zinc stimulates enzymes and hormones, rhizobium boosts nitrogen fixation and NPK supports root development together resulting in significantly taller plants at all growth stages. Singh and Yadav (2020) ^[29] also reported that plant height and nodulation showed significant enhancement with 6 kg Zn/ha + Rhizobium likely due to improved nitrogen

assimilation and growth hormone activity.

3.3 Effect of different level of zinc and rhizobium inoculation conjugated with recommended dose of NPK on yield parameters

The effect of different level of zinc and rhizobium inoculation conjugated with recommended dose of NPK on number of pods, test weight(g), grain yield (Q/ha) and stover yield (Q/ha) of green gram were found significant at 5% critical difference are presented in (Table 3). The maximum number of pods 23.30, test weight 39.62 g, grain yield 20.94 Q ha⁻¹ and stover yield 24.15 Q ha⁻¹ were observed in treatment T₆ [NPK+Zn₆+Rh₁₀₀] and minimum number of pods 17.67, test weight 34.21 g, grain yield 15.96 Q ha⁻¹ and stover yield 15.45 Q ha⁻¹ were recorded in treatment T₁ [NPK+Zn₀+Rh₀]. The combined application of zinc (6 kg/ha), 100% Rhizobium, and NPK significantly improves pod number (around 32%), root development and nutrient uptake in green gram. Zinc enhances enzyme activity, chlorophyll production and assimilate flow for better flowering and grain filling. Rhizobium boosts nitrogen fixation and protein synthesis, while NPK provides essential nutrients, collectively enhancing yield, biomass and stover production. Singh and Dubey (2024) ^[26] also reported a field experiment with four zinc levels (0-7.5 kg/ha) and rhizobium showed the highest pod number per plant under treatment along with improved plant height, nodulation, grain yield and stover yield compared to treatments without Zn or biofertilizer, demonstrating synergy among the inputs. Singh *et al.* (2020) ^[25] found that zinc and rhizobium increased test weight by 18% due to better carbohydrate translocation. Prasad *et al.* (2019) ^[20] zinc (6 kg/ha) reduced drought stress, increasing yield by 15-20% in legumes.

Table 1: Effect of different levels of zinc and rhizobium inoculation conjugated with recommended NPK on chemical properties of soil (0-15 cm)

Treatment	Organic carbon (%)	Available Nitrogen (Kg ha ⁻¹)	Available Phosphorous (Kg ha ⁻¹)	Available Potassium (Kg ha ⁻¹)	Extractable Zinc (mg kg ⁻¹)
T1	0.35	237.17	19.92	197.91	0.66
T2	0.37	238.06	20.45	211.77	0.71
T3	0.39	238.27	21.28	224.21	0.74
T4	0.40	240.87	21.93	224.36	0.77
T5	0.41	241.87	22.70	225.76	0.81
T6	0.42	242.31	22.73	228.95	0.87
T7	0.43	243.20	23.60	231.02	0.92
T8	0.44	244.40	24.30	235.86	0.97
F- test	S	S	S	S	S
S.Em. (±)	0.01	0.59	0.22	2.05	0.006
C.D. @ 5%	0.03	1.80	0.68	6.21	0.018

Table 2: Effect of different levels of zinc and rhizobium inoculation conjugated with recommended NPK on growth parameter of greengram at 15, 30, 45 and 60 DAS

Treatment	Plant height (cm)				Number of nodules (plant ⁻¹)			
	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS
T1	6.57	17.23	23.87	30.49	5.17	13.26	18.49	8.67
T2	7.55	19.28	26.63	34.62	6.00	15.00	19.88	8.83
T3	7.69	20.67	27.93	36.85	6.50	15.50	20.68	9.50
T4	7.95	21.50	28.75	37.81	7.00	16.00	21.08	9.67
T5	8.29	22.50	29.61	39.16	7.50	16.50	22.10	10.17
T6	9.20	26.00	33.99	43.19	9.75	19.82	26.42	12.56
T7	8.52	21.83	30.67	39.69	7.71	17.00	23.04	10.50
T8	8.78	25.00	32.83	42.11	8.65	18.25	24.72	11.24
F- test	S	S	S	S	S	S	S	S
S. Em. (±)	0.45	0.23	0.41	0.25	0.11	0.23	1.08	0.51
C.D. @ 5%	1.36	0.69	1.26	0.76	0.32	0.69	3.27	1.53

Table 3: Effect of different levels of zinc and rhizobium inoculation conjugated with recommended NPK on yield parameter of greengram at 15, 30, 45 and 60 DAS

Treatment	Number of pods (plant ⁻¹)	Test weight (g)	Grain yield (Q ha ⁻¹)	Stover yield (Q ha ⁻¹)
T1	17.67	34.21	15.96	15.45
T2	18.17	35.05	16.43	16.48
T3	19.12	35.65	16.81	17.93
T4	19.61	36.27	16.42	18.45
T5	20.78	36.72	18.28	19.23
T6	23.30	39.62	20.94	24.15
T7	21.45	37.44	18.63	22.83
T8	23.13	38.14	19.81	23.84
F- test	S	S	S	S
S. Em. (±)	1.01	0.04	0.72	0.88
C.D. @ 5 %	3.05	0.13	2.20	2.68

4. Conclusion

The result of experiment concluded as the effect of different levels of Zinc and Rhizobium inoculation conjugated with the recommended doses of NPK, treatment T₈ (NPK+Zn₉+Rh₁₀₀) significantly improved soil properties. On the contrary, the maximum plant height, number of nodules, number of pods, test weight, grain yield and stover yield was found in T₆ (NPK+Zn₆+Rh₁₀₀).

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