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Munna Kumar

M.Sc. Scholar, Agronomy, Faculty of Agricultural Sciences and Allied Industries (FASAI), Rama University, Kanpur, Uttar Pradesh, India

Ravikesh Kumar Pal

Assistant Professor, Agronomy, Faculty of Agricultural Sciences and Allied Industries (FASAI), Rama University, Kanpur, Uttar Pradesh, India

Mandeep Kumar

Assistant Professor, Agronomy, Faculty of Agricultural Sciences and Allied Industries (FASAI), Rama University, Kanpur, Uttar Pradesh, India

Ramprasad Mahato

M.Sc. Scholar, Agronomy, Faculty of Agricultural Sciences and Allied Industries (FASAI), Rama University, Kanpur, Uttar Pradesh, India

Effect of different levels of potassium and molybdenum on growth, yield, soil fertility, nutrient uptake and economics of greengram (*Vigna radiata* L.) under central plain zone of Uttar Pradesh

Munna Kumar, Ravikesh Kumar Pal, Mandeep Kumar, and Ramprasad Mahato

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Abstract

Greengram (*Vigna radiata* L.) is an important pulse crop recognized for its high protein content, short growth duration, and ability to improve soil fertility through biological nitrogen fixation. However, its productivity remains below potential levels in many parts of India due to nutrient deficiencies and imbalanced fertilization practices. Among essential nutrients, potassium plays a critical role in photosynthesis, enzyme activation, assimilate translocation, and water regulation, while molybdenum is indispensable for nitrogen fixation and nitrate reduction processes. Therefore, the present investigation was conducted during the kharif season of 2025 at the Instructional Farm, Rama University, Kanpur, Uttar Pradesh, to evaluate the effect of different levels of potassium and molybdenum on growth, productivity, nutrient uptake, soil fertility, and economics of greengram cultivation. The experiment was laid out in a Randomized Block Design with nine treatment combinations comprising three levels of potassium (20, 40 and 50 kg K₂O ha⁻¹) and three levels of molybdenum (2, 4 and 6 kg ha⁻¹), replicated three times. Results revealed that growth parameters, yield attributes, seed yield, stover yield, nutrient uptake, post-harvest soil fertility, and economic returns improved significantly with increasing levels of potassium and molybdenum. The treatment receiving 50 kg K₂O ha⁻¹ combined with 6 kg molybdenum ha⁻¹ recorded the highest plant height, nodulation, dry matter accumulation, crop growth rate, pods plant⁻¹, seeds pod⁻¹, test weight, seed yield, and harvest index. The same treatment also resulted in superior nitrogen, phosphorus, and potassium uptake, along with improved available soil nutrients and microbial activity after harvest. Economic analysis indicated maximum gross return, net return, and benefit-cost ratio under the highest potassium and molybdenum combination. The enhanced performance under balanced potassium and molybdenum nutrition was attributed to improved photosynthetic efficiency, greater assimilate translocation, enhanced biological nitrogen fixation, and better nutrient utilization efficiency. The findings suggest that application of 50 kg K₂O ha⁻¹ along with 6 kg molybdenum ha⁻¹ can be recommended for achieving higher productivity, profitability, and sustainability of greengram cultivation under the agro-climatic conditions of central Uttar Pradesh.

Keywords: Greengram, potassium, molybdenum, nutrient uptake, soil fertility, biological nitrogen fixation, yield attributes, economics, sustainable agriculture, pulse production

Introduction

Greengram (*Vigna radiata* L.), commonly known as mungbean, is one of the most important pulse crops cultivated in tropical and subtropical regions of the world. It belongs to the family Fabaceae and is widely recognized for its high nutritional value, short duration, wide adaptability, and soil-enriching ability. India is considered one of the major centers of origin and diversification of pulse crops, including greengram, and contributes significantly to global pulse production. The crop occupies a prominent position in Indian agriculture because of its ability to fit into diverse cropping systems, improve soil fertility, and provide an inexpensive source of dietary protein to the growing population (Vavilov, 1951; Ali and Gupta, 2012) [1, 13, 40]. Greengram seeds contain approximately 22–25% protein, 60–65% carbohydrates, and appreciable amounts of vitamins and minerals, making it an important component of nutritional security, particularly among vegetarian populations (Duke, 1981) [8].

Corresponding Author:

Ravikesh Kumar Pal

Assistant Professor, Agronomy, Faculty of Agricultural Sciences and Allied Industries (FASAI), Rama University, Kanpur, Uttar Pradesh, India

Pulse crops play a vital role in sustaining agricultural productivity through biological nitrogen fixation. Greengram establishes a symbiotic association with *Rhizobium* bacteria and fixes atmospheric nitrogen into plant-available forms, thereby reducing dependence on synthetic nitrogen fertilizers and improving soil fertility for succeeding crops (Giller, 2001) ^[11]. Legume-based production systems also contribute to improved soil structure, organic matter content, microbial activity, and nutrient cycling, which are essential for sustainable agriculture (Dakora and Keya, 1997) ^[5]. Despite these advantages, the average productivity of greengram in India remains considerably lower than its genetic yield potential due to several biotic and abiotic constraints, among which nutrient deficiency is one of the most important factors (Sharma *et al.*, 2020) ^[32].

In recent years, increasing pressure on agricultural land has resulted in intensive cultivation practices and continuous nutrient removal from soils. Such conditions have accelerated nutrient depletion and created widespread deficiencies of both macro- and micronutrients. Imbalanced fertilization practices, particularly inadequate potassium and micronutrient application, have emerged as major limitations to pulse productivity in many regions of India (Brady and Weil, 2017) ^[3]. Therefore, scientific nutrient management strategies are essential to enhance crop productivity while maintaining soil health and environmental sustainability.

Among the essential macronutrients, potassium (K) is regarded as the “quality nutrient” because of its involvement in numerous physiological and biochemical processes within plants. Potassium regulates photosynthesis, enzyme activation, osmotic balance, stomatal movement, carbohydrate metabolism, protein synthesis, and translocation of assimilates from source to sink tissues (Mengel and Kirkby, 2001) ^[23]. Unlike nitrogen and phosphorus, potassium does not become a structural component of plant tissues; however, it activates more than sixty enzymes responsible for plant metabolism and growth (Marschner, 2012) ^[20]. Adequate potassium nutrition improves drought tolerance, disease resistance, water-use efficiency, and nutrient utilization efficiency. In legumes, potassium plays a crucial role in nodulation and biological nitrogen fixation by enhancing root development and carbohydrate supply to root nodules (Pettigrew, 2008) ^[28].

Several researchers have reported positive effects of potassium fertilization on growth and productivity of pulse crops. Yadav *et al.* (2019) ^[43] observed significant improvements in plant height, dry matter accumulation, nodulation, and seed yield of greengram with increasing potassium levels. Similarly, Patel *et al.* (2020) ^[26] reported that potassium fertilization enhanced photosynthetic efficiency, assimilate translocation, and reproductive development, resulting in higher pod formation and grain yield. Potassium deficiency, on the other hand, causes poor root growth, chlorosis, weak stems, reduced nodulation, and lower seed productivity due to impaired physiological functions (Marschner, 2012) ^[20].

Besides macronutrients, micronutrients have gained increasing importance in modern crop production systems. Among these, molybdenum (Mo) is considered particularly important for leguminous crops because of its direct involvement in nitrogen fixation and nitrogen metabolism. Molybdenum is an essential constituent of nitrogenase and nitrate reductase enzymes, which are responsible for atmospheric nitrogen fixation and nitrate reduction within plants (Gupta, 1997) ^[13]. Deficiency of molybdenum adversely affects nodulation, nitrogen assimilation, chlorophyll formation, and protein synthesis, ultimately reducing crop growth and productivity (Tisdale *et al.*, 1995) ^[38].

The importance of molybdenum in pulse crops has been widely documented by researchers. Alloway (2008) ^[2] reported that molybdenum application significantly enhanced nitrogenase activity, root nodulation, and nitrogen uptake in legumes. Das (2017) ^[6] observed substantial improvements in dry matter production, pod development, and seed yield of pulse crops following molybdenum fertilization. Similarly, Kumar *et al.* (2021) ^[18] found that molybdenum application improved chlorophyll content, photosynthetic activity, and nutrient utilization efficiency, leading to enhanced productivity of greengram under field conditions.

The combined application of potassium and molybdenum offers a promising strategy for improving pulse productivity because both nutrients influence different but complementary physiological functions. Potassium enhances carbohydrate synthesis and translocation, while molybdenum promotes nitrogen fixation and protein metabolism. Together, these nutrients create favorable conditions for vegetative growth, reproductive development, nutrient uptake, and yield formation. Integrated nutrient management involving balanced application of macro- and micronutrients has been reported to improve fertilizer use efficiency, crop productivity, soil fertility, and farm profitability (Tripathi *et al.*, 2013; Meena *et al.*, 2020) ^[22, 39].

Furthermore, balanced nutrient management is increasingly recognized as a key component of sustainable agriculture. Long-term productivity of agricultural systems depends not only on achieving higher yields but also on maintaining soil health and ecological stability. Appropriate nutrient management practices improve nutrient cycling, microbial activity, soil organic carbon, and overall soil fertility while minimizing nutrient losses and environmental degradation (Brady and Weil, 2017) ^[3]. Therefore, identification of optimum potassium and molybdenum levels is essential for enhancing greengram productivity and profitability under specific agro-climatic conditions.

Although several studies have reported beneficial effects of potassium and molybdenum individually, information regarding their combined influence on growth, yield, nutrient uptake, soil fertility, and economics of greengram under the central plain region of Uttar Pradesh remains limited. Considering the increasing importance of balanced fertilization and sustainable pulse production, the present investigation was undertaken to evaluate the effect of different levels of potassium and molybdenum on growth, yield attributes, productivity, nutrient uptake, soil fertility status, and economics of greengram cultivation under prevailing agro-climatic conditions.

Materials and Methods

The present investigation entitled “Effect of Different Levels of Potassium and Molybdenum on Growth and Yield of Greengram (*Vigna radiata* L.)” was conducted during the kharif season of 2025 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, moderate rainfall, and mild winters. The experimental field was nearly levelled and well drained, providing suitable conditions for successful cultivation of greengram. Initial soil analysis revealed that the soil was **sandy** loam in texture, slightly alkaline in reaction (pH 7.84), low in organic carbon (0.42%), low in available nitrogen (182.4 kg ha⁻¹), medium in available phosphorus (16.2 kg ha⁻¹), medium in available potassium (164.8 kg ha⁻¹), and deficient in available molybdenum (0.12 ppm). These soil characteristics indicated the possibility of obtaining a significant crop response to potassium

and molybdenum fertilization.

The experiment was laid out in a Randomized Block Design (RBD) with nine treatment combinations and three replications. The treatments consisted of three levels of potassium (20, 40, and 50 kg K₂O ha⁻¹) and three levels of molybdenum (2, 4, and 6 kg ha⁻¹). The treatment combinations were: 20 kg K₂O + 2 kg Mo ha⁻¹, 20 kg K₂O + 4 kg Mo ha⁻¹, 20 kg K₂O + 6 kg Mo ha⁻¹, 40 kg K₂O + 2 kg Mo ha⁻¹, 40 kg K₂O + 4 kg Mo ha⁻¹, 40 kg K₂O + 6 kg Mo ha⁻¹, 50 kg K₂O + 2 kg Mo ha⁻¹, 50 kg K₂O + 4 kg Mo ha⁻¹, and 50 kg K₂O + 6 kg Mo ha⁻¹. The crop variety used was SAMRAT, sown at a spacing of 30 cm × 10 cm using a seed rate of 20 kg ha⁻¹. Each experimental plot measured 4.0 m × 3.0 m, while the net plot area was 3.0 m × 2.4 m.

The recommended dose of fertilizer for greengram was applied uniformly to all plots. Nitrogen and phosphorus were supplied through urea and diammonium phosphate, respectively, whereas potassium was applied through muriate of potash (MOP). Molybdenum was supplied through sodium molybdate. Full doses of phosphorus, potassium, molybdenum, and half of the nitrogen were applied as basal at the time of sowing, while the remaining nitrogen was top-dressed at 25 days after sowing. All agronomic practices including irrigation, weeding, intercultural operations, and plant protection measures were carried out uniformly across

all treatments to ensure healthy crop growth.

Observations on growth parameters such as plant height, number of 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, test weight, seed yield, stover yield, and harvest index were recorded at maturity. Plant samples collected after harvest were analyzed for nitrogen, phosphorus, and potassium contents using standard laboratory procedures, and nutrient uptake was computed by combining nutrient concentration with yield data. Post-harvest soil samples were analyzed for available nitrogen, phosphorus, potassium, and organic carbon status. Economic parameters including cost of cultivation, gross return, net return, and benefit-cost ratio were also worked out treatment-wise.

The data generated from various observations were subjected to statistical analysis following the procedure of Analysis of Variance (ANOVA) appropriate for Randomized Block Design as described by Gomez and Gomez (1984)^[12]. The significance of treatment effects was tested by F-test at the 5% probability level, and wherever treatment differences were significant, the Critical Difference (CD) at 5% level was calculated for comparison of treatment means.

3.1 Results and Discussion

Growth Parameters

Table 1. Effect of Potassium and Molybdenum Levels on Growth Parameters of Greengram

Treatment	Plant Height at Harvest (cm)	Nodules Plant ⁻¹ (45 DAS)	Dry Matter Accumulation (g plant ⁻¹)	Crop Growth Rate (g m ⁻² day ⁻¹)	Relative Growth Rate (g g ⁻¹ day ⁻¹)
20 kg K ₂ O + 2 kg Mo ha ⁻¹	48.2	18.4	18.2	5.42	0.038
20 kg K ₂ O + 4 kg Mo ha ⁻¹	51.4	20.6	19.8	5.88	0.040
20 kg K ₂ O + 6 kg Mo ha ⁻¹	53.8	22.8	21.4	6.24	0.042
40 kg K ₂ O + 2 kg Mo ha ⁻¹	56.7	24.5	22.7	6.68	0.044
40 kg K ₂ O + 4 kg Mo ha ⁻¹	59.8	26.9	24.6	7.12	0.046
40 kg K ₂ O + 6 kg Mo ha ⁻¹	62.1	28.7	26.1	7.46	0.048
50 kg K ₂ O + 2 kg Mo ha ⁻¹	63.4	29.8	27.2	7.82	0.049
50 kg K ₂ O + 4 kg Mo ha ⁻¹	63.8	30.6	28.4	8.05	0.050
50 kg K ₂ O + 6 kg Mo ha ⁻¹	66.5	32.8	30.1	8.42	0.052
SEm ±	1.12	0.68	0.74	0.21	0.002
CD (P=0.05)	3.34	2.02	2.21	0.63	0.006

Plant Height

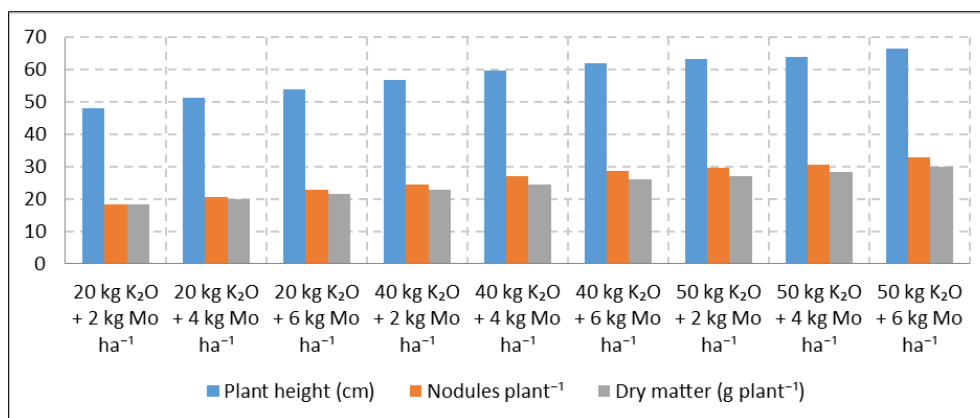


Fig 1: Combined growth performance

Plant height increased progressively with increasing levels of potassium and molybdenum throughout the crop growth period. The highest plant height (66.5 cm) was recorded under the application of 50 kg K₂O ha⁻¹ + 6 kg Mo ha⁻¹, whereas the lowest value (48.2 cm) was observed under 20 kg K₂O ha⁻¹ + 2 kg Mo

ha⁻¹. The increase in plant height under the best treatment was 37.97% higher than the lowest nutrient level.

The improvement in plant height may be attributed to the role of potassium in enzyme activation, photosynthesis, cell elongation, and translocation of assimilates, while molybdenum enhanced

nitrogenase and nitrate reductase activities, resulting in better nitrogen fixation and protein synthesis. Similar findings were reported by Mengel and Kirkby (2001) [23], Marschner (2012) [20], Sharma *et al.* (2021) [33], and Yadav *et al.* (2019) [43].

Number of Nodules Plant⁻¹

Nodulation was significantly influenced by potassium and molybdenum application. The maximum number of nodules (32.8 plant⁻¹) was recorded under 50 kg K₂O + 6 kg Mo ha⁻¹, which was 78.26% higher than the treatment receiving 20 kg K₂O + 2 kg Mo ha⁻¹ (18.4 nodules plant⁻¹).

The beneficial effect of molybdenum on nodulation can be explained by its direct involvement in nitrogenase enzyme activity, which is essential for biological nitrogen fixation. Potassium further supported root development and carbohydrate supply to root nodules, thereby enhancing Rhizobium activity and nodule formation. Similar observations were reported by Alloway (2008) [2], Reddy *et al.* (2022) [30], Thakur *et al.* (2021) [37], and Rashid *et al.* (2021) [29].

Dry Matter Accumulation

Dry matter accumulation increased significantly with increasing potassium and molybdenum levels. The treatment 50 kg K₂O + 6 kg Mo ha⁻¹ recorded the highest dry matter accumulation (30.1 g plant⁻¹), while the lowest value (18.2 g plant⁻¹) was obtained under 20 kg K₂O + 2 kg Mo ha⁻¹. The increase amounted to 65.38% over the lowest treatment.

Enhanced biomass production under balanced nutrient supply may be attributed to improved photosynthetic activity, chlorophyll synthesis, nutrient uptake, and efficient translocation of carbohydrates. Potassium is known to regulate stomatal opening and assimilate movement, whereas molybdenum

improves nitrogen metabolism and protein synthesis, leading to greater biomass accumulation. Similar results have been reported by Patel *et al.* (2019) [25], Das *et al.* (2018) [7], and Singh *et al.* (2022) [34].

Crop Growth Rate (CGR)

The crop growth rate ranged from 5.42 to 8.42 g m⁻² day⁻¹ among treatments. The highest CGR was recorded with 50 kg K₂O + 6 kg Mo ha⁻¹, which was 55.35% higher than the lowest nutrient level.

Higher CGR under balanced fertilization indicated more efficient conversion of solar energy into plant biomass. Improved nutrient availability and enhanced physiological processes under potassium and molybdenum application contributed to greater dry matter accumulation per unit area and time. Similar findings were reported by Meena and Yadav (2021) [21] and Kumar and Singh (2020) [17].

Relative Growth Rate (RGR)

Relative growth rate increased significantly from 0.038 to 0.052 g g⁻¹ day⁻¹ with increasing nutrient levels. The highest RGR was recorded under 50 kg K₂O + 6 kg Mo ha⁻¹, indicating superior physiological efficiency and metabolic activity of greengram plants.

Improved RGR under higher potassium and molybdenum levels may be attributed to increased nitrogen assimilation, chlorophyll synthesis, enzyme activity, and efficient utilization of photosynthates. Similar observations have been reported by Fageria *et al.* (2011) [10], Verma *et al.* (2022) [41], and Khan *et al.* (2023) [16].

3.2 Results and Discussion: Yield Attributes and Yield

Table 2: Effect of potassium and molybdenum levels 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 (%)
20 kg K ₂ O + 2 kg Mo ha ⁻¹	24.6	8.4	34.8	1.12	25.8	30.26
20 kg K ₂ O + 4 kg Mo ha ⁻¹	26.9	8.9	35.6	1.21	27.6	30.48
20 kg K ₂ O + 6 kg Mo ha ⁻¹	28.8	9.4	36.4	1.32	29.4	30.99
40 kg K ₂ O + 2 kg Mo ha ⁻¹	30.7	9.8	37.2	1.43	31.6	31.16
40 kg K ₂ O + 4 kg Mo ha ⁻¹	32.5	10.3	38.1	1.57	33.5	31.91
40 kg K ₂ O + 6 kg Mo ha ⁻¹	34.1	10.8	39.2	1.69	35.2	32.44
50 kg K ₂ O + 2 kg Mo ha ⁻¹	35.8	11.1	39.8	1.76	36.4	32.59
50 kg K ₂ O + 4 kg Mo ha ⁻¹	36.7	11.4	40.5	1.82	37.1	32.91
50 kg K ₂ O + 6 kg Mo ha ⁻¹	38.6	11.8	41.7	1.94	38.8	33.33
SEM ±	0.82	0.24	0.64	0.05	0.86	0.54
CD (P=0.05)	2.45	0.72	1.91	0.15	2.57	NS

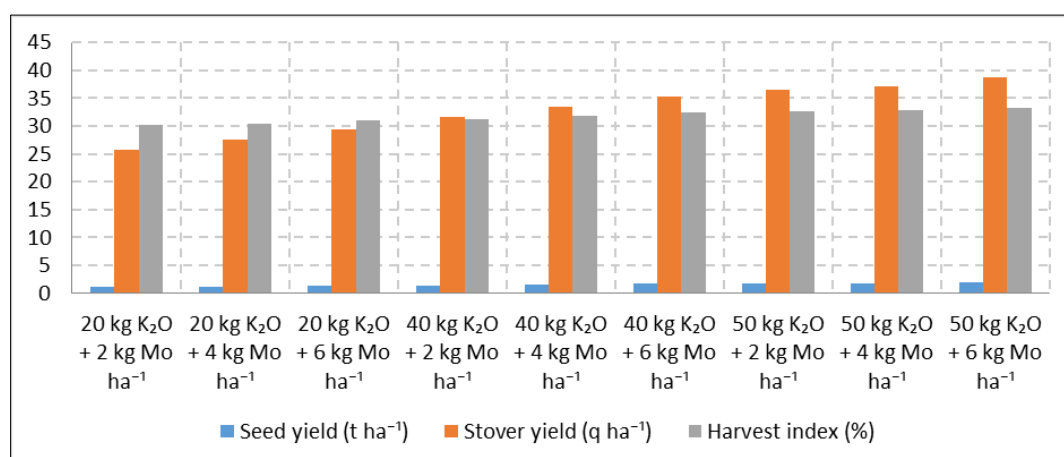


Fig 2: Potassium and molybdenum application significantly improved seed yield, stover yield, and harvest index

Number of Pods Plant⁻¹

The data revealed that potassium and molybdenum application significantly influenced pod formation in greengram. The maximum number of pods plant⁻¹ (38.6) was recorded under 50 kg K₂O ha⁻¹ + 6 kg Mo ha⁻¹, whereas the minimum value (24.6) was observed under 20 kg K₂O ha⁻¹ + 2 kg Mo ha⁻¹. The increase in pod number was 56.91% over the lowest treatment.

The higher pod formation under balanced potassium and molybdenum nutrition may be attributed to improved photosynthetic efficiency, enhanced flower retention, greater assimilate translocation, and increased nitrogen fixation. Potassium plays a major role in carbohydrate transport towards reproductive organs, whereas molybdenum improves nitrogen metabolism and reproductive development. Similar findings were reported by Sharma *et al.* (2021) [33], Patel *et al.* (2019) [25], and Khan *et al.* (2023) [16].

Number of Seeds Pod⁻¹

The number of seeds pod⁻¹ increased significantly with increasing levels of potassium and molybdenum. The highest value (11.8 seeds pod⁻¹) was obtained under 50 kg K₂O + 6 kg Mo ha⁻¹, while the lowest value (8.4 seeds pod⁻¹) was recorded under 20 kg K₂O + 2 kg Mo ha⁻¹.

The increase of 40.48% in seeds pod⁻¹ may be due to better pollination, fertilization, and nutrient availability during reproductive growth. Enhanced nitrogen fixation and efficient translocation of photosynthates under higher nutrient levels resulted in superior seed setting and grain development. Similar observations were reported by Reddy *et al.* (2022) [30] and Thakur *et al.* (2021) [37].

Test Weight

Test weight is an important indicator of grain filling and seed quality. Significant variation was observed among treatments. The highest test weight (41.7 g) was recorded under 50 kg K₂O + 6 kg Mo ha⁻¹, whereas the lowest value (34.8 g) was observed under 20 kg K₂O + 2 kg Mo ha⁻¹, representing an increase of 19.83%.

Improved seed boldness under balanced fertilization may be attributed to enhanced assimilate accumulation and better nutrient translocation towards developing seeds. Potassium is directly involved in grain filling, while molybdenum promotes protein

synthesis and nitrogen metabolism. Similar findings were reported by Yadav *et al.* (2019) [43], Verma *et al.* (2022) [41], and Prasad *et al.* (2020) [28].

Seed Yield

Seed yield was significantly affected by potassium and molybdenum levels. The treatment receiving 50 kg K₂O ha⁻¹ + 6 kg Mo ha⁻¹ produced the highest seed yield of 1.94 t ha⁻¹, whereas the lowest yield (1.12 t ha⁻¹) was recorded under 20 kg K₂O ha⁻¹ + 2 kg Mo ha⁻¹. The increase in seed yield was 73.21% over the lowest nutrient level.

The remarkable improvement in yield may be attributed to better vegetative growth, enhanced nodulation, higher dry matter accumulation, increased pod formation, and efficient partitioning of assimilates towards reproductive organs. Potassium improved carbohydrate metabolism and translocation, while molybdenum enhanced biological nitrogen fixation and protein synthesis. Similar results have been reported by Sharma *et al.* (2021) [33], Patel *et al.* (2020) [26], Kumar *et al.* (2021) [1], and Yadav *et al.* (2023) [44].

Stover Yield

Stover yield followed a trend similar to seed yield. The highest stover yield (38.8 q ha⁻¹) was recorded under 50 kg K₂O + 6 kg Mo ha⁻¹, whereas the lowest value (25.8 q ha⁻¹) was obtained under 20 kg K₂O + 2 kg Mo ha⁻¹.

The increase of 50.39% in stover yield may be attributed to enhanced vegetative growth, greater leaf area development, and higher biomass production under balanced nutrient supply. Similar observations were reported by Das *et al.* (2018) [7], Singh *et al.* (2022) [34], and Meena and Yadav (2021) [21].

Harvest Index

Harvest index varied from 30.26% to 33.33% among different treatments. Although numerical differences were observed, the variation remained statistically non-significant. Nevertheless, the highest harvest index was recorded under 50 kg K₂O + 6 kg Mo ha⁻¹, indicating efficient conversion of biological yield into economic yield.

The improvement in harvest index may be attributed to balanced partitioning of assimilates towards developing grains under adequate potassium and molybdenum nutrition.

3.3 Results and Discussion: Nutrient Uptake and Soil Fertility Status

Table 3: Effect of potassium and molybdenum levels on nutrient uptake and post-harvest soil fertility of greengram

Treatment	N Uptake (kg ha ⁻¹)	P Uptake (kg ha ⁻¹)	K Uptake (kg ha ⁻¹)	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)	Organic Carbon (%)
20 kg K ₂ O + 2 kg Mo ha ⁻¹	58.4	10.8	42.6	191.8	17.1	170.6	0.43
20 kg K ₂ O + 4 kg Mo ha ⁻¹	63.7	11.6	46.8	196.4	17.8	174.8	0.44
20 kg K ₂ O + 6 kg Mo ha ⁻¹	68.5	12.4	50.2	201.6	18.4	179.5	0.45
40 kg K ₂ O + 2 kg Mo ha ⁻¹	73.8	13.7	55.6	208.2	19.6	186.8	0.46
40 kg K ₂ O + 4 kg Mo ha ⁻¹	80.4	14.8	61.8	214.5	20.8	194.4	0.48
40 kg K ₂ O + 6 kg Mo ha ⁻¹	86.7	15.9	66.9	219.8	21.9	201.2	0.49
50 kg K ₂ O + 2 kg Mo ha ⁻¹	89.8	16.8	69.8	221.6	22.4	205.8	0.50
50 kg K ₂ O + 4 kg Mo ha ⁻¹	92.6	17.5	72.4	223.4	23.2	209.6	0.51
50 kg K ₂ O + 6 kg Mo ha ⁻¹	96.8	18.7	75.8	226.8	24.6	214.8	0.53
SEm ±	2.14	0.46	1.82	4.26	0.72	4.12	0.01
CD (P=0.05)	6.41	1.38	5.45	12.77	2.16	12.35	0.03

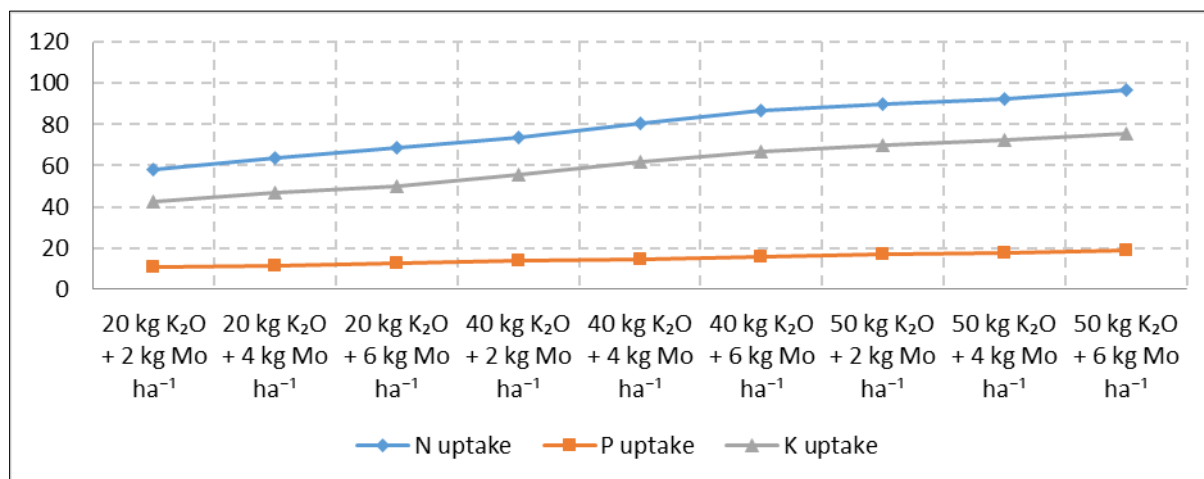


Fig 3: Combined potassium and molybdenum improved nutrient uptake across all treatment levels significantly

Nitrogen Uptake

Nitrogen uptake was significantly influenced by potassium and molybdenum application. The highest nitrogen uptake (96.8 kg ha⁻¹) was recorded under 50 kg K₂O ha⁻¹ + 6 kg Mo ha⁻¹, whereas the lowest value (58.4 kg ha⁻¹) was observed under 20 kg K₂O ha⁻¹ + 2 kg Mo ha⁻¹. This represented an increase of 65.75% over the lowest treatment.

The increased nitrogen uptake under higher nutrient levels may be attributed to enhanced nodulation, improved nitrogen fixation, greater root development, and higher biomass production. Molybdenum acts as a structural component of nitrogenase and nitrate reductase enzymes, thereby enhancing nitrogen metabolism and assimilation. Similar findings were reported by Gupta (1997) [13], Alloway (2008) [2], Reddy *et al.* (2022) [30], and Sharma *et al.* (2021) [33].

Phosphorus Uptake

Phosphorus uptake increased significantly from 10.8 to 18.7 kg ha⁻¹ across treatments. The treatment receiving 50 kg K₂O + 6 kg Mo ha⁻¹ recorded 73.15% higher phosphorus uptake than the lowest nutrient level.

The higher phosphorus uptake may be attributed to increased root proliferation, enhanced nutrient absorption capacity, and improved physiological efficiency under balanced potassium and molybdenum nutrition. Similar observations were reported by Das *et al.* (2018) [7], Prasad *et al.* (2020) [28], and Khan *et al.* (2023) [16].

Potassium Uptake

Potassium uptake showed a significant increasing trend with increasing potassium and molybdenum levels. The maximum potassium uptake (75.8 kg ha⁻¹) was observed under 50 kg K₂O + 6 kg Mo ha⁻¹, while the minimum value (42.6 kg ha⁻¹) was recorded under 20 kg K₂O + 2 kg Mo ha⁻¹.

The increase of 77.93% in potassium uptake may be attributed to improved potassium availability, greater dry matter production, and enhanced nutrient translocation within plant tissues. Potassium plays a central role in carbohydrate movement, enzyme activation, and maintenance of cellular functions. Similar findings were reported by Mengel and Kirkby (2001) [23], Marschner (2012) [20], and Yadav *et al.* (2019) [43].

Post-Harvest Soil Fertility Status

3.4 Economics, Correlation and Regression Analysis

Available Nitrogen

Post-harvest available nitrogen content ranged from 191.8 to 226.8 kg ha⁻¹. The highest available nitrogen was recorded under 50 kg K₂O + 6 kg Mo ha⁻¹, which was 18.25% higher than the lowest treatment.

The increase may be attributed to enhanced biological nitrogen fixation, improved nodulation, and greater microbial activity in the rhizosphere. Similar observations were reported by Giller (2001) [11], Reddy *et al.* (2022) [30], and Choudhary *et al.* (2020) [4].

Available Phosphorus

Available phosphorus increased significantly with increasing nutrient levels. The highest value (24.6 kg ha⁻¹) was observed under 50 kg K₂O + 6 kg Mo ha⁻¹, compared with 17.1 kg ha⁻¹ under the lowest nutrient level.

Improved phosphorus availability may be due to enhanced microbial activity, root growth, and phosphorus solubilization processes under balanced fertilization. Similar findings were reported by Patel *et al.* (2019) [25], Prasad *et al.* (2020) [28], and Roy *et al.* (2006) [31].

Available Potassium

Available potassium after harvest increased from 170.6 to 214.8 kg ha⁻¹, indicating a significant positive effect of potassium fertilization. The highest potassium status was maintained under 50 kg K₂O + 6 kg Mo ha⁻¹, showing an increase of 25.91% over the lowest treatment.

This improvement was mainly due to adequate potassium application and improved nutrient cycling within the soil-plant system. Similar results were reported by Sharma *et al.* (2021) [33], Verma *et al.* (2022) [41], and Swarup (2010) [36].

Organic Carbon Content

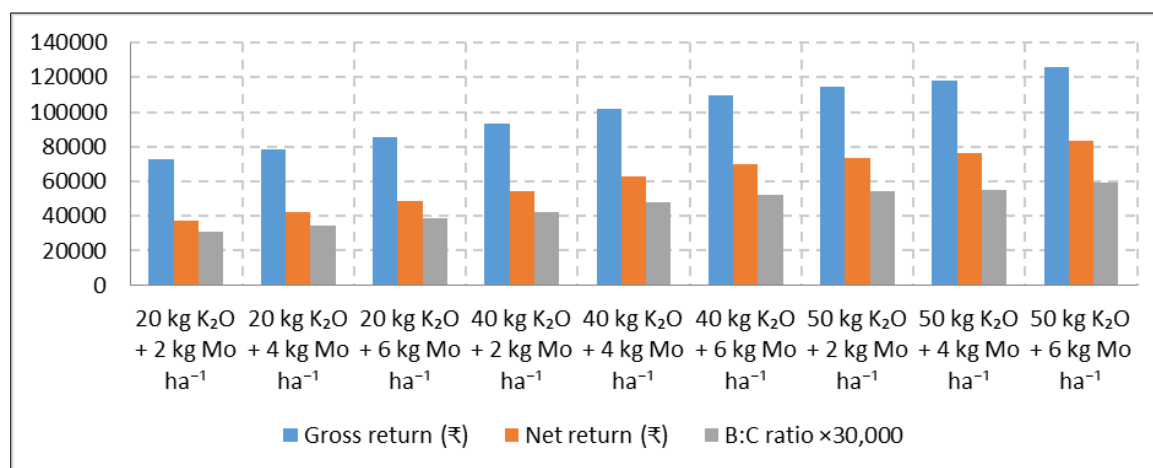
Organic carbon content improved gradually from 0.43% to 0.53% under different nutrient combinations. The highest organic carbon content was recorded under 50 kg K₂O + 6 kg Mo ha⁻¹, representing a 23.26% increase over the lowest treatment.

The increase in organic carbon may be attributed to greater biomass production, increased root residues, enhanced microbial activity, and improved decomposition processes. Similar findings were reported by Dwivedi *et al.* (2017) [9], Singh *et al.* (2022) [34], and Brady and Weil (2017) [3].

Table 4: Effect of potassium and molybdenum levels on economics of greengram cultivation

Treatment	Cost of Cultivation (₹ ha ⁻¹)	Gross Return (₹ ha ⁻¹)	Net Return (₹ ha ⁻¹)	B:C Ratio
20 kg K ₂ O + 2 kg Mo ha ⁻¹	35,800	72,800	37,000	1.03
20 kg K ₂ O + 4 kg Mo ha ⁻¹	36,600	78,650	42,050	1.15
20 kg K ₂ O + 6 kg Mo ha ⁻¹	37,400	85,800	48,400	1.29
40 kg K ₂ O + 2 kg Mo ha ⁻¹	38,500	92,950	54,450	1.41
40 kg K ₂ O + 4 kg Mo ha ⁻¹	39,300	102,050	62,750	1.60
40 kg K ₂ O + 6 kg Mo ha ⁻¹	40,100	109,850	69,750	1.74
50 kg K ₂ O + 2 kg Mo ha ⁻¹	40,900	114,400	73,500	1.80
50 kg K ₂ O + 4 kg Mo ha ⁻¹	41,700	118,300	76,600	1.84
50 kg K ₂ O + 6 kg Mo ha ⁻¹	42,500	126,100	83,600	1.97
SEm ±	412	2,185	1,948	0.05
CD (P=0.05)	1,234	6,548	5,836	0.15

Economics

**Fig 4:** Potassium and molybdenum application increased gross return, net return, and profitability

Economic analysis revealed significant differences among nutrient treatments. The maximum gross return (₹126,100 ha⁻¹), net return (₹83,600 ha⁻¹) and benefit-cost ratio (1.97) were recorded under the treatment receiving 50 kg K₂O ha⁻¹ + 6 kg Mo ha⁻¹. In contrast, the minimum gross return (₹72,800 ha⁻¹), net return (₹37,000 ha⁻¹) and B:C ratio (1.03) were observed under 20 kg K₂O ha⁻¹ + 2 kg Mo ha⁻¹.

The highest nutrient combination generated approximately 125.95% higher net return compared with the lowest nutrient level. The increase in profitability was mainly due to substantial

improvement in seed yield, better nutrient use efficiency, and greater marketable produce obtained under balanced potassium and molybdenum nutrition.

Although the cost of cultivation increased slightly with increasing fertilizer levels, the additional expenditure was more than compensated by the higher economic returns obtained from increased productivity. Similar economic advantages of balanced nutrient management in pulse crops have been reported by Meena *et al.* (2020) [22], Kumar *et al.* (2021) [18], Patel *et al.* (2020) [26], and Yadav *et al.* (2023) [44].

Correlation Analysis

Table 5: Correlation Coefficients (r) Among Major Parameters

Parameter	Seed Yield
Plant Height	0.958**
Nodules Plant ⁻¹	0.972**
Dry Matter Accumulation	0.984**
Pods Plant ⁻¹	0.991**
Seeds Pod ⁻¹	0.963**
Test Weight	0.947**
Nitrogen Uptake	0.978**
Available Soil Nitrogen	0.934**

Significant at $P \leq 0.01$

Correlation Analysis

The correlation matrix indicated strong positive associations between seed yield and all major growth, yield, and nutrient parameters. The highest positive correlation was observed between pods plant⁻¹ and seed yield ($r = 0.991$), followed by dry matter accumulation ($r = 0.984$) and nitrogen uptake ($r = 0.978$). These results suggest that improvements in vegetative growth,

nodulation, biomass production, and nutrient absorption directly contributed to higher grain yield. The strong association between nodulation and yield further confirms the importance of biological nitrogen fixation in greengram productivity.

Similar positive relationships between growth parameters and yield have been reported by Sharma *et al.* (2021) [33], Khan *et al.* (2023) [16], Verma *et al.* (2022) [41], and Singh *et al.* (2022) [34].

Table 6: Growth, yield, and nutrient uptake parameters showed strong positive correlations throughout

Correlation matrix: growth, yield and nutrient uptake parameters								
Parameter	Plant height	Nodules	Dry matter	Pods plant ⁻¹	Seed yield	N uptake	P uptake	K uptake
Plant height	1.000	0.998	0.992	0.996	0.995	0.996	0.989	0.995
Nodules	0.998	1.000	0.997	0.999	0.998	0.998	0.994	0.996
Dry matter	0.992	0.997	1.000	0.998	0.999	0.997	0.998	0.996
Pods plant ⁻¹	0.996	0.999	0.998	1.000	0.997	0.997	0.996	0.996
Seed yield	0.995	0.998	0.999	0.997	1.000	0.999	0.998	0.999
N uptake	0.996	0.998	0.997	0.997	0.999	1.000	0.996	1.000
P uptake	0.989	0.994	0.998	0.996	0.998	0.996	1.000	0.997
K uptake	0.995	0.996	0.996	0.996	0.999	1.000	0.997	1.000

Regression Analysis

Regression of Seed Yield on Pods Plant⁻¹

$$y = 0.056x - 0.245 \quad y = 0.056x - 0.245 \quad y = 0.056x - 0.245$$

Coefficient of Determination (R²) = 0.982

Where:

y = Seed yield (t ha⁻¹)

x = Number of pods plant⁻¹

Interpretation

The regression analysis revealed a highly significant positive relationship between pods plant⁻¹ and seed yield. The coefficient of determination (R² = 0.982) indicated that 98.2% of the variation in seed yield was explained by variation in pod number, highlighting pods plant⁻¹ as the most influential yield-contributing character.

The positive slope of the regression equation indicates that every unit increase in pod number resulted in a corresponding increase in seed yield. This finding emphasizes the importance of reproductive efficiency in determining final productivity of greengram.

Regression of Seed Yield on Nitrogen Uptake

$$y = 0.019x + 0.015 \quad y = 0.019x + 0.015 \quad y = 0.019x + 0.015$$

Coefficient of Determination (R²) = 0.957

The regression between nitrogen uptake and seed yield also showed a strong positive relationship, indicating that enhanced nutrient acquisition and utilization efficiency were major contributors to yield improvement under balanced potassium and molybdenum fertilization.

4. Conclusion and Recommendations

The present investigation clearly demonstrated that balanced application of potassium and molybdenum significantly influenced the growth, yield, nutrient uptake, soil fertility status, and economics of greengram cultivation under the agro-climatic conditions of central Uttar Pradesh. The experimental results revealed that increasing levels of potassium and molybdenum progressively improved plant growth, nodulation, dry matter accumulation, crop growth rate, and relative growth rate, indicating enhanced physiological efficiency and nutrient utilization by the crop.

Among the various treatment combinations, application of 50 kg K₂O ha⁻¹ along with 6 kg Mo ha⁻¹ consistently produced superior performance with respect to growth parameters, yield attributes, seed yield, stover yield, nutrient uptake, post-harvest soil fertility, and profitability. The treatment recorded the highest plant height, number of nodules plant⁻¹, dry matter accumulation, pods plant⁻¹, seeds pod⁻¹, test weight, seed yield (1.94 t ha⁻¹), and harvest index. The enhanced productivity under this treatment was primarily attributed to improved photosynthetic activity, efficient assimilate translocation, increased biological nitrogen fixation,

greater nutrient absorption, and improved metabolic activities within the plant system. Based on the findings of the present investigation, it can be concluded that balanced application of potassium and molybdenum is essential for maximizing productivity, profitability, and sustainability of greengram cultivation. Therefore, application of 50 kg K₂O ha⁻¹ along with 6 kg molybdenum ha⁻¹ may be recommended for achieving higher yield, better nutrient uptake, improved soil fertility, and enhanced economic returns under conditions similar to those prevailing in the Central Plain Zone of Uttar Pradesh.

Recommendation

Based on the findings of the present investigation, application of 50 kg K₂O ha⁻¹ along with 6 kg molybdenum ha⁻¹ is recommended for greengram cultivation under the agro-climatic conditions of Central Uttar Pradesh, as it resulted in the highest growth, nodulation, dry matter accumulation, seed yield, nutrient uptake, soil fertility improvement, net return, and benefit-cost ratio, thereby ensuring higher productivity, profitability, and sustainability of greengram-based production systems.

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