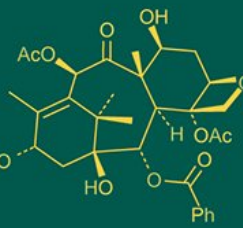
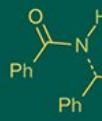
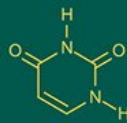


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Effect of integrated nutrition on productivity, profitability and quality of black gram (*Vigna mungo* L.) in plateau region of Jharkhand

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Abstract

A two-year field experiment (2020-2022) conducted in Ranchi, Jharkhand, sought to establish the most effective Integrated Nutrient Management (INM) package for boosting the growth, yield, quality, and nutrient content of black gram (*Vigna mungo* L., variety WBU-109). By testing four levels of chemical fertilizer (up to 125% of the recommended dose), the inclusion of Farm Yard Manure (5 tonnes ha^{-1}), and three biofertilizer treatments (*Rhizobium*, LMn16, and a combination), the results clearly demonstrated that applying the 125% Recommended Dose of Fertilizer significantly maximized all yield parameters, nutrient content, and uptake. Similarly, adding FYM and using a dual inoculation of *Rhizobium* + LMn16 also led to highly significant increases over control treatments. While the complex interaction among all three factors was not significant, the combined use of the higher fertilizer levels and FYM did interact positively to strongly influence the black gram's final yield, economic returns, and quality, identifying this combination as a highly suitable and productive strategy.

Keywords: Biofertilizer, Black gram, INM, Plant height, *Rhizobium*, Yield

Introduction

Black gram (*Vigna mungo* L.) is one of the most important pulse crops of India and plays a vital role in nutritional security, soil health improvement and sustainable agriculture. It is widely cultivated across diverse agro-climatic regions of the country, particularly under rainfed conditions. India is considered the centre of origin of black gram and contributes nearly 70 per cent of global production, making it both the largest producer and consumer of this pulse. During 2020-21, black gram was cultivated over about 4.6 million hectares with an annual production of approximately 24.5 lakh tonnes and an average productivity of 533 kg ha^{-1} . The crop alone accounts for nearly one-fifth of the total pulse area in India and contributes about 23 per cent to national pulse production. In Jharkhand, black gram occupies around 1.32 lakh hectares with a production of 1.15 lakh tonnes and productivity of 872 kg ha^{-1} , indicating its regional importance.

Nutritionally, black gram is rich in protein (about 24%), carbohydrates, minerals and essential micronutrients such as calcium, phosphorus and iron. Apart from its food value, the crop improves soil fertility through biological nitrogen fixation and contributes approximately 22 kg ha^{-1} of atmospheric nitrogen via root nodules. Its dense canopy provides good ground cover, which helps reduce soil erosion. Despite these advantages, black gram productivity remains low, largely because it is cultivated on marginal and sub-marginal lands characterized by low soil fertility, poor organic matter content and moisture stress. Being an indeterminate crop, it faces continuous competition between vegetative and reproductive sinks, which often limits assimilate translocation to developing pods and ultimately reduces yield potential.

The upland soils of Jharkhand are predominantly acidic and inherently deficient in essential nutrients such as nitrogen, phosphorus and sulphur. Continuous cultivation under rainfed conditions, coupled with imbalanced and excessive reliance on chemical fertilizers, has further aggravated soil degradation and nutrient depletion. Rising fertilizer costs and their adverse effects on soil health, environmental quality and human safety necessitate alternative

nutrient management strategies that are both economically viable and environmentally sustainable.

Integrated nutrient management (INM), involving the judicious use of inorganic fertilizers, organic manures and biofertilizers, has emerged as a promising approach to address these challenges. While chemical fertilizers are indispensable for meeting immediate crop nutrient requirements, their continuous and imbalanced use adversely affects soil physical, chemical and biological properties. On the other hand, organic sources alone often fail to supply nutrients in sufficient quantities due to their low nutrient concentration. Hence, combining organic manures with chemical fertilizers and biofertilizers ensures better nutrient availability, enhanced nutrient use efficiency and sustained soil fertility.

Biofertilizers, particularly *Rhizobium* and other plant growth-promoting rhizobacteria (PGPR), play a crucial role in improving nutrient availability in the rhizosphere, stimulating plant growth and suppressing soil-borne pathogens. *Rhizobium* inoculation has been reported to fix substantial amounts of nitrogen and enhance growth, yield and biochemical characteristics of black gram. The use of biofertilizers not only reduces dependency on chemical fertilizers but also contributes to soil health maintenance and environmental protection. With increasing concerns over climate change and sustainability, PGPR-based nutrient management strategies are gaining significance as eco-friendly alternatives for enhancing crop productivity.

Given the multiple constraints limiting black gram productivity, particularly under the plateau region of Jharkhand, it is essential to develop balanced and region-specific nutrient management strategies. Therefore, the present study was undertaken to evaluate suitable integrated nutrient management packages involving different fertility levels, farmyard manure and biofertilizer applications for improving growth, yield, quality and nutrient uptake in black gram under rainfed conditions.

Materials and Methods

A field experiment was carried out during two consecutive *kharif* seasons of 2020-21 and 2021-22 at the Agronomy Research Farm of Birsa Agricultural University, Kanke, Ranchi, Jharkhand, to evaluate suitable integrated nutrient management (INM) packages for black gram production and to study their effects on growth, yield, quality and nutrient uptake of black gram (*Vigna mungo* L.).

The experimental site is located in Agro-climatic Zone VII (Eastern Plateau and Hill Region), sub-zone North-Eastern Plateau Zone of Jharkhand, and experiences a humid subtropical climate. The soil of the experimental field was sandy loam in texture, consisting of 60.8% sand, 27.8% silt and 11.4% clay. It was acidic in reaction (pH 5.89), low in available nitrogen (247.13 kg ha⁻¹) and organic carbon (0.39%), medium in available phosphorus (47.52 kg ha⁻¹), potassium (186.32 kg ha⁻¹) and sulphur (32.12 kg ha⁻¹).

The experiment was laid out in a randomized block design with a factorial arrangement and three replications, comprising 24 treatment combinations. The treatments consisted of three factors: four fertility levels [control, 75%, 100% and 125% recommended dose of fertilizers (RDF)], two levels of farmyard manure (no FYM and 5 t FYM ha⁻¹), and three biofertilizer treatments (*Rhizobium*, LMn16 and dual inoculation of *Rhizobium* + LMn16). The recommended fertilizer dose of black gram was 20:40:20:20 kg ha⁻¹ of N:P₂O₅:K₂O:S.

Nitrogen, phosphorus and potassium were supplied through urea, diammonium phosphate and muriate of potash, respectively, while sulphur was applied using phosphogypsum. Farmyard manure containing 0.5% nitrogen, 0.2% phosphorus and 0.5% potassium was incorporated into the soil as per treatment two weeks prior to sowing. To correct soil acidity, lime was uniformly applied at the rate of 0.5 t ha⁻¹ in the sowing furrows at the time of sowing.

Black gram variety WBU-109 was used for the study. Seeds were inoculated with biofertilizers (*Rhizobium* and/or LMn16) at the rate of 400 g per 20 kg seed according to the respective treatments. The crop was sown at a seed rate of 20 kg ha⁻¹ with a spacing of 30 cm × 10 cm. Sowing was done on 10 July during the 2020-21 season and on 6 July during the 2021-22 season, while harvesting was carried out on 23 September 2021 and 22 September 2022, respectively. During the crop growth period, the maximum and minimum temperatures recorded were 34.0 °C and 21.2 °C in 2020-21, and 34.3 °C and 22.1 °C in 2021-22. The total rainfall received during the cropping seasons was 1054.3 mm in 2020-21 and 1551.9 mm in 2021-22.

Yield attributes such as number of pods per plant, pod length, number of grains per pod and 1000-grain weight were recorded from five randomly selected plants from each plot at harvest. Grain yield was recorded from the net plot area, sun-dried to approximately 12% moisture content and expressed in kg ha⁻¹.

Plant samples (grain and straw) were collected from each plot after harvest and analyzed for nitrogen, phosphorus, potassium and sulphur content using standard laboratory procedures. Quality parameters such as protein content and protein yield were also determined. Nutrient uptake was calculated based on nutrient concentration and corresponding dry matter yield. The data obtained were statistically analyzed following standard procedures as described by Gomez and Gomez (1984)^[8].

Results and Discussion

Effect on yield attributes and yields

Data The results presented in Table 1 show that fertility levels, FYM application and biofertilizer inoculation significantly influenced the yield attributes and yield of black gram. Increasing levels of inorganic fertilizers resulted in a consistent improvement in yield attributes. Application of 125% RDF recorded the highest values for pods per plant (25.58), pod length (4.86 cm), grains per pod (7.49) and 1000-seed weight (38.59 g), followed by 100% RDF.

Application of FYM at 5 t ha⁻¹ significantly enhanced yield attributes over the control, recording higher pods per plant (21.67), pod length (4.83 cm), grains per pod (7.43) and 1000-seed weight (38.56 g). Similarly, dual seed inoculation with *Rhizobium* + LMn16 resulted in superior yield attributes compared to sole inoculation, indicating a synergistic effect of the combined biofertilizers.

Seed yield increased significantly with higher fertility levels, FYM application and dual biofertilizer inoculation. The highest seed yield (1558 kg ha⁻¹) was obtained with 125% RDF, followed by 100% RDF, registering yield increases of 36% and 12% over 75% RDF, respectively. FYM application at 5 t ha⁻¹ produced a higher seed yield (1276 kg ha⁻¹) compared to no FYM, while dual inoculation with *Rhizobium* + LMn16 recorded the maximum seed yield (1291 kg ha⁻¹) among biofertilizer treatments.

The improvement in yield attributes and yield under integrated nutrient management may be attributed to better

nutrient availability, improved soil environment and enhanced microbial activity in the rhizosphere. Combined use of inorganic fertilizers, FYM and biofertilizers likely promoted balanced nutrition, increased biological nitrogen fixation and efficient assimilate translocation, resulting in higher productivity. These findings are in agreement with earlier reports by Kumpawat (2010)^[14], Kumawat *et al.* (2015a)^[12], Kumar *et al.* (2015)^[13] and Meena *et al.* (2021)^[16].

Effect on nutrient contents and uptakes

The data presented in Tables 2 and 3 show that fertility levels, FYM application and biofertilizer inoculation significantly influenced nutrient (N, P, K and S) content and uptake in both seed and stover of black gram. Nutrient content increased progressively with higher fertility levels. Application of 125% RDF recorded the highest nitrogen, phosphorus, potassium and sulphur content in seed (3.46, 0.43, 0.87 and 0.41%, respectively), followed by 100% RDF, while the lowest values were observed under 75% RDF. Compared to the control, 125% RDF increased seed N, P, K and S content by 4.46, 10.39, 4.56 and 8.16%, respectively. A similar trend was observed in the stover.

Application of FYM at 5 t ha⁻¹ significantly enhanced nutrient content in both seed and stover compared to no FYM. Higher contents of N (3.45% and 0.76%), P (0.42% and 0.24%), K (0.86% and 1.13%) and S (0.40% and 0.32%) were recorded in seed and stover, respectively. Among biofertilizer treatments, dual seed inoculation with *Rhizobium* + LMn16 resulted in the highest N, P, K and S contents in seed and stover, followed by LMn16 and *Rhizobium* applied individually. These results are consistent with earlier findings by Kumar and Jat (2010) and Yadav *et al.* (2017)^[10, 23].

Nutrient uptake by seed and stover increased significantly with increasing fertility levels and showed a strong positive relationship with nutrient availability (Table 3). The highest uptake of nitrogen, phosphorus, potassium and sulphur by seed (50.18, 6.15, 12.62 and 5.95 kg ha⁻¹, respectively) and stover (29.55, 9.28, 44.10 and 12.70 kg ha⁻¹, respectively) was recorded with 125% RDF, which was statistically comparable with 100% RDF. Application of FYM at 5 t ha⁻¹ significantly enhanced nutrient uptake by both seed and stover over without FYM treatments. Similarly, dual seed inoculation with *Rhizobium* + LMn16 resulted in the maximum uptake of N, P, K and S, followed by LMn16 alone.

The increased nutrient content and uptake under integrated nutrient management practices may be attributed to improved nutrient availability, enhanced soil biological activity and more efficient absorption and translocation of nutrients. The combined application of inorganic fertilizers, FYM and biofertilizers likely improved soil buffering capacity, nutrient chelation and microbial-mediated mineralization, particularly under acidic soils. FYM decomposition produces humic and fulvic acids that enhance nutrient solubility and mobility, while *Rhizobium* and PGPR improve nitrogen fixation, nutrient acquisition and overall plant growth (Chahal *et al.*, 2020; Desai *et al.*, 2020; Bhavithra *et al.*, 2025)^[5, 7, 4]. Similar trends have also been reported by Danga *et al.* (2023)^[24].

Quality parameters

Quality parameters of black gram, including protein content, protein yield, zinc and iron content, are presented in Table 4. Fertility levels had a significant effect on protein content and protein yield. Application of 125% RDF recorded the

highest protein content (21.65%), protein yield (314 kg ha⁻¹), zinc (29 ppm) and iron content (49 ppm), followed by 100% RDF, while the lowest values were observed under 75% RDF. The improvement in protein content and yield under higher fertility levels may be attributed to increased nitrogen availability through mineralization and biological nitrogen fixation, which enhances protein synthesis in seeds (Kumawat *et al.*, 2015)^[12].

Application of farmyard manure significantly improved protein content and protein yield (21.54% and 277 kg ha⁻¹, respectively), whereas its effect on zinc and iron content was not significant. Biofertilizer treatments did not significantly influence protein content or micronutrient concentration; however, protein yield was highest under dual seed inoculation with *Rhizobium* + LMn16, followed by LMn16 alone, while the lowest protein yield was recorded with *Rhizobium* alone. These findings are in agreement with the results reported by Shekhawat *et al.* (2017)^[21].

The increase in protein content with integrated nutrient management may be explained by the close association between nitrogen availability and protein synthesis. Enhanced nitrogen supply under higher fertilizer levels, along with FYM and biofertilizers, likely improved enzymatic activity involved in amino acid biosynthesis and increased assimilate availability, resulting in improved grain quality. Similar observations have been reported earlier by Selvakumar *et al.* (2012)^[20].

Nodule count

Data presented in Table 5 indicate that the number of root nodules per plant at 30 and 45 DAS (days after sowing) increased significantly with higher fertility levels. The highest nodule count was recorded with 125% RDF (24.89 and 38.59), followed by 100% RDF (19.48 and 37.40) and 75% RDF (16.74 and 32.88). Application of FYM at 5 t ha⁻¹ also significantly enhanced nodule formation, recording 19.03 and 37.40 nodules per plant at 30 and 45 DAS, respectively, representing increases of 24.43% and 14.45% over the control.

Among the biofertilizer treatments, dual seed inoculation with *Rhizobium* + LMn16 resulted in the maximum number of nodules per plant (18.04 and 34.65 at 30 and 45 DAS), followed by LMn16 and *Rhizobium* applied alone. The increased nodulation under higher fertility levels, FYM application and biofertilizer inoculation may be attributed to improved plant vigor, enhanced photosynthetic activity and greater availability of assimilates, which strengthened source sink relationships and supported better nodulation. Enhanced nodulation, in turn, contributed to improved seed, stover and biological yields of black gram. The findings of the present study are in close agreement with earlier reports by Kumawat *et al.* (2015)^[12].

Effects on economics

Data presented in Table 6 indicate that integrated nutrient management practices significantly influenced the economics of black gram production. Increasing fertility levels resulted in marked improvements in gross return, net return, benefit-cost (B:C) ratio, production efficiency and economic efficiency. Application of 125% RDF recorded the highest gross return (₹95,619 ha⁻¹), net return (₹66,454 ha⁻¹), production efficiency (20.10 kg ha⁻¹ day⁻¹), economic efficiency (₹857 ha⁻¹ day⁻¹) and B:C ratio (2.27), followed by 100% RDF.

Table 1: Number of pods per plant, seeds per pod, 1000 seed weight and yield of black gram as influenced by integrated nutrient management

Treatment	Pods per plant (Nos.)			Seeds per pod (Nos.)			1000 seed weight (gm)			Seed yield (kg ha ⁻¹)			Stover yield (kg ha ⁻¹)		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
Fertility levels (CF)															
Control	12.39	12.04	12.22	7.06	7.06	7.06	38.2	38.11	38.16	810	787	798	2450	2443	2447
75 % RDF	17.09	18.48	17.78	7.31	7.49	7.4	38.35	38.41	38.38	1128	1167	1147	3177	3237	3207
100 % RDF	23.31	24.64	23.98	7.39	7.57	7.48	38.46	38.52	38.49	1349	1410	1379	3742	3861	3802
125 % RDF	24.78	26.38	25.58	7.42	7.57	7.49	38.55	38.64	38.59	1519	1597	1558	4179	4350	4265
SEm±	0.609	0.581	0.586	0.1	0.08	0.088	0.19	0.19	0.188	28.02	29.6	27.36	100.85	88.87	88.12
CD (P=0.05)	1.73	1.653	1.669	NS	NS	NS	NS	NS	NS	79.77	84.26	77.9	287.08	252.99	250.86
FYM levels (t ha⁻¹)															
0	16.83	18.05	17.44	7.23	7.33	7.28	38.23	38.26	38.25	1084	1132	1108	3090	3182	3136
5	21.95	22.72	22.34	7.36	7.51	7.43	38.55	38.58	38.56	1319	1348	1334	3684	3764	3724
SEm±	0.431	0.410	0.415	0.07	0.06	0.062	0.13	0.13	0.133	19.82	20.93	19.35	71.31	62.84	62.31
CD (P=0.05)	1.226	1.169	1.180	NS	NS	NS	NS	NS	NS	56.41	59.58	55.08	202.99	178.89	177.39
Biofertilizers (PGPR /BF)															
<i>Rhizobium</i>	18.29	19.37	18.83	7.2	7.36	7.28	38.31	38.34	38.33	1141	1192	1167	3238	3339	3288
LMn16	18.96	20.09	19.53	7.31	7.43	7.37	38.35	38.39	38.37	1182	1228	1205	3346	3460	3403
<i>Rhizobium</i> + LMn16	20.91	21.70	21.31	7.38	7.48	7.43	38.51	38.53	38.52	1281	1301	1291	3578	3620	3599
SEm±	0.501	0.503	0.508	0.089	0.072	0.076	0.162	0.163	0.162	24.27	25.63	23.7	87.34	76.97	76.32
CD (P=0.05)	1.527	1.431	1.446	NS	NS	NS	NS	NS	NS	69.09	72.97	67.46	249	219.09	217.25
Interactions															
CF X FYM SEm±	0.861	0.821	0.829	-	-	-	-	-	-	39.63	41.86	38.70	142.62	125.68	124.63
CD (P=0.05)	2.453	2.338	2.362	NS	NS	NS	NS	NS	NS	112.88	119.22	110.22	406.21	357.98	354.97
CV%	13.33	12.08	12.51	5.95	4.73	5.05	2.07	2.07	2.07	9.9	10.13	9.51	12.62	10.86	10.9

Table 2: Effect of INM on Macro nutrient content on seed and stover of black gram

Treatment	Nitrogen content seed (%)			Nitrogen content Stover (%)			P content Seed (%)			P content Stover (%)			K content Seed (%)			K content Stover (%)			S content Seed (%)			S content Stover (%)		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Fertility levels (CF)																								
Control	3.33	3.30	3.32	0.72	0.70	0.71	0.39	0.38	0.39	0.23	0.22	0.22	0.83	0.83	0.83	1.05	1.05	1.05	0.38	0.37	0.37	0.16	0.16	0.16
75 % RDF	3.36	3.38	3.37	0.74	0.75	0.74	0.41	0.42	0.42	0.23	0.23	0.23	0.85	0.85	0.85	1.11	1.11	1.11	0.38	0.39	0.39	0.18	0.18	0.18
100 % RDF	3.44	3.46	3.45	0.75	0.76	0.76	0.42	0.42	0.42	0.24	0.24	0.24	0.86	0.87	0.86	1.14	1.13	1.13	0.39	0.39	0.39	0.18	0.18	0.18
125 % RDF	3.46	3.47	3.46	0.76	0.77	0.76	0.42	0.43	0.43	0.24	0.24	0.24	0.87	0.87	0.87	1.16	1.14	1.14	0.39	0.40	0.40	0.18	0.19	0.19
SEm±	0.04	0.04	0.04	0.03	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.007	0.004	0.004	0.004
CD (P=0.05)	NS	0.11	0.104	NS	0.038	0.04	0.017	0.017	0.017	0.01	0.01	0.01	NS	0.03	0.03	0.06	0.06	0.05	NS	NS	NS	0.011	0.011	0.011
FYM levels (t ha⁻¹)																								
0	3.35	3.36	3.35	0.73	0.73	0.73	0.40	0.41	0.41	0.23	0.23	0.23	0.85	0.85	0.85	1.08	1.08	1.08	0.38	0.38	0.38	0.17	0.17	0.17
5	3.44	3.45	3.45	0.76	0.77	0.76	0.42	0.42	0.42	0.24	0.24	0.24	0.86	0.86	0.86	1.14	1.13	1.13	0.39	0.39	0.39	0.18	0.18	0.18
SEm±	0.03	0.03	0.03	0.01	0.01	0.01	0.004	0.004	0.004	0.002	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.005	0.003	0.003	0.003
CD (P=0.05)	0.76	0.08	0.07	0.02	0.03	0.02	0.01	0.012	0.012	0.01	0.01	0.01	NS	NS	NS	0.04	0.04	0.04	NS	NS	NS	NS	NS	NS
Biofertilizers																								
<i>Rhizobium</i>	3.36	3.37	3.37	0.73	0.73	0.73	0.41	0.41	0.41	0.23	0.23	0.23	0.85	0.85	0.85	1.10	1.10	1.10	0.38	0.39	0.38	0.17	0.17	0.17
LMn16	3.39	3.40	3.40	0.74	0.75	0.74	0.41	0.41	0.41	0.23	0.23	0.232	0.85	0.86	0.85	1.11	1.11	1.11	0.39	0.39	0.39	0.18	0.18	0.18
<i>Rhizobium</i> +	3.43	3.44	3.44	0.75	0.76	0.76	0.42	0.42	0.42	0.24	0.24	0.238	0.86	0.86	0.86	1.13	1.12	1.12	0.39	0.39	0.39	0.18	0.18	0.18

LMn16																								
SEm±	0.03	0.03	0.03	0.01	0.01	0.01	0.005	0.005	0.005	0.003	0.002	0.003	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.006	0.003	0.004	0.003
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)	4.47	4.9	4.57	6.58	7.68	6.94	6.13	6.10	6.11	6.00	5.12	5.45	4.71	5.17	4.91	7.76	7.37	6.95	7.75	8.26	8.00	9.36	9.66	9.50

Table 3: Effect of INM on Macro nutrient uptake by seed and stover of black gram

Treatments	Nitrogen uptake seed (kg ha ⁻¹)			Nitrogen uptake Stover (kg ha ⁻¹)			P uptake Seed (kg ha ⁻¹)			P uptake Stover (kg ha ⁻¹)			K uptake Seed (kg ha ⁻¹)			K uptake Stover (kg ha ⁻¹)			S uptake Seed (kg ha ⁻¹)			S uptake Stover (kg ha ⁻¹)		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Fertility levels (CF)																								
Control	27.01	26.07	26.54	17.711	17.32	17.88	3.14	3.02	3.08	5.72	5.49	5.61	11.11	10.9	10.99	33.79	33.3	33.56	2.96	2.88	2.92	2.66	2.6	2.63
75 % RDF	38.04	39.68	38.87	23.55	24.36	24.00	4.68	4.88	4.78	7.34	7.62	7.48	13.4	13.7	13.53	43.41	44.4	33.89	3.63	3.73	3.68	3.41	3.51	3.46
100 % RDF	46.59	48.88	47.74	28.42	29.53	28.42	5.68	5.96	5.82	8.82	9.02	8.92	14.8	15.1	14.44	48.83	49.6	49.22	4.01	4.13	4.07	3.86	3.94	3.9
125 % RDF	52.77	55.75	50.18	31.91	33.66	29.55	6.04	6.26	6.15	9.16	9.41	9.28	15.81	16.1	15.94	51.63	52.3	51.95	4.3	4.43	4.36	3.99	4.06	4.02
SEm±	1.39	1.51	1.40	1.08	1.11	1.19	0.18	0.19	0.18	0.37	0.34	0.34	0.609	0.63	0.62	2.034	2.02	1.951	0.179	0.191	0.185	0.16	0.16	0.156
CD (P=0.05)	3.96	4.30	4.00	3.09	3.15	3.40	0.52	0.54	0.52	1.07	0.98	0.99	1.735	1.8	1.765	5.789	5.74	5.555	0.51	0.545	0.527	0.456	0.47	0.445
FYM levels (t ha⁻¹)																								
0	36.53	38.29	37.41	22.60	23.36	22.80	4.43	4.66	4.55	7.09	7.24	7.17	12.72	12.8	12.78	41.64	42.1	41.89	3.42	3.47	3.45	3.22	3.27	3.25
5	45.67	46.90	44.25	28.19	29.08	27.12	5.34	5.41	5.37	8.42	8.54	8.48	14.84	15	14.92	47.2	47.7	47.42	4.03	4.11	4.07	3.73	3.78	3.76
SEm±	0.98	1.07	0.99	0.77	0.78	0.84	0.13	0.13	0.13	2.66	0.24	0.24	0.431	0.45	0.438	1.438	1.43	1.38	0.127	0.135	0.131	0.113	0.12	0.11
CD (P=0.05)	2.80	3.04	2.83	2.18	2.23	2.40	0.37	0.38	0.37	0.75	0.69	0.7	1.227	1.27	1.248	4.093	4.06	3.928	0.36	0.385	0.373	0.322	0.33	0.315
Biofertilizers																								
<i>Rhizobium</i>	38.63	40.49	38.46	23.87	24.77	23.32	4.6	4.78	4.69	7.23	7.39	7.31	13.29	13.4	13.34	43.23	45.5	43.38	3.58	3.64	3.61	3.37	3.39	3.38
LMn16	40.38	42.10	40.14	25.11	26.13	24.36	4.78	4.95	4.87	7.52	7.65	7.58	13.8	14	13.87	44.21	44.8	44.52	3.73	3.8	3.76	3.47	3.53	3.50
<i>Rhizobium</i> + LMn16	44.29	45.20	43.89	27.21	27.76	27.20	5.27	5.37	5.32	8.53	8.62	8.58	14.26	14.4	14.33	45.82	46.3	46.06	3.86	3.94	3.90	3.60	3.66	3.63
SEm±	1.20	1.31	1.22	0.94	0.96	1.03	0.15	0.16	0.15	0.32	0.29	0.3	0.528	0.55	0.537	1.761	1.75	1.69	0.155	0.166	0.16	0.139	0.14	0.135
CD (P=0.05)	3.43	3.72	3.46	2.67	2.73	2.95	0.45	0.47	0.45	0.92	0.85	0.85	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)	14.35	15.04	14.59	18.11	17.91	20.31	15.97	16.12	15.71	20.56	18.58	18.86	18.76	19.2	19.00	19.42	19.1	18.54	20.4	21.4	20.9	19.54	19.7	18.93

Table 4: Quality parameters of black gram as influenced by integrated nutrient management in black gram

	Protein content (%)			Protein Yield (kg ha ⁻¹)			Zn content (%)			Fe content (%)		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Fertility levels (CF)												
Control	20.81	20.64	20.72	168.81	162.92	165.86	0.0023	0.0023	0.0023	0.0045	0.0045	0.0045
75 % RDF	21.01	21.15	21.08	237.92	247.99	242.96	0.0026	0.0027	0.0026	0.0047	0.0048	0.0048
100 % RDF	21.47	21.6	21.54	291.19	305.52	298.35	0.0028	0.0029	0.0028	0.0048	0.0049	0.0049
125 % RDF	21.6	21.7	21.65	308.1	319.12	313.61	0.0029	0.0029	0.0029	0.0049	0.005	0.0049
SEm±	0.22	0.25	0.23	8.7	9.33	8.78	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
CD (P=0.05)	NS	0.7	0.65	24.75	26.57	24.99	0.0002	0.0003	0.0002	NS	0.0003	0.0003
FYM levels (t ha⁻¹)												
0	20.94	20.98	20.96	228.32	239.31	233.82	0.0026	0.0026	0.0026	0.0046	0.0047	0.0047
5	21.51	21.56	21.54	274.78	278.47	276.58	0.0027	0.0028	0.0027	0.0049	0.0049	0.0049

SEm±	0.16	0.17	0.16	6.15	6.6	6.21	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
CD (P=0.05)	0.45	0.5	0.46	17.51	18.79	17.67	NS	NS	NS	0.0002	0.0002	0.0002
Biofertilizers (Rhizobium/PGPR)												
Rhizobium	21.01	21.05	21.03	235.9	244.87	240.38	0.0026	0.0026	0.0026	0.0047	0.0047	0.0047
LMn16	21.21	21.24	21.23	246.88	254.89	250.88	0.0026	0.0027	0.0027	0.0048	0.0048	0.0048
Rhizobium + LMn16	21.45	21.52	21.49	271.73	276.9	274.32	0.0027	0.0028	0.0027	0.0048	0.0049	0.0049
SEm±	0.2	0.21	0.2	7.53	8.08	7.6	0.00007	0.00008	0.0001	0.0001	0.0001	0.0001
CD (P=0.05)	NS	NS	NS	21.44	23.01	21.64	NS	NS	NS	NS	NS	NS
Interaction												
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)	4.47	4.9	4.57	14.67	15.3	14.59	12.76	14.96	13.76	8.67	9.11	8.87

Table 5: Nodule count (Nos.) of black gram as influenced by integrated nutrient management

Treatment	15DAS			30DAS			45 DAS			60 DAS		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Fertility levels (CF)												
Control	1.93	1.61	1.77	9.53	9.13	9.33	23.76	20.21	21.98	12.10	11.61	11.86
75 % RDF	4.23	5.58	4.91	15.84	17.64	16.74	31.44	34.32	32.88	17.11	19.92	18.52
100 % RDF	6.02	6.42	6.22	18.19	20.76	19.48	36.46	38.34	37.40	20.89	22.52	21.71
125 % RDF	6.97	7.20	7.08	19.59	22.19	20.89	37.40	39.79	38.59	21.51	24.94	23.23
SEm±	0.13	0.15	0.14	0.34	0.47	0.37	0.67	0.65	0.65	0.52	0.69	0.53
CD (P=0.05)	0.38	0.44	0.40	0.97	1.33	1.07	1.90	1.85	1.85	1.47	1.95	1.51
FYM levels (t ha⁻¹)												
0	4.10	4.43	4.27	13.68	14.70	14.19	30.21	30.82	30.51	15.53	17.73	16.63
5	5.48	5.97	5.73	17.89	20.16	19.03	34.32	35.51	34.92	20.27	21.77	21.02
SEm±	0.09	0.11	0.10	0.24	0.33	0.27	0.47	0.46	0.46	0.37	0.48	0.38
CD (P=0.05)	0.27	0.31	0.28	0.68	0.94	0.75	1.34	1.31	1.31	1.04	1.38	1.07
Biofertilizers (PGPR /BF)												
Rhizobium	4.30	4.64	4.47	14.84	16.17	15.51	30.85	31.63	31.24	16.32	18.33	17.33
LMn16	4.71	5.13	4.92	15.50	17.06	16.28	31.66	32.85	32.25	17.48	19.49	18.49
Rhizobium + LMn16	5.35	5.83	5.59	17.03	19.06	18.04	34.28	35.02	34.65	19.91	21.43	20.67
SEm±	0.12	0.13	0.12	0.29	0.41	0.32	0.58	0.56	0.56	0.45	0.59	0.46
CD (P=0.05)	0.33	0.38	0.34	0.84	1.16	0.92	1.65	1.61	1.61	1.28	1.69	1.31
Interaction												
CF x FYM SEm±	0.19	0.22	0.20	0.84	0.66	0.53	0.94	0.92	0.92	0.73	0.97	0.75
CD (P=0.05)	0.54	0.62	0.56	1.37	1.89	1.51	NS	NS	NS	NS	NS	NS
Other Interactions												
CV%	11.84	12.64	11.79	9.13	11.40	9.56	8.78	8.33	8.45	12.26	14.71	11.95

Table 6: Yield and economics and of black gram as influenced by integrated nutrient management

Treatment	Seed Yield (kg ha ⁻¹)			Cost of cultivation (₹ ha ⁻¹)	Gross Return (₹.ha ⁻¹)			Net Return (₹ ha ⁻¹)			B:C			Production Efficiency (kg ha ⁻¹ day ⁻¹)			Economic Efficiency (Rs. ha ⁻¹ day ⁻¹)		
	2020	2021	Pooled			2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021
Fertility levels (CF)																			
Control	810	787	798	24872	49802	48462	49132	24929	23589	24259	1.00	0.95	0.97	11	10.09	10.30	324	302	313
75 % RDF	1128	1167	1147	27448	69269	71625	70447	41821	44177	42999	1.52	1.61	1.56	15	14.96	14.80	543	566	555
100 % RDF	1349	1410	1379	28306	82801	86501	84651	54495	58194	56345	1.92	2.06	1.99	18	18.07	17.79	708	746	727
125 % RDF	1519	1597	1558	29165	93256	97982	95619	64092	68817	66454	2.18	2.35	2.27	20	20.47	20.10	832	882	857
SEm±	28.02	29.60	27.36		1725	1818	1683	1725	1818	1683	0.062	0.065	0.061	0.36	0.38	0.35	22.40	23.31	21.71
CD (P=0.05)	79.77	84.26	77.90		4911	5175	4790	4911	5175	4790	0.176	0.185	0.172	1.04	1.080	1.00	63.77	66.35	61.80
FYM levels (t ha ⁻¹)																			
0	1084	1132	1108	25648	66568	69504	68036	40921	43857	42389	1.57	1.68	1.63	14	14.51	14.29	531	562	547
5	1319	1348	1334	29248	80996	82780	81888	51748	53532	52640	1.74	1.80	1.77	17	17.29	17.21	672	686	679
SEm±	19.82	20.93	19.35		1220	1285	1190	1220	1285	1190	0.044	0.046	0.043	0.26	0.27	0.25	15.84	16.48	15.35
CD (P=0.05)	56.41	59.58	55.08		3472	3659	3387	3472	3659	3387	0.125	0.131	0.122	0.73	0.764	0.71	45.09	46.915	43.70
Biofertilizers (PGPR /BF)																			
Rhizobium	1141	1192	1167	27423	70104	73197	71650	42681	45774	44228	1.53	1.63	1.58	15	15.28	15.05	554	587	571
LMn16	1182	1228	1205	27423	72620	75390	74005	45198	47967	46582	1.62	1.72	1.67	15	15.74	15.55	587	615	601
Rhizobium + LMn16	1281	1301	1291	27498	78622	79840	79231	51124	52342	51733	1.82	1.87	1.84	17	16.67	16.65	664	671	667
SEm±	24.27	25.63	23.70		1494	1574	1457	1494	1574	1457	0.054	0.056	0.052	0.32	0.329	0.31	19.40	20.18	18.80
CD (P=0.05)	69.09	72.97	67.46		4253	4482	4149	4253	4482	4149	0.153	0.160	0.149	0.90	0.936	0.87	55.23	57.46	53.52
Interaction																			
CF X FYM SEm±	39.63	41.86	38.70		2440	2571	2380	2440	2571	2380	0.088	0.092	0.086	0.51	0.54	0.50	31.68	32.96	30.70
CD (P=0.05)	112.88	119.22	110.22		6948	7323	6778	6948	7323	6778	NS	NS	NS	1.47	1.53	1.42	90.24	93.88	87.45
CV%	9.90	10.13	9.51		9.92	10.13	9.52	15.80	15.84	15.03	15.88	15.86	15.12	9.90	10.13	9.51	15.80	15.84	15.03

Application of FYM at 5 t ha⁻¹ significantly enhanced economic returns compared to control, recording gross return of ₹81,888 ha⁻¹, net return of ₹52,640 ha⁻¹, production efficiency of 17.0 kg ha⁻¹ day⁻¹, economic efficiency of ₹679 ha⁻¹ day⁻¹ and a B:C ratio of 1.77. The net return and economic efficiency increased by 24.18% and 20.43%, respectively, over plots without FYM application. Among biofertilizer treatments, seed inoculation with *Rhizobium* + LMn16 produced the maximum gross return (₹79,321 ha⁻¹), net return (₹51,733 ha⁻¹), B:C ratio (1.84), production efficiency (16.65 kg ha⁻¹ day⁻¹) and economic efficiency (₹667 ha⁻¹ day⁻¹). The superior economic performance under dual inoculation was primarily due to higher seed and stover yields.

Conclusion

Based on the results of the two-year field experiment, it can be concluded that integrated nutrient management involving farmyard manure and biofertilizers in combination with inorganic fertilizers significantly improves growth, yield attributes, yield, nutrient content and nutrient uptake in black gram. Application of a higher fertility level (125% RDF; 25-50-25-25 kg N-P-K-S ha⁻¹) along with FYM at 5 t ha⁻¹ and dual seed inoculation with *Rhizobium* and PGPR LMn16 proved superior in enhancing productivity, nutrient uptake and economic returns compared to the use of recommended fertilizer dose alone. Therefore, this integrated nutrient management practice can be recommended for achieving higher yield, improved quality and better profitability of black gram under the plateau region of Jharkhand.

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