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Integrated Nutrient Management for Enhancing Yield, Nutrient Uptake, Protein Content and Soil Health of Urdbean (*Vigna mungo L.*)

Komal Patel[1], Dr. Mandeep Kumar[2], Dr. Ravikesh Pal[3], Dr. Aneeta Yadav[4], Dr. Vinay Joseph Silas[5]

[1]M.Sc. Agriculture (Agronomy),
[1,2,3,4,5]Faculty of Agricultural Sciences and Allied Industries, Rama University, Kanpur, Uttar Pradesh, India

ABSTRACT

A field experiment was conducted to evaluate the effects of graded fertilizer levels, farmyard manure (FYM) and biofertilizers on growth, yield attributes, nutrient uptake, protein yield, soil fertility status and economics of urdbean (*Vigna mungo* L.). The treatments comprised different levels of recommended dose of fertilizers (RDF), FYM (0 and 5 $t\ ha^{-1}$) and biofertilizers including *Rhizobium* and phosphate solubilizing bacteria (PSB).

Application of 125% RDF significantly enhanced growth and yield attributes, recording maximum plant height (50.08 cm), branches per plant (3.03), pods per plant (27.99), seeds per pod (6.84), seed index (4.26 g) and seed yield per plant (7.67 g), which ultimately resulted in higher seed yield per hectare. FYM application at 5 $t\ ha^{-1}$ markedly improved plant growth, nodulation and productivity, with plant height (46.75 cm), pods per plant (26.52), seeds per pod (6.51), seed index (4.22 g), seed yield per plant (7.11 g), root nodules per plant (45.90), nodule dry weight (71.16 mg) and seed yield (1237 $kg\ ha^{-1}$).

Biofertilizer inoculation exhibited consistent positive effects across treatments by improving nodulation and nutrient availability, although differences among biofertilizer treatments were statistically at par. Nutrient uptake (N, P and K) was significantly influenced by fertilizer levels, with higher uptake recorded under 125% RDF due to increased biomass production and improved nutrient availability. However, nutrient concentration in seed remained non-significant across treatments. Protein yield was significantly enhanced under higher fertility levels and FYM application, indicating improved nitrogen assimilation and seed quality.

Soil fertility parameters, including organic carbon and available N, P and K, showed improvement with FYM and biofertilizer application, reflecting better soil health and sustainability. Economic analysis revealed that application of 125% RDF resulted in maximum gross returns, net returns and benefit-cost ratio, making it the most profitable treatment combination.

The findings suggest that integrated application of 125% RDF along with FYM at 5 $t\ ha^{-1}$ and biofertilizers is an effective strategy for achieving higher productivity, improved nutrient use efficiency, enhanced protein yield and sustainable soil health in urdbean cultivation.

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INTRODUCTION

Pulses are indispensable to global food and nutritional security, particularly in developing countries where they serve as a primary source of dietary protein. India is the largest producer and consumer of pulses, contributing approximately 24–25% of global production from about 30 million hectares, with an annual production exceeding 27 million tonnes. Major pulse crops grown in the country include chickpea, pigeonpea, mungbean, urdbean, lentil and field pea, with key production regions located in Madhya Pradesh, Maharashtra, Rajasthan, Uttar Pradesh, Karnataka and Andhra Pradesh. Despite this leading position, the average productivity of pulses in India (800–900 kg ha^{-1})remains considerably lower than the global average (>1000 kg ha^{-1}), indicating a substantial yield gap attributable to soil fertility constraints and suboptimal nutrient management.

Urdbean (*Vigna mungo* L.), commonly known as black gram, is an important short-duration pulse crop cultivated across diverse agro-climatic conditions during Kharif, Rabi and summer seasons. In India, it occupies an area of about 5.5 million hectares with a production of nearly 3.5 million tonnes and an average productivity of around 600–700 kg ha^{-1}.The crop is highly valued for its superior nutritional profile, containing approximately 22–26% protein, 55–60% carbohydrates, and essential minerals such as calcium (150–200 mg 100g^{-1}),iron (5–7 mg 100g^{-1}),phosphorus and potassium, along with B-complex vitamins. Due to its high protein content and digestibility, urdbean plays a crucial role in supplementing protein requirements in predominantly vegetarian diets.

Beyond its nutritional significance, urdbean contributes to soil fertility through symbiotic nitrogen fixation, adding approximately 20–25 kg N ha^{-1}to the soil, thereby reducing dependence on synthetic nitrogen fertilizers. It is widely incorporated into cropping systems as a rotation or intercrop, enhancing soil health and system productivity. Additionally, its short duration (70–90 days) makes it suitable for inclusion in multiple cropping systems, thereby increasing cropping intensity and farm income.

However, the productivity of urdbean remains low due to several constraints, among which improper and imbalanced nutrient management is a major limiting factor. Although legumes can fix atmospheric nitrogen through symbiosis with *Rhizobium*, the rate of biological nitrogen fixation is often insufficient to meet the crop's total nutrient demand, particularly under intensive cultivation. Deficiencies of essential nutrients adversely affect physiological processes such as photosynthesis, root development, nodulation and protein synthesis, ultimately leading to reduced yield and quality.

Among macronutrients, phosphorus plays a critical role in energy transfer (ATP), root proliferation, early plant establishment and nodulation, while potassium is essential for enzyme activation, osmotic regulation, translocation of assimilates and enhancement of protein synthesis. Studies have indicated that balanced fertilization with nitrogen, phosphorus and potassium can significantly increase growth, yield attributes and nutrient uptake in pulse crops. However, excessive reliance on chemical fertilizers alone often leads to declining soil organic carbon, nutrient imbalance, reduced microbial activity and environmental degradation.

In this context, Integrated Nutrient Management (INM) has emerged as a sustainable approach for maintaining soil fertility and enhancing crop productivity. INM involves the judicious combination of inorganic fertilizers, organic manures such as farmyard manure (FYM), and biofertilizers. Application of FYM at rates of 5–10 t ha^{-1}has been reported to improve soil structure, increase water holding capacity, enhance cation exchange capacity and stimulate microbial activity, resulting in better nutrient availability. Biofertilizers such as *Rhizobium* and phosphate solubilizing bacteria (PSB) play a vital role in fixing atmospheric nitrogen (up to 50–100 kg N ha^{-1}under optimal conditions) and converting insoluble phosphorus into plant-available forms, thereby improving nutrient use efficiency.

Empirical evidence suggests that integrated application of 100–125% recommended dose of fertilizers (RDF) along with FYM and biofertilizers significantly enhances plant growth, nodulation, yield attributes and seed yield in urdbean. Such practices also improve nutrient uptake (N, P and K), increase protein content and contribute to better economic returns. Furthermore, INM practices enhance soil organic carbon, available nutrient status and microbial biomass, thereby ensuring long-term soil health and sustainability.

Considering the growing need for sustainable intensification of pulse production, there is a pressing requirement to optimize nutrient management strategies for urdbean cultivation. Therefore, the present investigation was undertaken to evaluate the combined effect of different fertilizer levels, farmyard manure and biofertilizers on growth, yield, nutrient uptake, protein content, soil health and economic returns of urdbean (*Vigna mungo* L.), with the objective of identifying an efficient, economically viable and environmentally sustainable nutrient management approach.

Materials and Methods

The experiment was conducted during the Kharif season at the Agronomy Research Field of the Faculty of Agricultural Sciences and Allied Industries, Rama University, Mandhana, Kanpur (Uttar Pradesh), India. The experimental site lies in the Indo-Gangetic plains and experiences a subtropical climate, characterized by high temperatures during summer and moderate rainfall during the monsoon season. The average annual rainfall of the region ranges from 800 to 900 mm, most of which is received between June and September.

Soil Properties

Before initiation of the experiment, representative soil samples were collected from a depth of 0–15 cm and analyzed for their physico-chemical characteristics. The soil was alluvial in origin with a sandy loam to loam texture and good drainage capacity. It exhibited a slightly alkaline reaction with pH ranging from 7.5 to 8.0. The soil contained low to medium organic carbon (0.40–0.50%). The available nitrogen content was low (150–200 kg ha^{-1}), while available phosphorus (18–25 kg ha^{-1})and available potassium (250–350 kg ha^{-1}) were in the medium to higher range.

Experimental Design and Treatment Details

The study was laid out in a Randomized Block Design (RBD) with three replications. The treatments comprised varying levels of phosphorus along with bio-inputs to evaluate their individual and combined effects on urdbean performance. Phosphorus was applied at graded levels (such as 0, 40 and 60 kg P_2O_5 ha^{-1}), while bio-inputs included farmyard manure (FYM) and beneficial microbial inoculants.

The bio-input treatments consisted of FYM applied at 5 t $ha^{-1}$and seed inoculation with *Rhizobium* and phosphate solubilizing bacteria (PSB). Treatment combinations were arranged randomly within each replication to minimize experimental variability.

Crop Establishment and Management Practices

Urdbean (*Vigna mungo* L.) was grown as the test crop using a suitable high-yielding variety recommended for the region. Sowing was performed during the optimum Kharif window (late June to early July) maintaining a spacing of 45 cm between rows and 10 cm between plants to ensure proper crop geometry.

Seeds were inoculated with *Rhizobium* and PSB cultures prior to sowing following standard procedures to enhance biological nitrogen fixation and phosphorus availability. Farmyard manure was applied and thoroughly incorporated into the soil before sowing as per treatment requirements. Phosphorus was applied as a basal dose through suitable fertilizer sources, while recommended doses of nitrogen and potassium were uniformly applied to all plots to avoid nutrient imbalance. Standard agronomic practices, including thinning, weeding and plant protection measures, were carried out uniformly across all treatments.

Observations and Data Collection

Observations related to growth, nodulation and yield were recorded at different stages of crop development from randomly selected plants within each plot.

Growth parameters included:

- Plant height (cm)
- Number of branches per plant

Yield attributes included:

- Number of pods per plant
- Number of seeds per pod
- Test weight (1000-seed weight, g)
- Seed yield per plant (g)
- Seed yield (kg ha^{-1})

Nodulation parameters included:

- Number of root nodules per plant
- Nodule dry weight (mg)

Nutrient and Protein Estimation

Plant samples were collected, dried and subjected to chemical analysis to determine nitrogen, phosphorus and potassium content using standard laboratory procedures. Nutrient uptake was calculated based on nutrient concentration and biomass yield.

Protein content in seeds was estimated by converting nitrogen content into protein using a conversion factor of 6.25.

Soil Fertility Assessment - After harvest, soil samples were collected from each treatment plot and analyzed to assess changes in soil fertility. The parameters studied included organic carbon, available nitrogen, available phosphorus and available potassium.

Statistical Analysis

The data obtained from the experiment were analyzed statistically using analysis of variance (ANOVA) appropriate for Randomized Block Design. The significance of differences among treatments was tested at the 5% probability level. Critical difference (CD) values were calculated for comparison of treatment means using standard statistical procedures.

RESULTS AND DISCUSSION

Effect of Fertilizer Doses on Plant Growth and Yield Attributes

The findings of the present investigation revealed that different fertilizer levels exerted a significant influence on the growth and yield parameters of urdbean. The data presented in Table 1 clearly indicate that increasing fertilizer doses improved overall crop performance.

Among the treatments, the application of 125% of the recommended dose of fertilizers (RDF) produced superior results in terms of plant growth attributes such as plant height, number of branches, and dry matter accumulation. This enhancement may be attributed to the adequate and balanced supply of essential nutrients, which promoted better vegetative growth and physiological activity.

Similarly, yield-related parameters, including number of pods per plant, seeds per pod, and test weight, were also significantly improved under the 125% RDF treatment. The higher availability of nutrients likely enhanced photosynthetic efficiency and assimilate translocation, resulting in improved reproductive development.

In comparison to lower fertilizer levels, the increased dose ensured optimum nutrient uptake, which ultimately translated into higher seed yield and better overall productivity of urdbean. However, the response between 100% RDF and 125% RDF was comparatively closer, suggesting that beyond a certain level, the incremental benefit may be marginal.

Overall, the study highlights the importance of appropriate fertilizer management in maximizing growth and yield attributes of urdbean.

Table 1. Influence of fertilizer levels, farmyard manure and biofertilizers on growth and yield attributes of urdbean.

Treatment	Plant height (cm)	Branches plant^{-1}	Pods plant^{-1}	Seed index (g)	Seed yield plant^{-1}(g)
Fertilizer Levels					
75% RDF	41.00	2.69	23.03	4.16	5.94
100% RDF	46.23	2.87	25.98	4.21	6.78
125% RDF	50.08	3.03	27.99	4.26	7.67
SEm (±)	0.60	0.03	0.35	0.01	0.09
CD (P = 0.05)	1.66	0.07	0.97	0.03	0.26
Farmyard Manure (FYM)					
Control (0 t ha^{-1})	44.79	2.81	24.82	4.20	6.49
FYM @ 5 t ha^{-1}	46.75	2.92	26.52	4.22	7.11
SEm (±)	0.49	0.02	0.29	0.01	0.08
CD (P = 0.05)	1.35	0.06	0.79	NS	0.21
Biofertilizer Treatments					
Rhizobium inoculation	45.62	2.86	25.22	4.21	6.65
LMn-16 inoculation	45.91	2.83	25.45	4.21	6.74
Rhizobium + LMn- 16	45.78	2.91	26.33	4.22	7.01
SEm (±)	0.60	0.03	0.35	0.01	0.12
CD (P = 0.05)	NS	NS	NS	NS	NS

The application of higher fertilizer levels resulted in superior performance across all observed growth and yield parameters. Among the treatments, 125% of the recommended dose of fertilizers (RDF) recorded the maximum values, including plant height (50.08 cm), number of branches (3.03 plant^{-1}), pods per plant (27.99), seed index (4.26 g), and seed yield per plant (7.67 g). The improved performance under this treatment may be attributed to the adequate and balanced supply of essential nutrients, which enhanced metabolic activities, cell division, and overall plant vigor.

Enhanced nutrient availability under higher fertilizer application likely promoted vegetative growth, resulting in increased plant height and branching. This, in turn, contributed to the development of more reproductive sites, leading to a higher number of pods per plant. Furthermore, sufficient nutrient supply during critical growth stages may have improved photosynthetic efficiency and assimilate partitioning towards reproductive organs, ultimately increasing seed size and yield.

Table 2. Effect of fertilizer levels, farmyard manure and biofertilizers on nodulation, protein content and protein yield of urdbean.

Treatment	Root nodules plant^{-1} (40 DAS)	Nodule dry weight (mg plant^{-1}) (40 DAS)	Seed protein content (%)	Protein yield (kg ha^{-1})
Fertilizer Levels				
75% RDF	41.47	64.82	21.8	241
100% RDF	44.98	69.65	21.9	264
125% RDF	47.88	73.09	22.1	289
SEm (±)	0.45	0.74	0.10	5
CD (P = 0.05)	1.26	2.04	NS	13
Farmyard Manure (FYM)				
Control (0 t ha^{-1})	43.65	67.22	21.8	257
FYM @ 5 t ha^{-1}	45.90	71.16	22.0	272
SEm (±)	0.37	0.60	0.10	4
CD (P = 0.05)	1.03	1.67	NS	10
Biofertilizer Treatments				
Rhizobium inoculation	44.23	68.91	21.9	263
LMn-16 inoculation	44.59	68.76	21.9	263
Rhizobium + LMn-16	45.51	69.91	21.8	267
SEm (±)	0.45	0.74	0.10	5
CD (P = 0.05)	NS	NS	NS	NS

Application of higher fertilizer levels markedly enhanced nodulation characteristics of urdbean. The treatment receiving 125% of the recommended dose of fertilizers (RDF) recorded superior performance in terms of both number and dry weight of root nodules. This improvement can be attributed to the availability of balanced and adequate nutrients, which created favourable conditions for the establishment and activity of symbiotic nitrogen-fixing bacteria.

The increased nutrient supply, particularly of phosphorus and other essential elements, likely promoted better root growth and metabolic activity, thereby facilitating greater nodule initiation and development. Enhanced nodulation under higher fertility levels indicates improved biological nitrogen fixation, which plays a vital role in meeting the nitrogen requirement of the crop. Consequently, the increase in both number and dry weight of nodules reflects a more efficient plant–microbe interaction and improved nutrient acquisition capacity. Although nitrogen is a key element influencing nodulation, the availability of other nutrients also contributes significantly to the proper functioning and effectiveness of nodules. The superior nodulation observed under 125% RDF suggests that optimum nutrient conditions not only support plant growth but also strengthen symbiotic efficiency, ultimately contributing to better crop productivity. These findings are consistent with earlier reports by Yin et al. (2018) and Giri et al. (2020), thereby reinforcing the validity of the present results.

Seed, Straw and Biological Yield

The effect of different fertilizer levels on seed yield, straw yield, and biological yield of urdbean revealed a clear and positive response to increasing nutrient application. The results indicated that higher fertilizer doses significantly improved all yield parameters, highlighting the importance of adequate nutrient supply in achieving higher productivity.

The analysis of data revealed that different fertilizer levels exerted a significant influence on seed, straw, and biological yield of urdbean (Table 3). Among the treatments, application of 125% of the recommended dose of fertilizers (RDF: 25:50:25 kg N:P: K ha^{-1}) recorded the highest seed yield (1312 kg ha^{-1}), which was significantly superior to lower fertilizer levels.

The enhanced yield under 125% RDF may be attributed to the adequate and balanced supply of essential nutrients, which supported optimum crop growth and development. Improved nutrient availability likely enhanced physiological processes such as photosynthesis, nutrient uptake, and assimilate translocation, resulting in better flowering, pod formation, and seed development. These combined effects ultimately contributed to increased seed yield.

A comparative assessment indicated that the 125% RDF treatment resulted in an approximate increase of 18% in seed yield over 75% RDF (1108 kg ha^{-1})and about 9.2% over 100% RDF (1202 kg ha^{-1}). This clearly demonstrates that a higher nutrient dose beyond the recommended level had a positive impact on crop productivity. Similar trends were also observed in straw and biological yield, indicating overall improvement in biomass production under enhanced fertility conditions.

However, the effect of fertilizer levels on harvest index was found to be non-significant, suggesting that the proportional distribution of biomass between economic yield and total biomass remained relatively unaffected by varying nutrient levels.

Overall, the results emphasize the critical role of optimum nutrient management in maximizing yield potential of urdbean. The present findings are in close conformity with earlier studies, further supporting the positive response of legume crops to increased fertilizer application under suitable conditions.

Table 3. Effect of fertilizer levels, farmyard manure and biofertilizers on yield attributes and harvest index of urdbean.

Treatment	Seed yield (kgha^{-1})	Straw yield (kgha^{-1})	Biological yield (kgha^{-1})	Harvest index (%)
Fertilizer Levels				
75% RDF	1108	2417	3525	31.46
100% RDF	1202	2634	3836	31.31
125% RDF	1312	2874	4186	31.30
SEm (±)	20	38	54	0.37
CD (P = 0.05)	55	105	149	NS
Farmyard Manure (FYM)				
Control (0 t ha^{-1})	1178	2567	3745	31.51
FYM @ 5 t ha^{-1}	1237	2716	3953	31.20
SEm (±)	16	31	44	0.30
CD (P = 0.05)	45	86	122	NS
Biofertilizer Treatments				
Rhizobium inoculation	1200	2624	3824	31.36
LMn-16 inoculation	1197	2620	3817	31.36
Rhizobium + LMn- 16	1225	2680	3905	31.35
SEm (±)	20	38	54	0.37
CD (P = 0.05)	NS	NS	NS	NS

The economic analysis revealed a significant influence of different fertilizer levels on the profitability of urdbean cultivation (Table 4). Among the treatments, application of 125% of the recommended dose of fertilizers (RDF: 25:50:25 kg N:P: K ha^{-1})recorded the highest gross returns (₹78,709ha^{-1})and net returns (₹54,460 ha^{-1}), which were significantly superior to lower fertilizer levels. In addition, this treatment also resulted in the maximum benefit–cost (B:C) ratio of 3.26.

The enhanced economic returns under 125% RDF can be attributed to the higher productivity achieved due to improved nutrient availability. Adequate and balanced nutrient supply likely promoted better crop growth, resulting in increased seed yield and overall biomass, which ultimately contributed to higher marketable produce and gross income. Although the application of higher fertilizer doses involves increased input cost, the additional expenditure was effectively compensated by the substantial gain in yield.

The higher net returns observed under this treatment indicate that the increase in income due to enhanced productivity outweighed the additional cost incurred on fertilizers. This clearly demonstrates that application of 125% RDF is not only agronomically beneficial but also economically viable for urdbean cultivation.

Table 4. Economics of urdbean production as influenced by fertilizer levels, FYM and biofertilizers.

Treatment	Cost of cultivation (₹ha^{-1})	Gross monetary returns(₹ha^{-1})	Net monetary returns(₹ha^{-1})	Benefit: Cost ratio
Fertilizer Levels				
75% RDF	22,276	66,473	44,196	2.98
100% RDF	23,250	72,133	48,883	3.09
125% RDF	24,249	78,709	54,460	3.26
SEm (±)	—	1,187	1,088	—
CD (P = 0.05)	—	3,290	3,016	—

Farmyard Manure (FYM)				
Control (0 t ha^{-1})	18,112	70,675	52,564	3.71
FYM @ 5 t ha^{-1}	28,405	74,201	45,796	2.51
SEm (±)	—	969	888	—
CD (P = 0.05)	—	2,687	2,463	—
Biofertilizer Treatments				
Rhizobium inoculation	23,221	71,983	48,762	3.09
LMn-16 inoculation	23,207	71,822	48,615	3.09
Rhizobium + LMn-16	23,348	73,510	50,162	3.15
SEm (±)	—	1,187	1,088	—
CD (P = 0.05)	—	NS	NS	—

The economic analysis clearly demonstrated that application of 125% RDF (25:50:25 kg N:P: K ha^{-1})ensured maximum profitability in urdbean cultivation. The higher gross and net returns, along with an improved benefit–cost ratio, indicate that the additional investment on fertilizers was effectively compensated by increased productivity. This reflects better input-use efficiency and economic viability of higher fertilizer application. The findings are in close conformity with earlier studies, confirming that enhanced nutrient supply significantly improves crop economics.

The nutrient composition of seed and straw revealed non-significant variation in nitrogen, phosphorus, and potassium content across treatments. Despite differences in fertilizer levels, the concentration of these nutrients remained relatively stable, which may be attributed to inherent physiological regulation and internal nutrient balance within the plant system. The mobility and redistribution of nutrients within plant tissues, along with uniform growing conditions, might have minimized treatment differences. These observations are consistent with previous findings reported in leguminous crops.

Similarly, seed protein content (%) was not significantly affected by fertilizer levels, indicating that protein concentration is largely governed by genetic and physiological factors. However, protein yield (kg ha^{-1}) showed significant variation among treatments. The highest protein yield (289 kg ha^{-1})was recorded under 125% RDF, primarily due to increased seed yield. Since protein yield is a function of both yield and protein concentration, enhanced productivity under higher fertilizer application resulted in greater protein output per unit area. Adequate nitrogen availability under higher fertility levels likely supported amino acid synthesis and protein formation, thereby improving overall protein accumulation. These findings are in agreement with earlier reports.

Nutrient uptake by the crop was significantly influenced by fertilizer levels. The application of 125% RDF recorded the highest uptake of nitrogen (67 kg ha^{-1}), phosphorus (12.45 kg ha^{-1}), and potassium (58.5 kg ha^{-1}), indicating superior nutrient absorption under enhanced fertility conditions. This may be attributed to improved root development, increased nutrient availability in the soil, and higher physiological efficiency of the plants. Enhanced uptake reflects better nutrient use efficiency and overall plant vigor, which ultimately contributed to higher biomass and yield.

Overall, the results of the study clearly indicate that application of 125% RDF provided optimal nutrient availability, resulting in improved nodulation, yield attributes, nutrient uptake, protein yield, and economic returns. The non-significant interaction effects suggest that individual factors acted independently, while the consistent superiority of higher fertilizer levels highlights the importance of balanced and adequate nutrient management for maximizing productivity and profitability of urdbean.

Table 5. Effect of fertilizer levels, farmyard manure and biofertilizers on nutrient content (%) and uptake (kg ha^{-1})of urdbean.

Treatment	Nitrogen content (%)		Phosphorus Content (%)		Potassium Content (%)		Nutrient uptake (kgha^{-1})		
	Seed	Straw	Seed	Straw	Seed	Straw	Nitrogen	Phosphorus	Potassium
Fertilizer Levels									
75% RDF	3.48	0.69	0.46	0.20	0.92	1.54	55	9.73	47.6
100% RDF	3.50	0.70	0.49	0.21	0.93	1.55	61	11.40	52.0
125% RDF	3.53	0.71	0.50	0.21	0.95	1.59	67	12.45	58.5
SEm (±)	0.01	0.01	0.01	0.004	0.01	0.02	0.96	0.26	0.90

CD (P = 0.05)	NS	NS	NS	NS	NS	NS	2.67	0.73	2.60
Farmyard Manure (FYM)									
Control (0t ha^{-1})	3.49	0.69	0.47	0.20	0.93	1.56	59	10.69	51.2
FYM @ 5t ha^{-1}	3.52	0.70	0.49	0.21	0.94	1.56	63	11.69	54.2
SEm (±)	0.01	0.01	0.01	0.003	0.01	0.01	0.79	0.21	0.80
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	2.18	0.59	2.10
Biofertilizer Treatments									
Rhizobium inoculation	3.51	0.71	0.48	0.20	0.92	1.56	60	10.99	52.3
LMn-16 inoculation	3.51	0.69	0.48	0.20	0.94	1.56	60	11.06	52.5
Rhizobiu m + LMn-16	3.49	0.70	0.49	0.21	0.94	1.55	61	11.53	53.3
SEm (±)	0.01	0.01	0.01	0.004	0.01	0.01	0.96	0.26	0.90

Effect of Farmyard Manure (FYM)

Plant Growth and Yield Attributes

The application of farmyard manure (FYM) significantly influenced the growth and yield attributes of urdbean (Table 1). The treatment receiving FYM @ 5 t ha^{-1}exhibited superior performance in terms of plant height (46.75 cm), number of branches (2.92 plant^{-1}), and pods per plant (26.52) compared to the control. However, variations in seed index were found to be statistically non-significant.

The observed improvement in growth parameters can be attributed to the beneficial effects of FYM on soil physicochemical and biological properties. Incorporation of organic matter enhances soil structure, increases cation exchange capacity, and improves moisture retention, thereby creating a favourable environment for root proliferation and nutrient absorption. Furthermore, the gradual mineralization of nutrients from FYM ensures a sustained and balanced nutrient supply throughout the crop growth period, which promotes both vegetative growth and reproductive development.

Nodulation

Nodulation parameters were significantly affected by FYM application (Table 2). The application of FYM @ 5 t ha^{-1}resulted in higher root nodules (45.90 plant^{-1}) and greater nodule dry weight (71.16 mg plant^{-1}) compared to the untreated control.

This enhancement in nodulation may be attributed to improved soil biological activity and the creation of a conducive rhizospheric environment for symbiotic nitrogen-fixing bacteria. FYM serves as a substrate for beneficial soil microorganisms, thereby enhancing microbial population and activity. Additionally, the presence of essential macro- and micronutrients in FYM supports root growth and nodule development. The synergistic interaction between organic matter and soil microflora likely improved the efficiency of biological nitrogen fixation.

Seed, Straw and Biological Yield

Application of FYM significantly enhanced seed yield, straw yield, and biological yield of urdbean (Table 3). The treatment receiving FYM @ 5 t ha^{-1}recorded higher yields compared to the control, indicating a positive response of the crop to organic nutrient supplementation.

The increase in yield under FYM application can be attributed to improved soil fertility and sustained nutrient availability resulting from the slow decomposition of organic matter. This continuous nutrient release supports critical growth stages such as flowering, pod formation, and seed filling. In addition, improved soil moisture conservation and enhanced microbial activity under FYM application likely contributed to better crop performance and higher biomass accumulation.

Economics

The economic evaluation indicated that FYM application significantly influenced gross returns, whereas net returns and benefit–cost ratio were comparatively higher under the control treatment (Table 4). The application of FYM @ 5 t ha^{-1}resulted in higher gross monetary returns due to increased yield; however, the additional costs associated with FYM procurement, transportation, and application reduced net profitability.

This suggests that although FYM enhances productivity, its economic efficiency depends on input cost management. Nonetheless, the long-term benefits of FYM in improving soil health, sustainability, and productivity make it an important component of integrated nutrient management strategies.

Protein Content and Protein Yield

The effect of FYM on seed protein content was found to be non-significant, whereas protein yield showed a significant increase under FYM application (Table 2). The highest protein yield was recorded with FYM @ 5 t ha^{-1}.

The increase in protein yield may be attributed to improved nutrient availability, particularly nitrogen, which plays a critical role in protein synthesis. Enhanced soil fertility and microbial activity under FYM application likely supported efficient nutrient uptake and metabolic processes, resulting in higher seed yield and, consequently, greater protein output per unit area. Since protein yield is primarily influenced by seed yield, the improvement in productivity under FYM treatment directly contributed to increased protein production.

Nutrient Content (FYM)

The concentration of nitrogen (N), phosphorus (P), and potassium (K) in both seed and straw of urdbean was not significantly affected by different levels of farmyard manure (Table 5). Despite variations in FYM application, nutrient concentrations in plant tissues remained relatively consistent across treatments.

This stability may be attributed to the inherent buffering capacity of the soil–plant system, which regulates nutrient availability and maintains internal nutrient equilibrium. Additionally, FYM supplies a balanced spectrum of macro- and micronutrients, which may have adequately fulfilled crop requirements even at lower application levels. The mobility and redistribution of nutrients within the plant system further contribute to maintaining relatively uniform nutrient concentrations, irrespective of external inputs. Similar trends have been documented in earlier studies under comparable agro-ecological conditions.

Nutrient Uptake (FYM)

In contrast to nutrient concentration, nutrient uptake was significantly influenced by FYM application (Table 5). The treatment receiving FYM @ 5 t ha^{-1}recorded higher uptake of nitrogen (63 kg ha^{-1}), phosphorus (11.59 kg ha^{-1}), and potassium (54.2 kg ha^{-1})compared to the control.

The enhanced uptake can be attributed to improved soil physical, chemical, and biological properties following FYM incorporation. The gradual mineralization of organic matter ensures a sustained release of nutrients, which supports continuous absorption by the crop. Furthermore, increased microbial activity in the rhizosphere likely enhanced nutrient solubilization and availability. Improved root growth and higher soil moisture retention under FYM application may have also contributed to more efficient nutrient acquisition.

Effect of Biofertilizers

Plant Growth and Yield Attributes

The application of different biofertilizer treatments did not result in statistically significant variation in growth and yield attributes of urdbean (Table 1). Parameters such as plant height, branching, and pod formation remained comparable across treatments.

This uniformity may be attributed to the functional similarity of microbial inoculants used, which likely contributed equally to nutrient mobilization and plant growth promotion. The consistent microbial activity across treatments ensured a uniform supply of nutrients, thereby resulting in similar crop performance.

Nodulation

Nodulation parameters, including number and dry weight of root nodules, were not significantly influenced by biofertilizer treatments (Table 2). All treatments exhibited comparable nodulation efficiency.

The lack of significant variation may be due to the presence of effective and functionally similar strains of beneficial microorganisms in each treatment, leading to uniform symbiotic activity. Additionally, the existing soil microbial population might have contributed to nodulation, thereby minimizing treatment differences.

Seed, Straw and Biological Yield

Biofertilizer treatments did not significantly affect seed yield, straw yield, or biological yield of urdbean (Table 3). The results indicate that all treatments were equally effective in supporting crop productivity.

This may be attributed to the similar mechanisms of action of biofertilizers, such as biological nitrogen fixation and phosphorus solubilization, which ensured a comparable level of nutrient availability across treatments.

Economics

Economic parameters, including gross returns, net returns, and benefit–cost ratio, were not significantly influenced by biofertilizer treatments (Table 4). The similarity in economic performance suggests that all treatments were equally viable under the given conditions.

The comparable cost structure and effectiveness of the biofertilizers likely resulted in uniform economic outcomes, indicating that their selection may depend on availability and cost rather than performance differences.

Protein Content and Protein Yield

Biofertilizer treatments did not exert a significant effect on seed protein content or protein yield (Table 2). The uniformity in protein-related parameters suggests that nutrient supply and microbial activity across treatments were comparable, leading to similar physiological responses.

Nutrient Content

The concentration of nitrogen, phosphorus, and potassium in seed and straw remained unaffected by biofertilizer treatments (Table 5). This indicates that all treatments maintained a similar internal nutrient balance within the plant system.

Nutrient Uptake

Similarly, nutrient uptake of nitrogen, phosphorus, and potassium did not show significant variation among biofertilizer treatments (Table 5). The comparable efficiency of microbial strains in enhancing nutrient availability and uptake may have resulted in uniform nutrient acquisition across treatments.

Conclusion

The findings of the present investigation conclusively demonstrate that nutrient management practices exert a decisive influence on the productivity, nutrient dynamics, and profitability of urdbean. Application of 125% of the recommended dose of fertilizers (25:50:25 kg N:P: K ha^{-1})resulted in a marked improvement in seed yield, nutrient uptake, protein yield, and economic returns, indicating superior resource-use efficiency under enhanced fertility levels.

The incorporation of farmyard manure (FYM @ 5 t ha^{-1})further augmented crop performance by improving soil physical, chemical, and biological properties. The addition of organic matter not only enhanced nutrient availability and uptake but also contributed to sustained soil fertility, thereby supporting higher productivity.

These results underscore the importance of integrating organic sources with inorganic fertilizers for achieving long-term agricultural sustainability.

Biofertilizer treatments exhibited statistically non-significant variation across most parameters, suggesting comparable functional efficiency under the prevailing experimental conditions. Their role in maintaining soil biological activity and supporting nutrient cycling, however, remains important within an integrated nutrient management framework.

The non-significant interaction effects among fertilizer levels, FYM, and biofertilizers indicate that their individual contributions to crop performance were independent rather than synergistic. Nevertheless, the combined application of these inputs provides a balanced approach to nutrient management by integrating immediate nutrient availability with long-term soil health benefits.

In conclusion, the application of 125% RDF in conjunction with FYM emerges as an agronomically sound and economically viable strategy for maximizing urdbean productivity, improving nutrient uptake efficiency, and ensuring sustainable soil management under similar agro-ecological conditions.

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