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Response of integrated nutrient management on growth and yield of black gram (*Vigna mungo* L. (Hepper)

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ABSTRACT
In the Kharif season 2022, a field experiment was conducted at the Students' Instruction Farm, C.S.A.U.A & T, Kanpur, Uttar Pradesh, to assess the impact of integrated nutrient management on the growth and yield of Black gram (*Vigna mungo* L. (Hepper)). The experiment was arranged in a Randomized Block Design and comprised eight treatments, each with three replications. The treatments included a Control (T_1), RDF + Rhizobium (T_2), FYM at 4 tons/ha (T_3), 100% RDF + FYM at 2 tons/ha + Rhizobium (T_4), 50% RDF + FYM at 2 tons/ha + Rhizobium (T_5), Vermicompost at 2 tons/ha + Rhizobium (T_6), 100% RDF + Vermicompost at 1 ton/ha + Rhizobium (T_7), and 50% RDF + Vermicompost at 1 ton/ha + Rhizobium (T_8). The variety used for planting was Shekhar-1, and it was sown on July 26, 2022, at a seed rate of 18 kg/ha, with a spacing of 30 x 10 cm. Various parameters related to growth, yield attributes, and overall yield were recorded. Notably, applying 100% RDF, Vermicompost at 1 ton/ha, and seed inoculation with Rhizobium resulted in the most favorable outcomes across all the parameters mentioned. This treatment led to a significant increase in plant height (49.90 cm), the number of branches (5.30), pod length (5.13 cm), the number of pods per plant (25.80), the number of seeds per pod (6.12), grain yield (1414.66 kg/ha), and biological yield (3511.9 kg/ha). These improvements represented a substantial enhancement of 22.6%, 42.07%, 27.29%, 25.58%, 35.78%, 39.27%, and 39.43%, respectively, compared to the control group.
Keywords: Rhizobium inoculation, Sustainable agriculture, Vermicompost, Integrated Nutrient Management.

INTRODUCTION
In Indian agriculture, pulses hold a significant position, following cereals and oilseeds. Among the various pulses, Black gram (*Vigna mungo* L. (Hepper)), which originated in India, stands out as one of the most valuable and nutritious pulse crops cultivated primarily in tropical countries, with a strong focus on India. In the country, black gram is cultivated across approximately 39.6 lakh hectares of land, resulting in a production of 2.84 million tonnes in the year 2021-22 (source: agricoop.nic.in). India proudly holds the title of being the largest producer and consumer of black gram globally, accounting for a whopping 70% of the worldwide production, with Myanmar being the next significant contributor. Uttar Pradesh plays a substantial role in black gram production, contributing to 6.991 lakh hectares of land dedicated to its cultivation (source: Black Gram Outlook, Agricultural Market Intelligence Centre, PJTSAU 2022).

Black gram is primarily grown during the Kharif and summer seasons throughout India, with an exception in the eastern regions where it can also be cultivated during the Rabi or winter season. This versatile pulse crop has a relatively short growth duration. In the realm of cropping systems, pulses, including black gram, occupy a unique and significant position, serving various roles such as the primary crop, catch crop, cover crop, sequential crop, and even a fodder crop, (Bonepally *et al.*, 2021). As a leguminous crop, black gram not only enriches soil fertility but also contributes to the nitrogen economy of subsequent crops in the rotation.

Black gram is a nutritional powerhouse employed in Ayurvedic medicine, serving as an excellent dietary fiber source, facilitating digestion, and being easily digestible (Mansi *et al.,* 2019), boasting three times the quantity of high-quality protein compared to cereals. This pulse crop is also packed with essential nutrients including carbohydrates, fats, amino acids, vitamins, and minerals. Notably, it contains significant levels of potassium (983 mg/100g), calcium (138 mg/100g), iron (7.57 mg/100g), niacin (1.447 mg/100g), thiamine (0.273 mg/100g), riboflavin (0.254 mg/100g), and more. In South Indian cuisine, black gram finds a prominent place, being used to prepare a wide array of dishes such as dosa, idli, vada, and appe. Beyond these culinary uses, black gram is also transformed into dal, commonly consumed with roti and rice, and is utilized in making papad. Moreover, black gram serves as a valuable source of hay and forage. Its crop residues are a significant nutritional resource for livestock and animals.

Implementing organic nutrient sources represents a highly effective approach for sustaining soil health, bolstering productivity, and reducing reliance on synthetic fertilizers (Smith, 2022). The application of Farm Yard Manure (FYM) plays a crucial role in enhancing soil quality by augmenting organic matter content and furnishing plants with a comprehensive array of essential nutrients necessary for robust development and growth. Moreover, the inclusion of *Vermicompost* and *rhizobium* further amplifies the yield of black gram. Consequently, the primary objective of this research was to investigate the impact of integrated nutrient management on the growth and yield of black gram.

MATERIALS AND METHODOLOGY

Experiment Location:

The study was conducted at the Students' Instruction Farm of Chandra Shekhar Azad University of Agriculture and Technology in Kanpur, Uttar Pradesh, India, to assess the impact of Integrated Nutrient Management on the growth and yield of Black gram (*Vigna mungo* (L.) (Hepper)) during the Kharif season of 2022.

Replication and Treatments:

The study was conducted using a Randomized Block Design (RBD) with three replications, and it encompassed eight distinct treatment conditions. These treatments were as follows: Control, RDF + Rhizobium, FYM @ of 4 tons per hectare, 100% RDF + FYM @ 2 tons per hectare + Rhizobium, 50% RDF + FYM @ 2 tons per hectare + Rhizobium, Vermicompost @ 2 tons per hectare + Rhizobium, 100% RDF + Vermicompost @ 1 ton per hectare + Rhizobium, and 50% RDF + Vermicompost @ 1 ton per hectare + Rhizobium. The experimental setup involved the application of both organic and inorganic fertilizers, in conjunction with Rhizobium, at varying dosages. Importantly, all organic manures were uniformly applied according to their respective treatment protocols before the crop was sown.

Preparation of Plot:

Each plot had dimensions of 5 meters by 4.5 meters

Treatment of seed:

In the seed treatment process, Rhizobium was utilized at a rate of 200 grams per every 10 kilograms of seed. To prepare the Rhizobium treatment solution, 100 grams of jaggery were dissolved in 500 milliliters of water, and this solution was subsequently allowed to cool. Following this, 10 kilograms of seeds were thoroughly mixed with the Rhizobium culture suspension, which amounted to one package (200 grams) of the Rhizobium culture.Before the actual planting, the treated seeds were left to dry for 24 hours, with this drying process taking place in the shade. The specific black gram variety utilized for this experiment, known as Shekhar-1, was sown at a seeding rate of 18 kg ha^{-1} on July 26, 2022. Throughout the growth cycle of the black gram crop, various intercultural operations such as weeding, gap filling, thinning, and spraying were carried out as required to ensure proper crop management.

Data Recorded:

The growth parameters and yield attributing parameters were recorded at 30 and 60 DAS, respectively.

Statistical analysis:

The statistical analysis of the collected data was conducted at a significance level of 5% using the F-test to determine the Critical Difference (C.D) and the Standard Error of the Mean (S.E) for the statistical analysis. Means were compared using OPSTAT software, as outlined in the study by (Sheoran *et al.,* 1998).

RESULTS

Growth Parameters:

Plant Height:

The presented data illustrates the impact of various treatments **(T_1 to T_8)** on plant height at two critical growth stages - 30 days after sowing (30 DAS) and 60 days after sowing (60 DAS). In comparing these treatments to the control group, it becomes evident that there are notable variations in plant height. Specifically, treatment **T_7** involving "100% RDF + Vermicompost @ 1 tonn/ha + Rhizobium" (**Table 1)** at 30 DAS, exhibited the taller plants with a value of 18.13 cm. In comparison, Treatment **T_6** "Vermicompost @ 2 tonn/ha + Rhizobium" (**Table 1)** displayed the shorter plants at 11.10 cm. As the plants continued to develop, reaching 60 DAS, we observed substantial growth across all treatments. Treatment **T_7** maintained its position as the leader with a height of 49.90 cm, closely followed by Treatment **T_4** at 47.17 cm. Conversely, Treatment **T_6,** although still at the lower end, showed improvement, reaching 40.63 cm.

It's important to note that further statistical analysis is required to establish the statistical significance of these differences and provide a more comprehensive understanding of the treatment effects on plant height. These findings hold significant implications for optimizing agricultural practices to enhance plant growth and yield.

These findings suggest that all treatments experienced growth, but certain treatments consistently outperformed others. Treatment **T_7** consistently demonstrated the highest plant height at both 30 DAS and 60 DAS, indicating its potential as an effective choice for maximizing plant growth among all the treatments.

Number of Branches:

The experiment aimed to assess the impact of various treatments on the number of branches in a crop, with observations conducted at two different time points: 30 days after sowing (DAS) and 60 DAS. Eight distinct treatments, labeled T_1 through T_8, were applied to the crop, and the number of branches was measured as an indicator of plant growth and development.

At the initial assessment, which took place at 30 DAS, we observed notable differences among the treatments. Treatment **T_7** exhibits the highest number of branches at 3.20 (**Table 1**). It was followed closely by **T_4**, which had 3.10 branches, and T_8 with 2.77 branches. Conversely, T_1 had the lowest branch count at 1.83, and T_2 and T_6 also displayed relatively fewer branches at 2.37 and 2.20, respectively.

As the experiment progressed to 60 DAS, we witnessed a general increase in the number of branches across all treatments, reflecting the natural growth of the crop. T_7 maintained its lead with an average of 5.30 branches, followed by T_4 with 5.17 branches and T_8 with 5.13 branches. These treatments consistently promoted branch development. Conversely, T_1 remained at the lower end with 3.07 branches, and T_3 had 3.53 branches, indicating relatively slower growth.

In conclusion, treatments T_7, T_4, and T_8 consistently fostered higher branch development in the crop, both at 30 and 60 DAS. These findings provide valuable insights for optimizing crop management practices to enhance overall plant growth and yield.

Fresh wt. of plant (gm):

In our research, we examined the fresh weight of plants at two key growth stages - 30 days after sowing (30 DAS) and 60 days after sowing (60 DAS) - to evaluate the effects of different treatments **(T_1 to T_8).** At 30 DAS, Treatment **T_7** showed the highest fresh weight at 15.09 grams, while Treatment **T_3** displayed the lowest at 8.48 grams. As the plants continued to grow, reaching 60 DAS, we observed substantial weight gain across all treatments. Treatment **T_7** remained the leader, with plants weighing 47.47 grams, closely followed by Treatment **T_4** at 45.63 grams. Even though Treatment **T_3** started as the lowest at 30 DAS, it demonstrated an increase to 41.78 grams at 60 DAS. These results underscore the significance of Treatment **T_7** in promoting robust plant growth and fresh weight at both 30 DAS and 60 DAS.

Dry wt. Of plant (gm)

The dry weight of the plants was also used as an indicator of their overall growth and health. Results revealed that T_4 and T_7 treatments consistently exhibited the most significant effects on plant growth. At 30 DAS, T_7 recorded the highest dry plant weight of 3.80 grams, and this trend continued at 60 DAS with a weight of 20.42 grams followed by T_4. On the other hand, T_1, T_2, and T_3 showed comparatively lower growth rates, with T_1 recording the lowest weight at both time points.

In conclusion, T_4 and T_7 treatments appear to have a positive impact on the growth of the plant, while T_1, T_2, and T_3 treatments resulted in slower growth. These findings provide valuable insights for further research on optimizing plant growth and crop yield.

Table 1. Growth parameters as influenced by Integrated Nutrient Management in black gram.

Tr. No	Treatments combinations	Plant height (cm)		Number Of Branches		Fresh wt. of plant (gm)		Dry wt. Of plant (gm)	
		30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
T_1	**Control**	13	38.63	1.83	3.07	8.26	41.17	1.47	16.39
T_2	**RDF + *Rhizobium***	14.40	45.37	2.37	4.47	9.51	43.04	2.31	17.27
T_3	**FYM @ 4 tonn/ha**	13.67	39.97	2.07	3.53	8.48	41.78	1.89	16.60
T_4	**100 % RDF + FYM @ 2 tonn/ha + *Rhizobium***	16.40	47.17	3.10	5.17	13.13	45.63	3.57	19.30
T_5	**50 % RDF + FYM @ 2 tonn/ha + *Rhizobium***	15.57	45.60	2.63	4.97	10.22	43.81	3.02	17.95
T_6	**Vermicompost @ 2 tonn/ha + *Rhizobium***	11.10	40.63	2.20	4.07	9.07	42.42	2.03	17.02
T_7	**100 % RDF + Vermicompost @ 1 tonn/ha + *Rhizobium***	**18.13**	**49.90**	**3.20**	**5.3**	**15.09**	**47.47**	**3.80**	**20.42**
T_8	**50 % RDF + Vermicompost @ 1 tonn/ha + *Rhizobium***	15.73	45.87	2.77	5.13	12.63	44.39	3.20	18.40
	SE (d)	3.931	1.124	0.125	0.32	0.224	0.197	0.242	0.176
	CD (5%)	1.815	0.519	0.271	0.692	0.484	0.426	0.524	0.381

Yield Attributes:

The research investigated the impact of various treatments (T_1 to T_8) and employed statistical analysis to assess the significant differences among various treatments, with a calculated critical difference (CD) at a 5% significance level. As the observed differences between the mean values of the treatments exceed the CD, it is evident that there is a significant variation among the treatments.

With such an approach results can be obtained from various yield attributes such as;

Length of pod/plant (cm):

The research investigated the impact of various treatments (T_1 to T_8) on the pod length, measured in centimeters, and employed statistical analysis to assess the significance of these differences. The calculated critical difference (CD) at a 5% significance level was 0.334, and since this value is smaller than the observed differences between the mean values of the treatments, it indicates a significant variation in pod length among the treatments.

Among the treatments, $\mathbf{T_7}$ (100% RDF + Vermicompost @1 tonn/ha + Rhizobium) exhibited the highest mean pod length of 5.13 cm, signifying its effectiveness in promoting pod growth followed by $\mathbf{T_4}$ (100% RDF + FYM @2 tonn/ha + Rhizobium) also demonstrated a substantial pod length of 4.97 cm, further highlighting its efficacy**. (Table 2).**

In summary, the study underscores the substantial impact of different treatments on pod length, with T_7 and T_4 emerging as the most promising options for achieving optimal pod length. Therefore, for maximizing pod length in the studied crop, T_7 and T_4 are the recommended treatments.

Number of pods/plant:

With a calculated critical difference (CD) at a 5% significance level of 1.057. As the observed differences between the mean values of the treatments exceed the CD, it is evident that there is a significant variation in the number of pods per plant among the treatments.

Among the treatments, $\mathbf{T_7}$ demonstrated the highest mean number of pods per plant, with an average value of 34.60. This indicates that $\mathbf{T_7}$ is the most effective treatment for promoting pod production. $\mathbf{T_4}$ also showed a substantial number of pods per plant, with a mean value of 33.27. **(Table 2).**

In summary, the research highlights the considerable impact of different treatments on pod production, with $\mathbf{T_7}$ and $\mathbf{T_4}$ emerging as the top choices for achieving optimal pod numbers per plant in the studied crop. Therefore, for maximizing pod production, T_7 and T_4 are the recommended treatments.

Number of seeds/pod:

Our research reveals a significant difference in the number of seeds/pods among the various treatments (T_1 to T_8). The critical difference at the 5% significance level (CD 5%) of 0.545 to assess the data. Notably, treatments T_4 and T_7 displayed the highest average seed counts, with 5.80 and 6.12, respectively **(Table 2).** The differences between these treatments and the rest were larger than the critical difference, indicating statistical significance. This means T_4 and T_7 are the best treatments for maximizing seed production. Simply put, if you want the most seeds, go with treatments T_4 and T_7. These results emphasize the importance of choosing the right treatment for better crop yields, making it easier for farmers to decide which approach to use.

Test weight:

In our study on crop quality, we examined different treatments (T_1 to T_8) and their impact on test weight. A critical difference at a 5% significance level (CD 5%) of 1.057 to assess the results.

Remarkably, treatments T_4 and T_7 emerged with the highest test weight values, registering 33.27 and 34.60, respectively **(Table 2).** Importantly, the differences between these treatments and the rest were more significant than the critical difference, signifying their statistical importance. This indicates that T_4 and T_7 are the top choices for achieving the best test weight results. In simpler terms, if you want better crop quality, go for treatments T_4 and T_7. These findings stress the importance of selecting the right treatment for improved crop quality and provide valuable insights for agricultural practices.

Table 2. Yield attributes as influenced by Integrated Nutrient Management in Black gram.

Tr. No	Treatment combinations	Length of pod/plant (cm)	Number of pods/plant	Number of seeds/pod	Test weight
T_1	Control	3.73	27.97	3.93	27.97
T_2	RDF + *Rhizobium*	4.63	30.70	4.87	30.70
T_3	FYM @ 4 tonn/ha	4.20	28.40	4.40	28.40
T_4	100 % RDF + FYM @ 2 tonn/ha + Rhizobium	4.97	33.27	5.80	33.27
T_5	50 % RDF + FYM @ 2 tonn/ha + *Rhizobium*	4.83	31.13	5.40	31.13
T_6	Vermicompost @ 2 tonn/ha + *Rhizobium*	4.40	29.33	4.63	29.33
T_7	100 % RDF + Vermicompost @ 1 tonn/ha + *Rhizobium*	5.13	34.60	6.12	34.60
T_8	50 % RDF + Vermicompost @ 1 tonn/ha + *Rhizobium*	4.93	32.17	5.60	32.17
	SE (d)	0.154	0.488	0.252	0.488
	CD (5%)	0.334	1.057	0.545	1.057

Yield:

In our research, we conducted a comprehensive study on different treatments to enhance crop production, considering key factors such as grain yield, biological yield, straw yield, and harvest index (HI). The treatments encompassed various combinations of fertilizers, organic matter, and microbial agents**. (Figure 1).**

Among these treatments, **T_7** demonstrated remarkable success. It combined 100 % RDF, vermicompost, and Rhizobium to achieve a grain yield of 1414.66 units, a biological yield of 3511.9 units, and a Harvest index of 40.27 %. **T_4,** involving 100 % RDF, FYM at 2 tons per hectare, and Rhizobium, also showed significant promise, with a grain yield of 1339.27 units and a biological yield of 3353.2 units. **(Table 3).**

While the control (T_1) and FYM treatment (T_3) had respectable results, treatments with RDF, Rhizobium, and organic matter (T_2, T_5, T_6, T_8) generally outperformed them, with HI values ranging from 39.10 % to 40.92 %.

Our findings emphasize the significance of treatment selection for crop improvement. For those seeking higher yields, particularly in grain and biological yield, T_7 and T_4 are the recommended treatments. These results have valuable implications for agricultural practices and crop management strategies, assisting in optimizing crop production for a sustainable and productive future.

Table 3. Yield influenced by Integrated Nutrient Management in black gram

Tr. No.	Treatment combinations	Grain yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)
T_1	Control	859.12	2127	1267.9	40.65
T_2	RDF + *Rhizobium*	964.27	2361.1	1396.8	40.92
T_3	FYM @ 4 tonn/ha	928.56	2400.8	1472.2	38.86
T_4	100 % RDF + FYM @ 2 tonn/ha + Rhizobium	1339.27	3353.2	2013.9	40.15
T_5	50 % RDF + FYM @ 2 tonn/ha + *Rhizobium*	1146.81	2936.5	1789.7	39.10
T_6	Vermicompost @ 2 tonn/ha + *Rhizobium*	908.72	2301.6	1392.9	39.55
T_7	100 % RDF + Vermicompost @ 1 tonn/ha + *Rhizobium*	1414.66	3511.9	2097.2	40.27
T_8	50 % RDF + Vermicompost @ 1 tonn/ha + *Rhizobium*	1295.62	3234.1	1938.5	40.17
	SE (d)	63.964	214.46	174.59	2.153
	CD (5%)	138.52	464.43	378.09	NS

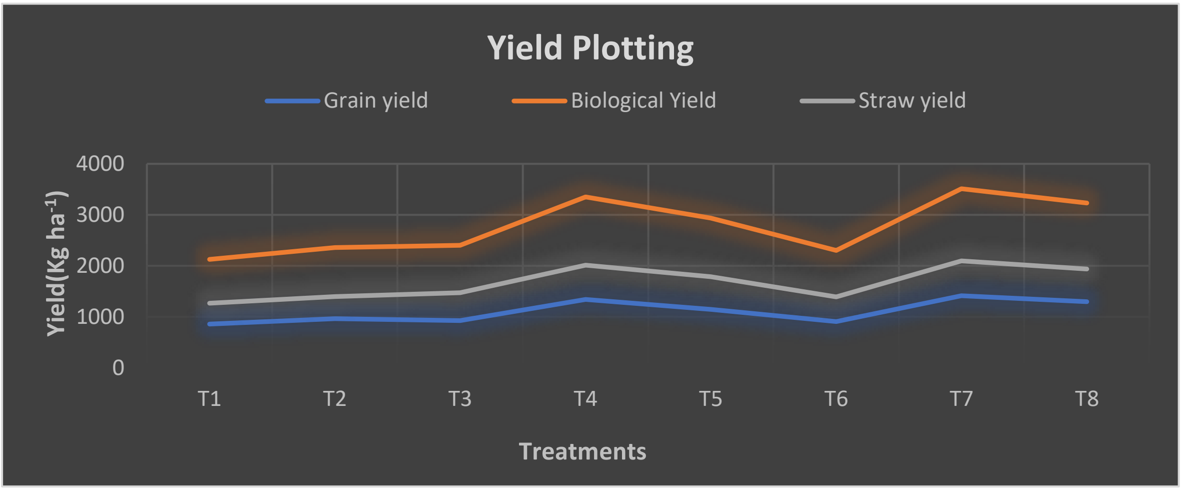

Fig.1. Yield influenced by Integrated nutrient management in black gram

DISCUSSION

The inclusion of Rhizobium in Treatment **T₇** could have had a positive impact on plant growth. Recent studies have shown that inoculation with beneficial microbes, like Rhizobium, can enhance nutrient uptake by plants and subsequently promote growth (Zhang *et al.,* 2021). The need to optimize fertilizer use to ensure that plants receive the right amount of essential nutrients can lead to improved crop growth (Jat *et al.,* 2019).

The positive impact of Treatment **T_7,** on increasing the number of branches in the urad crop highlights the importance of effective nutrient management. These findings also emphasized the role of balanced nutrient application in improving plant growth and branching (Kumar *et al.,* 2020). Treatment **T_4** underscores the importance of organic matter (FYM) and Rhizobium inoculation in promoting branching in urad, these practices can enhance soil health and improve nutrient availability, leading to better branching and crop development (Kumar *et al.,* 2018). Treatment **T_1,** the control group with no additional inputs, exhibited the lowest number of branches. This reaffirms that reliance solely on natural soil fertility may not optimize crop yield and quality (Mishra *et al.,* 2020). Modern agriculture emphasizes the importance of a holistic approach that includes nutrient management, organic matter incorporation, and the use of beneficial microorganisms to optimize crop yield and quality while minimizing environmental impact (Kumar *et al.,* 2021).

At 30 DAS, Treatment **T_7** exhibited the highest fresh weight and maintained its lead in terms of fresh weight at 60 DAS. This observation agrees with the result of (Tandon *et al.,* 2019). Treatment **T_4,** which also included Rhizobium along with 100% RDF and a lower rate of FYM, closely followed **T_7**, demonstrating the effectiveness of this combination in promoting fresh weight, recognizing the role of Rhizobium in enhancing nutrient uptake and overall crop productivity (Kumar *et al.,* 2020). Treatment **T_3** displayed the lowest fresh weight at 30 DAS. This result suggests that while organic matter like FYM is beneficial, excessive application can negatively impact early growth. Recent research supports this notion, emphasizing the need for proper organic matter incorporation to avoid potential nutrient imbalances (Patil *et al.,* 2021).

Treatment **T_7** exhibited the highest dry plant weight at 30 DAS, these results are going with the findings of the positive effects of such integrated approaches on enhancing crop biomass (Natarajan *et al.,* 2019). Treatment **T_4,** which also included Rhizobium, 100% RDF, and farmyard manure (FYM), followed closely. which could contribute to the observed results (Rashid *et al.,* 2021). In contrast, Treatment **T_1** (Control) consistently recorded the lowest dry plant weight at both time points. This reaffirms that relying solely on natural soil fertility may not optimize crop yield and quality (Sankaran and Chidambaram, 2020). These findings align with contemporary practices in sustainable urad crop management, emphasizing the need for integrated nutrient management approaches. Such approaches, combining chemical fertilizers, organic matter, and beneficial microorganisms, can enhance early and sustained growth, leading to increased biomass and higher crop yields (Anitha and Jagadeesh, 2021).

Variations in yield attributes, specifically pod length, number of pods plant^{-1}, number of seeds pod^{-1}, and test weight, exhibited significant differences across the various treatments. Notably, Treatment **T_7,** which incorporated an integrated approach involving Rhizobium, Vermicompost, and recommended doses of fertilizers (RDF) at a ratio of 20:60:20, demonstrated superior results. This treatment displayed the maximum pod length (5.13 cm), the highest number of pods plant^{-1} (25.80), the greatest number of seeds pod^{-1} (6.12), and the heaviest test weight (34.60 g). Conversely, Treatment T1 yielded the least favorable results, with a minimum pod length of 3.73 cm, a reduced number of pods plant^{-1} (19.2), a lower number of seeds pod^{-1} (3.93), and a lighter test weight (27.97 g). These findings align with prior research in the field of urad (Vigna mungo) have supported the positive effects of integrated nutrient management, encompassing the use of Rhizobium, Vermicompost, and a balanced RDF, on enhancing urad crop yield and quality by (Patil *et al*., 2017), (Anasuyamma *et al.,* 2022), (Choudhary *et al.*, 2023), (Tyagi and Singh 2019)

The yield of black gram is significantly affected by the synergistic application of various nutrient sources, including organic, inorganic, and biofertilizers. In our study, Treatment **T_7,** which involved the use of a 100% recommended dose of fertilizers (RDF), Vermicompost at a rate of 1 ton/ha, and the inoculation of Rhizobium, demonstrated remarkable results. This treatment produced the highest grain yield (1414.6 kg ha^{-1}), straw yield (2097.2 kg ha^{-1}), and biological yield (3511.9 kg ha^{-1}). Importantly, statistical analysis indicated that these outcomes were statistically comparable to those of Treatment **T_4.** Following closely in yield performance were Treatments **T_8, T_5,** and **T_2.** In contrast, the control treatment **T_1,** yielded the lowest grain yield (859.12 kg ha^{-1}), straw yield (1267.9 kg ha^{-1}), and biological yield (2127 kg ha^{-1}). These findings are consistent with prior research in the field of black gram cultivation conducted by (Rajasekaran *et al.,* 2017), (Anasuyamma *et al.,* 2022), (Subbarayappa *et al.,* 2009), and (Singh *et al.,* 2017) have consistently affirmed the positive impacts of integrated nutrient management strategies, which involve the incorporation of organic matter, inorganic fertilizers, and biofertilizers, in enhancing black gram yield. These outcomes underscore the significance of employing these integrated practices to maximize both grain and biomass yields in black gram cultivation. Moreover, vermicompost stands out as an excellent remedy for preserving soil health and enhancing crop productivity, particularly when employed alongside chemical fertilizers, these findings are consistent with (Dhyani *et al*. 2011) and (Sunil Kumar and Yadav, 2018).

Based on the research findings in the study, it is clear that the superior treatment, encompassing the use of Rhizobium-treated seeds along with the combined application of Vermicompost and the recommended dose of inorganic fertilizers, consistently outperforms other methods in terms of growth parameters, yield attributes, and overall crop yield. This integrated approach consistently delivers the highest value across all aspects of black gram cultivation. In summary, to maximize black gram productivity and enhance soil health in various regions, it is recommended to utilize Rhizobium-treated seeds in combination with Vermicompost and the recommended dose of inorganic fertilizers at a balanced ratio of 20:60:20 kg N:P: K per hectare. This holistic approach has consistently proven to be effective and is recommended as a best practice for black gram cultivation on an international scale.

CONCLUSION

In conclusion, the study's findings underscore the pivotal role of integrated nutrient management in optimizing black gram cultivation. The treatment **T_7** (100 % RDF + Vermicompost @ 1 tonn/ha + Rhizobium) that combined Rhizobium-treated seeds, Vermicompost, and recommended inorganic fertilizers at a balanced ratio of 20:60:20 kg N:P: K per hectare demonstrated superior results across various growth parameters, yield attributes, and overall crop productivity. These outcomes align with previous research in the field and emphasize the significance of adopting such integrated practices to enhance black gram yield and soil health. This comprehensive strategy has consistently proven effective and is recommended as a best practice for black gram cultivation on a global scale, offering a promising pathway toward increased agricultural productivity and sustainability.

Conflict of Interest: The authors declare no conflict of interest.

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