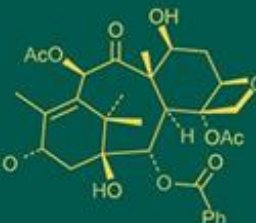
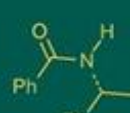
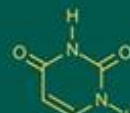
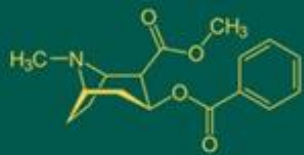


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Mayur Asatkar
M.Sc. Vegetable Science
Scholar, Department of
Horticulture, School of
Agriculture Science,
Technology & Research,
Sardar Patel University,
Balaghat, Madhya Pradesh,
India

Avadhesh Singh Choudhary
HOD, Department of
Horticulture, School of
Agriculture Science,
Technology & Research,
Sardar Patel University,
Balaghat, Madhya Pradesh,
India

Prakash Ghodeswar
Assistant Professor, School of
Agriculture Science,
Technology & Research,
Sardar Patel University,
Balaghat, Madhya Pradesh,
India

Mohd Wamiq
Assistant Professor, School of
Agriculture Science,
Technology & Research,
Sardar Patel University,
Balaghat, Madhya Pradesh,
India

Pallavi Verma
Assistant Professor, School of
Agriculture Science,
Technology & Research,
Sardar Patel University,
Balaghat, Madhya Pradesh,
India

Corresponding Author:
Mohd Wamiq
Assistant Professor, School of
Agriculture Science,
Technology & Research,
Sardar Patel University,
Balaghat, Madhya Pradesh,
India

Impact of integrated nutrient management on growth and yield attributing traits of fenugreek (*Trigonella foenum-graecum* L.)

Mayur Asatkar, Avadhesh Singh Choudhary, Prakash Ghodeswar, Mohd Wamiq and Pallavi Verma

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Abstract

The current investigation, entitled "Impact of Integrated Nutrient Management on Growth and Yield Attributing Traits of Fenugreek (*Trigonella foenum-graecum* L.)," was undertaken during the Rabi season of 2022-23 at the Horticultural Research Farm, Sardar Patel University, Balaghat, Madhya Pradesh. The experiment was set up in a Randomised Block Design (RBD), with eight treatments and three replications. The treatments included various combinations of the prescribed amount of fertiliser (RDF), farmyard manure (FYM), vermicompost, Rhizobium and phosphatesolubilizing bacteria (PSB). The results revealed that integrated nutrient management significantly influenced all growth and yield parameters of fenugreek. Among the treatments, T (75% RDF + Vermicompost @ 6 t ha⁻¹ + Rhizobium + PSB) proved to be the most effective, recording the maximum plant height (17.83, 45.68, and 55.38 cm at 30, 60, and 90 DAS, respectively), highest number of primary branches (5.28, 7.38, and 9.24), maximum secondary branches (11.65 and 17.96), earliest flowering (41.15 days), earliest first pod formation (49.65 days), earliest 50% pod formation (59.75 days), highest number of pods per plant (6.89), maximum number of seeds per pod (24.21), highest seed weight per pod (0.32 g), maximum seed yield per plant (2.20 g) and the highest seed yield (661.44 kg ha⁻¹). Therefore, the integrated application of 75% RDF + Vermicompost @ 6 t ha⁻¹ + Rhizobium + PSB can be recommended as an efficient and environmentally sustainable nutrient management strategy for profitable fenugreek cultivation under the agro-climatic conditions of Balaghat, Madhya Pradesh.

Keywords: Fenugreek, integrated nutrient management, vermicompost, rhizobium, phosphate solubilizing bacteria, seed yield

Introduction

Fenugreek (*Trigonella foenum-graecum* L.) is a major annual leguminous seed spice crop from the Fabaceae family. It is widely grown in India, North Africa, the Mediterranean area, and various Asian nations for its use as both a green vegetable and a seed spice. Fenugreek seeds and leaves are high in proteins, dietary fibre, vitamins, minerals, alkaloids (trigonelline), flavonoids, diosgenin, galactomannan, and other bioactive substances, making them valuable for nutrition, medicine, and therapy. The crop is widely employed in the pharmaceutical, nutraceutical, cosmetic, and food processing sectors because to its antioxidant, antidiabetic, hypocholesterolemic, antibacterial, and anti-inflammatory qualities (Acharya *et al.*, 2021; Kumar *et al.*, 2022) [1, 2].

India is the world's largest producer, user, and exporter of fenugreek, accounting for around 80-90% of worldwide output. Rajasthan has the largest proportion of national output, followed by Gujarat, Madhya Pradesh, Uttar Pradesh, Haryana, and Tamil Nadu. Aside from its commercial value, fenugreek enhances soil fertility through biological nitrogen fixation, making it an essential component of sustainable cropping systems. Its deep root system improves soil structure and boosts the availability of nutrients for subsequent crops (FAOSTAT, 2024) [3].

Nutrient management is critical for optimizing the growth, productivity, quality, and profitability of fenugreek. Although chemical fertilisers provide immediate nutrient availability and quick crop development, their continued and indiscriminate use frequently results in nutritional imbalance, loss of soil physical and biological features, decreased nutrient-use efficiency, and environmental contamination. Long-term reliance on inorganic fertilisers has also resulted in decreased soil organic carbon and microbial activity, reducing agricultural yield and sustainability (Lal, 2020; Meena *et al.*, 2021) [4, 5].

As a result, there is a greater emphasis on using nutrient management systems that combine inorganic fertilisers, organic manures, and beneficial microbes.

Integrated Nutrient Management (INM) is an environmentally friendly and sustainable technique that blends chemical fertilisers, organic manures, and biofertilizers to maximise nutrient availability while preserving soil health and environmental quality. Organic supplies including farmyard manure (FYM) and vermicompost enhance soil structure, water-holding capacity, cation exchange capacity, microbial biomass, and nitrogen buffering capacity. They also offer a steady and consistent release of important macro- and micronutrients throughout the crop's growth cycle (Singh *et al.*, 2021) [6]. The incorporation of organic manures increases soil enzymatic activity and promotes beneficial microbes, boosting nutrient mineralisation and absorption efficiency.

Biofertilizers like *Rhizobium* and phosphate-solubilizing bacteria (PSB) have gained popularity as long-term nutrient sources in legume growth. *Rhizobium* creates symbiotic connections with leguminous roots and converts air nitrogen into plant-available forms, lowering reliance on synthetic nitrogen fertilisers. Phosphate-solubilizing bacteria produce organic acids and phosphatase enzymes, which enhance phosphorus absorption by plants. *Rhizobium* and PSB inoculation has been shown to promote root development, nodulation, nutrient absorption, photosynthetic efficiency, and seed output in legumes (Sharma *et al.*, 2022; Verma *et al.*, 2023) [7, 8, 9].

Farmyard manure is still one of the most often used organic fertiliser sources due to its balanced nutrient content and favourable impacts on soil fertility. Continuous application of FYM boosts organic carbon content, improves soil aggregation, promotes microbial communities, and improves nutrient availability. Similarly, vermicompost, which is created by the biological breakdown of organic leftovers by earthworms, is a nutrient-rich organic amendment that contains easily accessible nitrogen, phosphate, potassium, micronutrients, enzymes, vitamins, and plant growth-promoting compounds. Vermicompost also enhances soil aeration, moisture retention, microbial activity, and root proliferation, resulting in increased crop growth and production (Edwards *et al.*, 2021; Suthar *et al.*, 2023) [10, 11].

Several studies have shown that combining lower levels of recommended fertilisers with organic manures and biofertilizers can result in yields that are equivalent to or even greater than those produced with 100% recommended chemical fertilisers alone. Such integrated techniques increase nutrient efficiency, lower fertiliser costs, reduce nutrient losses, and boost soil biological activity while preserving crop output. Integrated nutrition management in legumes has repeatedly been linked to improved plant height, branching, nodulation, chlorophyll content, dry matter accumulation, pods per plant, seeds per pod, seed production, and quality metrics (Kumar *et al.*, 2023; Meena *et al.*, 2022) [12, 13, 21].

Fenugreek growth and production are heavily impacted by balanced nutrition during the crop growing cycle. Adequate nitrogen supports vegetative growth and chlorophyll synthesis, phosphorus improves root development, nodulation, blooming, and seed production, while potassium controls enzyme activation, photosynthesis, water relations, and stress tolerance. Organic manures supplement inorganic fertilisers by providing secondary and micronutrients and increasing soil health. Chemical fertilisers, FYM, vermicompost, *Rhizobium*, and PSB

work together synergistically to boost nutrient absorption, physiological efficiency, biomass output, and seed yield.

The growing emphasis on sustainable agriculture and climate-resilient agricultural methods has amplified the significance of integrated nutrient management. Sustainable nutrient management strategies boost agricultural yield while simultaneously lowering greenhouse gas emissions, increasing carbon sequestration, conserving soil biodiversity, and reducing reliance on synthetic fertilisers. These techniques are especially crucial for seed spice crops like fenugreek, where quality, nutritional density, and export potential are critical economic factors (FAO, 2022) [14].

Several papers have emphasized the favourable impacts of individual nutrient sources, however evidence on the combined application of decreased amounts of recommended fertilisers with FYM, vermicompost, *Rhizobium*, and PSB under central India's agro-climatic conditions is scarce. As a result, the current study, titled "Impact of Integrated Nutrient Management on Growth and Yield Attributing Traits of Fenugreek (*Trigonella foenum-graecum* L.)," was conducted to assess the impact of various integrated nutrient management practices on fenugreek growth, yield attributing characters, and productivity, as well as to identify the most efficient nutrient combination for sustainable cultivation.

Below is a research paper style "Materials and Methods" section written in paragraph form based on your experiment. The treatment details and observations recorded are also presented in paragraph form instead of tables.

Materials and Methods

Experimental site

The present investigation entitled "Impact of Integrated Nutrient Management on Growth and Yield Attributing Traits of Fenugreek (*Trigonella foenum-graecum* L.)" was conducted during the Rabi season of 2022–2023 at the Horticultural Research Farm, Department of Horticulture, School of Agriculture Science, Technology and Research, Sardar Patel University, Balaghat, Madhya Pradesh, India. During the crop growing period, the prevailing weather conditions remained favorable for normal growth and development of fenugreek.

The experimental field consisted of sandy loam soil with good drainage and moisture-holding capacity. Prior to sowing, composite soil samples were collected from the experimental area at a depth of 0–30 cm and analyzed for their physico-chemical properties. The soil was slightly alkaline in reaction (pH 7.81), contained 0.42% organic carbon, available nitrogen of 148.0 kg ha⁻¹, available phosphorus of 15.15 kg ha⁻¹ and available potassium of 226.30 kg ha⁻¹, indicating low⁻ nitrogen, medium phosphorus and adequate potassium status.

The experiment was laid out in a Randomized Block Design (RBD) consisting of eight nutrient management treatments replicated three times. Thus, a total of twenty-four experimental plots were maintained during the study. Fenugreek variety Co-1 was used as the experimental material. The crop was sown on 7 October 2022 by maintaining a spacing of 25 × 15 cm. Each experimental plot measured 2.0×2.0 m (4.0 m²) and consisted of three rows.

Eight nutrient management treatments were evaluated to study the effect of integrated nutrient management on growth and yield of fenugreek. The treatments comprised T₁: 100% Recommended Dose of Fertilizers (RDF) @ 40:40:30 kg N : P₂O₅ : K₂O ha⁻¹ (Control); T₂: 100% RDF + *Rhizobium* + Phosphate Solubilizing Bacteria (PSB) @ 4 kg ha⁻¹; T₃: 75% RDF + *Rhizobium* + PSB @ 4 kg ha⁻¹; T₄: 50% RDF +

Rhizobium + PSB @ 4 kg ha⁻¹; T₅: 75% RDF + Farmyard Manure (FYM) @ 10 t ha⁻¹ + *Rhizobium* + PSB @ 4 kg ha⁻¹; T₆: 50% RDF + FYM @ 12 t ha⁻¹ + *Rhizobium* + PSB @ 4 kg ha⁻¹; T₇: 75% RDF + Vermicompost @ 6 t ha⁻¹ + *Rhizobium* + PSB @ 4 kg ha⁻¹; and T₈: 50% RDF + Vermicompost @ 8 t ha⁻¹ + *Rhizobium* + PSB @ 4 kg ha⁻¹.

Regular intercultural operations were carried out throughout the crop growth period. Thinning was performed at 30 DAS to maintain the recommended plant population. Hand weeding and hoeing were carried out periodically to keep the experimental plots free from weeds. Irrigation was provided at suitable intervals depending upon soil moisture conditions. Appropriate plant protection measures were adopted whenever required to control insect pests and diseases, including collar rot, aphids, and powdery mildew, following recommended practices. The crop was harvested at physiological maturity when pods turned yellowish and lower leaves started drying. Harvested plants were dried, threshed manually, and seed yield was recorded.

Observations recorded

Five healthy plants were randomly selected from the net plot area of each treatment in every replication for recording observations while avoiding border plants. Growth observations were recorded at 30, 60 and 90 days after sowing (DAS), whereas yield and yield-attributing characters were recorded at harvest.

The growth parameters included plant height (cm) measured from the ground level to the growing tip of the plant, number of primary branches per plant, number of secondary branches per

plant, days to 50% flowering, days to first pod formation, and days to 50% pod formation.

The yield and yield-attributing observations comprised number of pods per plant, number of seeds per pod, seed weight per pod (g), seed yield per plant (g), and seed yield per hectare (kg ha⁻¹). These observations were recorded at crop maturity using standard experimental procedures, and treatment means were computed for statistical analysis.

Statistical analysis

The experimental data recorded on various growth and yield parameters were subjected to statistical analysis following the analysis of variance (ANOVA) appropriate for the Randomized Block Design (RBD) as described by Gomez and Gomez (1984). The significance of treatment differences was tested using the F-test at the 5% probability level. Wherever the treatment effects were found significant, the critical difference (CD) was calculated for comparison of treatment means. The standard error of mean [SE(m) ±] and coefficient of variation (CV%) were also computed to assess the precision and reliability of the experiment.

Results and Discussion

Plant height is one of the most important vegetative growth parameters reflecting the overall vigor and nutrient status of a crop. The data presented in Table 1 revealed that integrated nutrient management practices exerted a significant influence on plant height of fenugreek at 30, 60 and 90 days after sowing (DAS).

Table 1: Impact of Integrated Nutrient Management on Growth and Yield Attributing Traits of Fenugreek (*Trigonella foenum-graecum* L.)

Treatments	Plant Height (cm)			Number of primary branches			Number of secondary branches		Days to 50 % flowering	Days to first pod formation	Days to 50% pod formation	Pods per plant
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	60 DAS	90 DAS				
T ₁	12.40	36.25	44.82	3.12	4.14	5.68	9.17	14.21	50.25	58.12	67.45	5.12
T ₂	13.27	38.87	47.24	3.25	4.38	6.27	9.28	14.85	49.14	57.45	66.24	5.54
T ₃	13.95	38.12	45.16	3.98	4.96	6.95	9.82	15.21	49.85	57.92	68.14	5.86
T ₄	14.24	38.44	47.75	4.04	5.38	7.14	10.14	15.96	48.24	56.45	67.25	6.12
T ₅	15.05	39.24	48.12	4.36	6.12	7.68	10.35	16.85	47.65	55.82	65.25	6.28
T ₆	14.54	41.25	50.19	4.95	6.37	8.41	10.84	16.47	44.85	53.12	63.85	6.57
T ₇	17.83	45.68	55.38	5.28	7.38	9.24	11.65	17.96	41.15	49.65	59.75	6.89
T ₈	15.52	43.19	54.35	4.83	6.92	8.77	10.98	17.14	42.65	52.14	62.25	6.74
S.Em.±	0.26	0.72	0.88	0.07	0.10	0.13	0.18	0.29	0.85	0.99	1.17	0.11
CD at 5 %	0.79	2.17	2.66	0.23	0.31	0.40	0.55	0.91	2.56	3.02	3.55	0.33

At 30 DAS, plant height varied significantly from 12.40 cm to 17.83 cm. The maximum plant height (17.83 cm) was recorded under T₇ (75% RDF + Vermicompost @ 6 t ha⁻¹ + *Rhizobium* + PSB), which was significantly superior to all other treatments. This was followed by T₈ (15.52 cm), T₅ (15.05cm) and T₆ (14.54cm), whereas the minimum plant height (12.40 cm) was observed under the control treatment (T₁: 100 % RDF). The increase in plant height under T₇ over the control was approximately 43.8%, indicating the beneficial effect of integrating organic and biological nutrient sources with reduced chemical fertilizers.

A similar trend was observed at 60 DAS, where plant height ranged from 36.25 cm in T₁ to 45.68 cm in T₇. Treatment T₈ (43.19cm) and T₆ (41.25cm) also produced significantly taller plants than the control. The superiority of T₇ became more pronounced during the active vegetative growth phase, suggesting sustained nutrient availability throughout crop development.

At 90 DAS, plant height further increased in all treatments and varied from 44.82 cm under T₁ to 55.38 cm under T₇. Treatment T₈ recorded the second-highest plant height (54.35 cm), followed by T₆ (50.19cm) and T₅ (48.12 cm). Statistical analysis indicated that differences among treatments were significant, as the observed treatment differences exceeded the critical difference (CD) at the 5% level.

The superior performance of T₇ can be attributed to the synergistic interaction among inorganic fertilizers, vermicompost, *Rhizobium*, and phosphate-solubilizing bacteria (PSB). Vermicompost is recognized as a rich source of readily available macro- and micronutrients, humic substances, amino acids, vitamins, enzymes, and beneficial microorganisms. These components improve soil structure, enhance water-holding capacity, stimulate root proliferation, and promote greater nutrient uptake. The gradual mineralization of nutrients from vermicompost ensures a continuous nutrient supply during

crop growth, thereby supporting sustained vegetative development.

The findings of the present investigation are in close agreement with those reported by [Patel et al. \(2022\)](#)^[15], [Singh and Panghal \(2022\)](#)^[16] reported that vermicompost significantly enhanced plant height and overall crop growth owing to improved nutrient availability and soil biological activity. [Leena et al. \(2023\)](#)^[17], [Sahu et al. \(2020\)](#)^[18], [Kumari et al. \(2022\)](#)^[19, 2] and [Meena et al. \(2024\)](#)^[20], also observed that vermicompost application stimulated vegetative growth in fenugreek by improving nutrient uptake and root development who attributed enhanced vegetative growth to the synergistic effects of organic manures, biofertilizers, and balanced fertilization.

At 30 DAS, the number of primary branches ranged from 3.12 to 5.28 per plant. The highest number of primary branches (5.28) was recorded under T₇ (75% RDF + Vermicompost + *Rhizobium*+PSB), which was significantly superior to all other treatments. The next best treatments were T₆ (4.95), T₈ (4.83), and T₅ (4.36), whereas the lowest number of branches (3.12) was observed in the control treatment (T₁). Compared with the control, T₇ increased the number of primary branches by approximately 69%, indicating the remarkable effectiveness of integrated nutrient management in promoting early vegetative growth.

The same was seen at 60 DAS, when plants attained maximum vegetative development. Treatment T₇ recorded the highest number of primary branches (7.38), followed by T₈ (6.92), T₆ (6.37), and T₅ (6.12). In contrast, the control treatment produced only 4.14 primary branches per plant. The statistical analysis revealed that the differences among treatments were significant at the 5% probability level.

At 90 DAS, primary branching further increased in all treatments, with values ranging from 5.68 under T₁ to 9.24 under T₇. Treatment T₈ recorded 8.77 branches per plant, followed by T₆ (8.41) and T₅ (7.68). The superiority of T₇ throughout the crop growth period clearly demonstrates the beneficial influence of vermicompost combined with biofertilizers and reduced inorganic fertilizer on vegetative growth.

The increased production of primary branches under integrated nutrient management can be attributed to improved nutrient availability and enhanced physiological activity within the plant. Vermicompost supplies readily available nitrogen, phosphorus, potassium, secondary nutrients, and essential micronutrients in a balanced manner while simultaneously improving soil aggregation, aeration, moisture retention, and microbial activity. These favorable soil conditions promote vigorous root growth, allowing plants to absorb nutrients more efficiently throughout the growing season.

The findings of the present study are in close conformity with those reported by [Patel et al. \(2022\)](#)^[15], [Kumari et al. \(2022\)](#)^[19, 2], [Sahu et al. \(2020\)](#)^[18], [Singh and Panghal \(2022\)](#)^[16] and [Leena et al. \(2023\)](#)^[17] who observed a significant increase in the number of branches per plant in fenugreek following the combined application of biocompost and recommended fertilizers.

At 60 DAS, the number of secondary branches ranged from 9.17 under T₁ (100% RDF) to 11.65 under T₇ (75% RDF + Vermicompost + *Rhizobium*+PSB). Treatment T₇ produced significantly more secondary branches than all other treatments, followed by T₈ (10.98), T₆ (10.84), T₅ (10.35), T₄ (10.14), T₃ (9.82), and T₂ (9.28). The lowest value was recorded in the control treatment. Statistical analysis indicated that these differences were significant, confirming the

positive effect of integrated nutrient management on branching behaviour of fenugreek plants.

A similar trend was observed at 90 DAS, where the number of secondary branches increased further in all treatments. The highest number of secondary branches (17.96) was recorded under T₇, followed by T₈ (17.14), T₅ (16.85), T₆ (16.47), T₄ (15.96), T₃ (15.21), T₂ (14.85), while the minimum (14.21) was observed under T₁. Compared with the control, T₇ produced approximately 26% more secondary branches, clearly indicating the superiority of integrating vermicompost and biofertilizers with reduced levels of inorganic fertilizers.

The increased production of secondary branches under integrated nutrient management can be explained by the improved nutritional environment created in the rhizosphere. The combined application of vermicompost, *Rhizobium*, PSB, and inorganic fertilizers ensured a continuous and balanced supply of essential nutrients throughout the crop growth period. Vermicompost not only supplied macro- and micronutrients but also enhanced soil physical properties, increased microbial biomass, and improved moisture retention, creating favourable conditions for root growth and nutrient absorption.

The present findings corroborate those of [Patel et al. \(2022\)](#)^[15], who reported that integrated nutrient management involving organic manures and recommended fertilizers significantly increased branching and dry matter accumulation in fenugreek. [Kumari et al. \(2022\)](#)^[19, 2] also observed maximum numbers of primary and secondary branches following the combined application of vermicompost, *Rhizobium*, *Azospirillum*, and PSB. Similar improvements in vegetative growth due to integrated nutrient management have been reported by [Singh and Panghal \(2022\)](#)^[16] and [Sahu et al. \(2020\)](#)^[18], who attributed increased branching to improved nutrient availability and enhanced microbial activity. Furthermore, [Leena et al. \(2023\)](#)^[17] demonstrated that vermicompost application improved shoot growth and branching through enhanced nutrient uptake and favourable rhizosphere conditions.

Table 2: Impact of Integrated Nutrient Management on Seed Yield of Fenugreek (*Trigonella foenum-graecum* L.)

Treatments	Number of seeds per pod	Weight of seeds per pod (g)	Seed yield per plant (g)	Seed yield per hectare (Kg/ha)
T ₁	14.12	0.14	0.72	215.04
T ₂	15.21	0.12	0.66	199.44
T ₃	17.96	0.19	1.11	334.02
T ₄	18.45	0.21	1.29	385.56
T ₅	19.78	0.25	1.57	471
T ₆	20.45	0.26	1.71	512.46
T ₇	24.21	0.32	2.20	661.44
T ₈	21.58	0.29	1.95	586.38
S.Em.±	0.34	0.01	0.04	7.55
CD at 5 %	1.02	0.02	0.12	22.91

Conclusion

The present investigation demonstrated that integrated nutrient management significantly improved the growth, flowering behaviour, yield-attributing characters, and seed yield of fenugreek compared with the sole application of inorganic fertilizers. Among the different nutrient management practices evaluated, T (75% RDF + Vermicompost @ 6 t ha⁻¹ + *Rhizobium* + PSB) consistently recorded the best performance for all major growth and yield parameters. This treatment produced the tallest plants, maximum primary and secondary branches, earlier flowering and pod formation, highest number of pods and seeds per pod, greater seed weight per pod,

maximum seed yield per plant, and the highest seed yield of 661.44 kg ha⁻¹. The superiority of this⁻ treatment may be attributed to the balanced and continuous supply of nutrients through vermicompost, enhanced biological nitrogen fixation by *Rhizobium*, improved phosphorus availability by phosphate-solubilizing bacteria, and increased microbial activity in the rhizosphere. These factors collectively promoted better root development, efficient nutrient absorption, improved photosynthetic activity, and greater assimilate translocation towards reproductive organs. The treatments involving farmyard manure in combination with reduced RDF and biofertilizers also performed significantly better than the control, confirming the beneficial role of organic nutrient sources in improving crop growth and productivity. Based on the findings of the present study, it can be concluded that the integrated application of 75% RDF + Vermicompost @ 6 t ha⁻¹ + ⁻ *Rhizobium* + PSB is the most suitable nutrient management practice for fenugreek cultivation under the agro-climatic conditions of Balaghat, Madhya Pradesh. This integrated approach not only enhances crop productivity but also reduces dependence on chemical fertilizers, improves soil fertility, and supports environmentally sustainable agriculture. Adoption of this nutrient management strategy can therefore contribute to higher economic returns while maintaining long-term soil health and sustainable fenugreek production.

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