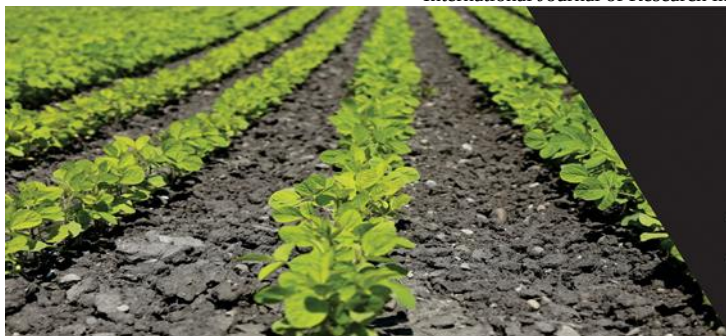




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Influence of organic manures and biofertilizers on growth of holy basil (*Ocimum tenuiflorum* L.)

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Abstract

An experiment entitled “Influence of organic manures and biofertilizers on growth of holy basil (*Ocimum tenuiflorum* L.)” was conducted over two year from 2023-24 to 2024-25 at Nursery No. 4, College of Horticulture, DBSKKV, Dapoli. Sixteen treatment combinations were arranged in factorial randomized block design with three replications. The pooled result of this experiment revealed that the application of vermicompost at 5 t/ha significantly recorded the highest growth parameters viz., plant height (94.61 cm and 60.14 cm), number of branches (26.51 and 19.06), plant spread (112.34 cm and 57.86 cm) at first harvest and second harvest, respectively and leaf area (9.54 cm²), leaf area index (0.1639) at second harvest. The biofertilizer treatment comprising *Azospirillum* at 6 kg/ha showed highest plant height (90.90 cm and 55.78 cm), number of branches (25.07 and 18.06), plant spread (103.03 cm and 54.99 cm) at first harvest and second harvest, respectively and leaf area (8.17 cm²), leaf area index (0.1462) at second harvest. Notably, the interaction effect of treatment combination M3B2 (Vermicompost at 5 t/ha and *Azospirillum* at 6 kg/ha) recorded the highest plant height (101.41 cm and 63.07 cm), number of branches (30.93 and 21.46), plant spread (123.88 cm and 64.85 cm) at first harvest and second harvest, respectively and leaf area (11.54 cm²) and leaf area index (0.1780) at second harvest.

Keywords: Holy basil, FYM, vermicompost, biogas slurry, *azospirillum*, *azotobacter*, PSB and VAM

Introduction

Queen of herb ‘Tulsi’ or ‘Holy basil’ (*Ocimum tenuiflorum* L.) 2n = 32 is biennial or triennial aromatic shrub belonging to the family Lamiaceae. It is renowned for its religious, spiritual sanctity and its important role in the herbal medicine of the east, traditional Ayurvedic and Unani system of holistic health. Tulsi is also mentioned in ‘Charak Samhita; An Ayurvedic text’ written by Charaka. *Ocimum tenuiflorum* Linn has a wide distribution, covering the entire Indian subcontinent, ascending up to 1800 m in the Himalayas and as far as the Andaman Nicobar Islands. In Indian two types of *Ocimum sanctum* are under cultivation; the green type (Sri type Tulsi) is the most common; The second type (Krishna Tulsi) which bears purple leaves and is preferred in the trade for its higher potency of drug. Traditionally, sacred basil has been used as medicinal plant in the treatment of kidney malfunction, coughs, warts, diarrhea, headaches, constipation and worms. (Javanmardi *et al.*, 2002)^[1]. The basil oil possesses some beneficial effects for antioxidant, antiseptic, antifungal, antibacterial and insecticidal properties (Baranauskiene *et al.*, 2003)^[2]. Organically grown holy basil has more demand in pharmaceutical industry as it produces chemical free drugs and it is also used daily in medicines to cure many ailments, hence there is strong need to boost the organic production of holy basil. The nutrients are supplied through chemical fertilizers to sacred basil. The indiscriminate use of chemical fertilizers had leads to an imbalance of nutrients in soil which in turn has adverse effect on soil health, thus affecting the yield and quality. The use of organic manure and biofertilizers is known to improve physicochemical and biological properties of soil, besides improving the efficiency of applied fertilizers. The potential of organic materials to supply nutrients and to support beneficial microbes is being realized recently with advent of biofertilizers viz., *Azotobacter*, *Azospirillum*, PSB and VAM.

Materials and Methods

A field experiment was conducted at Nursery No. 4, College of Horticulture, Dapoli, DBSKKV, Dapoli during 2023-24 and 2024-25. The experiment was laid out in FRBD with 16 treatment combinations and 3 replications, includes treatments comprising four organic manures (M₁:absolute control, M₂: FYM @ 10 t/ha, M₃: vermicompost @ 5 t/ha, M₄ : biogas slurry @ t/ha) and four biofertilizers (B₁:colon PSB @ 6 kg/ha, B₂ : *Azospirillum* @ 6 kg/ha, B₃ : *Azotobacter* @ 6 kg/ha, B₄: VAM @ kg/ha). All the cultural practices related to holy basil was done as per the requirement. The growth observations such as plant height (cm), number of branches and plant spread (cm) were recorded at first harvest (90 DAT) and second harvest (150 DAT) and leaf area (cm²), leaf area index were recorded at second harvest (150 DAT). The data recorded on the plant height, number of branches, plant spread, leaf area and leaf area index was statistically analyzed using SAS data analysis software and “ANOVA” table suggested by Panse and Sukhatme (1965)^[3].

Results and Discussion

The data on the plant height, number of branches, plant spread, leaf area and leaf area index as influenced by different levels of organic manures, biofertilizers and their interactions during 2023-24, 2024-25 and pooled data are presented in Table 1 to 5.

1. Plant height (cm)

1.1. Effect of organic manures on plant height of holy basil (M)

The experimental results consistently demonstrated that treatment M₃ (Vermicompost at 5 t/ha) significantly promoted plant height compared to all other treatments across both years and in the pooled analysis. In the 2023-24 trial, M₃ recorded highest plant height of 93.46 cm and 57.42 cm at first harvest (90 DAT) and second harvest (150 DAT), respectively, whereas M₁ (Absolute control) recorded the lowest plant height of 80.56 cm and 44.27 cm. Similarly, in 2024-25, M₃ maintained superiority with plant height of 95.75 cm and 62.86 cm, significantly outperforming M₁, which yielded 82.96 cm and 46.57 cm at the respective harvest. Reflecting these trends, the pooled data confirmed that M₃ achieved highly significant plant height of 94.61 cm and 60.14 cm, while M₁ remained the least effective treatment, recording mean values of 81.76 and 45.42 cm across the two harvesting stages. (Table 1-2). This growth enhancement is attributed to the fact that vermicompost improves soil physicochemical properties, enzymatic activity

and microbial populations. Notably, microbial activity generates organic acids that inhibit IAA oxidase, preventing auxin degradation and thereby promoting plant development (Leopold, 1974)^[4]. Additionally, vermicompost provides essential macronutrients, readily available micronutrients (Fe, Cu, Zn and Mn) and plant growth regulators, while facilitating phosphorus uptake via mycorrhizal associations (Bano *et al.*, 1987)^[5]. These biological benefits supported by increased beneficial microorganisms and humic acids. These results are in accordance with the findings of Dushyant *et al.* (2014)^[6] in stevia, El-Sayed *et al.* (2015)^[7] in holy basil, Zaman *et al.* (2015)^[8] in stevia and Suresh *et al.* (2018)^[9] in mint. Collectively, these factors underscore the effectiveness of vermicompost in optimizing growth parameters for holy basil.

1.2. Effect of biofertilizers on plant height of holy basil (B)

The experimental results consistently showed that the treatment B₂ (*Azospirillum* at 6 kg/ha) significantly increased the plant height throughout harvesting stages across both years and in the pooled analysis. In the 2023-24 trial, B₂ recorded highest plant height of 90.20 cm and 54.13 cm at 90 and 150 DAT, respectively, while B₁ (PSB at 6 kg/ha) recorded the lowest plant height of 84.76 cm and 50.05 cm. During the 2024-25 season, B₂ maintained its superiority with plant height of 91.60 cm and 57.42 cm, with B₁ remaining the lowest at 87.03 cm and 53.03 cm. The pooled data confirmed this trend, showing B₂ achieved the plant height of 90.90 cm and 55.78 cm, often performing at par with B₃ (*Azotobacter* at 6 kg/ha), while B₁ recorded the lowest plant height of 85.90 cm and 51.54 cm. This superior growth under biofertilizer application is attributed to the multifaceted biological functions of *Azospirillum* and *Azotobacter*. Beyond atmospheric nitrogen fixation, these bacteria synthesize and release vital phytohormones including IAA, gibberellic acid and cytokinins which stimulate the vegetative growth, enhance nutrient absorption and optimizes photosynthetic efficiency. These mechanisms facilitate improved root zone mineral availability, directly supporting increased plant stature (Hammadi *et al.*, 2014)^[10]. These results align with previous findings of Jayasri and Anuja (2010)^[11] in sweet basil, Srivastava (2017)^[12] in kalmegh and Harishkumar *et al.* (2019)^[13] in holy basil; they consistently demonstrated that plants treated with *Azospirillum* exhibited superior growth. This treatment is characterized by maximum plant height, significantly surpassing the performance of other treatments.

1.3. Interaction effect of organic manures and biofertilizers on plant height of holy basil (M X B)

Table 1: Effect of organic manures and biofertilizers on plant height (cm) of holy basil at first harvest (90 DAT)

Treatment	Plant height (cm) at first harvest (90 DAT)													
	2023-24					2024-25					Pooled			
	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄
M ₁	79.65	81.19	81.10	80.30	80.56	82.11	84.28	83.09	82.34	82.96	80.88	82.74	82.10	81.33
M ₂	86.45	91.61	90.80	88.99	89.46	88.78	91.50	90.75	89.85	90.22	87.62	91.56	90.78	89.43
M ₃	88.00	100.32	94.14	91.38	93.46	91.22	102.49	97.17	92.11	95.75	89.62	101.41	95.66	91.75
M ₄	84.93	87.68	87.66	84.93	86.30	86.02	88.15	87.62	86.77	87.14	85.48	87.92	87.65	85.85
Mean	84.76	90.20	88.42	86.40		87.03	91.60	89.66	87.77		85.90	90.90	89.04	87.09
	S.E.m ±		CD at 5%		F- test	S.E.m ±		CD at 5%		F- test	S.E.m ±		CD at 5%	
M	0.615		1.854		SIG	0.764		2.303		SIG	0.510		1.538	
B	0.615		1.854		SIG	0.764		2.303		SIG	0.510		1.538	
M X B	1.230		3.708		SIG	1.528		-		NS	1.020		3.076	

Table 2: Effect of organic manures and biofertilizers on plant height (cm) of holy basil at second harvest (150 DAT)

Treatment	Plant height (cm) at second harvest (150 DAT)														
	2023-24					2024-25					Pooled				
	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄	Mean
M ₁	42.53	46.04	44.85	43.68	44.27	44.53	48.64	47.48	45.63	46.57	43.53	47.34	46.17	44.66	45.42
M ₂	51.85	56.08	55.48	54.10	54.38	55.48	59.27	57.62	55.95	57.08	53.67	57.68	56.55	55.03	55.73
M ₃	54.94	60.48	57.88	56.40	57.42	60.17	65.66	63.01	62.61	62.86	57.56	63.07	60.45	59.51	60.14
M ₄	50.88	53.94	52.48	50.30	51.90	51.93	56.12	54.65	52.54	53.81	51.41	55.03	53.57	51.42	52.86
Mean	50.05	54.13	52.67	51.12		53.03	57.42	55.69	54.18		51.54	55.78	54.18	52.65	
	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%		F- test
M	0.966		2.911		SIG	0.881		2.656		SIG	0.754		2.272		SIG
B	0.966		2.911		SIG	0.881		2.656		SIG	0.754		2.272		SIG
MXB	1.932		-		NS	1.762		-		NS	1.508		-		NS

Treatment Details					
M ₁ :	Control	M ₂ :	FYM (10 t/ha)	M ₃ :	Vermicompost (5 t/ha)
B ₁ :	PSB (6 kg/ha)	B ₂ :	<i>Azospirillum</i> (6 kg/ha)	B ₃ :	<i>Azotobacter</i> (6 kg/ha)
					B ₄ : VAM (6 kg/ha)

The combined application of organic manures and biofertilizers exhibited a significant synergistic effect on the plant height of holy basil, with the M₃B₂ (Vermicompost at 5 t/ha + *Azospirillum* at 6 kg/ha) treatment combination consistently recording the highest values, while the M₁B₁ (Absolute control + PSB at 6 kg/ha) combination yielded the lowest plant height. Based on the pooled analysis, M₃B₂ achieved significant mean plant height of 101.41 cm at 90 DAT, whereas M₁B₁ recorded significantly lower plant height of 80.88 cm, with non-significant interaction effects observed at 150 DAT. This superior growth performance is attributed to the synergistic interaction between vermicompost which optimizes soil physicochemical properties and nutrient availability and *Azospirillum*, which enhances atmospheric nitrogen fixation and synthesizes growth promoting phytohormones like IAA and gibberellic acid. This integrated approach stimulates protein synthesis, accelerates vegetative growth and enhances apical dominance, thereby validating that the combined application of these inputs is an effective strategy for maximizing plant stature in holy basil (Rahman *et al.*, 2014)^[14]. These findings are in line with those of Kumar (2007)^[15] in lemon tulsi and Makkizadeh *et al.* (2012)^[16] in sweet basil through the combined application of vermicompost and *Azospirillum*, thereby validating the current results and highlighting the efficacy of this integrated nutrient management approach.

2. Number of branches

2.1 Effect of organic manures on number of branches of holy basil (M)

The experimental findings revealed that the application of M₃ (Vermicompost at 5 t/ha) significantly promoted the development of branches compared to the M₁ (Absolute control) across both seasons and in the pooled analysis. In the 2023-24 trial, M₃ recorded highest number of branches of 27.04 and 17.76 at 90 and 150 DAT, respectively, while M₁ recorded the lowest number of branches of 19.63 and 12.81. During the 2024-25 trial, M₃ maintained its superiority with branch counts of 25.98 and 20.36, significantly outperforming M₁ & which yielded 20.58 and 15.84. Reflecting these results, the pooled data confirmed that M₃ achieved highly significant number of branches of 26.51 and 19.06 across the harvesting stages, while M₁ remained the least effective, recording mean values of 20.10 and 14.33. This significant increase in number of branches is attributed to the superior efficacy of vermicompost in enhancing soil fertility upon decomposition. The process fosters an accumulation of humic substances and boosts microbial population and activity within the rhizosphere, which improves the bioavailability of essential macro and micronutrients.

Furthermore, the introduction of plant growth regulators specifically IAA, gibberellic acid and cytokinins stimulates higher photosynthetic rates and directly impacts lateral bud development (Kumar, 2007; Prajapati, 2025)^[15, 17]. These combined biological and nutritional benefits facilitate vigorous vegetative growth, as evidenced by the increased number of branches per plant in the vermicompost-treated holy basil. Similar observations were reported by Raina *et al.* (2013)^[18] in holy basil, Sharafi *et al.* (2019)^[19] in thyme and Beleri *et al.* (2024)^[20] in tulsi. The convergence of these findings validates the current study's results, highlighting the beneficial effects of vermicompost on the growth of holy basil, particularly in branch development.

2.2 Effect of biofertilizers on number of branches of holy basil (B)

The experimental data across both seasons and the pooled analysis confirm that the application of B₂ (*Azospirillum* at 6 kg/ha) consistently produced the highest number of branches in holy basil, demonstrating significant superiority over other biofertilizers. In the 2023-24 trial, B₂ recorded highest number of branches (24.80 and 16.78) at 90 and 150 DAT, respectively, while B₁ (PSB at 6 kg/ha) recorded the lowest number of branches (21.19 and 14.41). Similar results were observed in 2024-25, where B₂ recorded number of branches of 25.33 and 19.33, compared to the B₁ resulted in lowest number of branches (21.76 and 17.50). The pooled data validates these findings, with B₂ achieving mean number of branches (25.07 and 18.06) often performing at par with B₃ (*Azotobacter* at 6 kg/ha), while B₁ remained the least effective treatment. The increased branching observed with *Azospirillum* inoculation is attributed to its ability to stimulate cell division and cell elongation within the axillary buds. By enhancing photosynthetic efficiency and promoting the production of endogenous growth promoting substances, *Azospirillum* effectively mitigates apical dominance, allowing for greater lateral bud development. This physiological stimulation creates a "vegetative push", resulting in a higher number of branches per plant. These results highlight the critical role of nitrogen-fixing bacteria in optimizing the architecture and vegetative productivity of holy basil through direct hormonal and nutrient-mediated pathways. Similar results were documented by Jayasri and Anuja (2010)^[11] in sweet basil, Raina *et al.* (2013)^[18] in *Ocimum sanctum* and Harishkumar *et al.* (2019)^[13] in holy basil. The alignment of these literature findings validates the current study's results and underscores the beneficial impact of *Azospirillum* on branching density.

2.3 Interaction effect of organic manures and biofertilizers on number of branches of holy basil (M X B):

The interaction effect between organic manures and biofertilizers demonstrated a significant influence on the number of branches in holy basil, with the M₃B₂ (Vermicompost at 5 t/ha + *Azospirillum* at 6 kg/ha) treatment combination consistently producing the highest number of branches, while M₁B₁ (Absolute control + PSB at 6 kg/ha) recorded the lowest. In the 2023-24 trial, M₃B₂ achieved peak number of branches (32.38 and 20.93) at 90 and 150 DAT, respectively, significantly outperforming M₁B₁, which yielded 18.78 and 11.53 at 90 and 150 DAT, respectively. The 2024-25 results demonstrated a broader significance, with M₃B₂ recorded

highest number of branches (29.48 and 22.00) at 90 and 150 DAT, compared to the M₁B₁ recorded the lowest of 19.95 and 14.63. The pooled data confirmed these findings, showing that M₃B₂ consistently resulted superior mean values of 30.93 and 21.46 branches at 90 and 150 DAT, significantly surpassing M₁B₁, which recorded 19.37 and 13.08 branches at the respective harvesting. This enhancement is attributed to the synergistic interaction between the nutrient rich vermicompost and the nitrogen fixing capacity of *Azospirillum*. By optimizing nitrogen availability and promoting hormonal balance, this combination elevates the protein synthesis and accelerates vegetative growth, which effectively

Table 3: Effect of organic manures and biofertilizers on number of branches of holy basil at first harvest (90 DAT)

Number of branches at first harvest (90 DAT)															
Treatment	2023-24					2024-25					Pooled				
	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄	Mean
M ₁	18.78	20.65	19.95	19.13	19.63	19.95	21.35	20.93	20.08	20.58	19.37	21.00	20.44	19.60	20.10
M ₂	22.25	23.68	23.55	23.25	23.18	22.33	25.98	25.25	24.95	24.63	22.29	24.83	24.40	24.10	23.90
M ₃	22.48	32.38	28.90	24.40	27.04	22.75	29.48	26.65	25.03	25.98	22.62	30.93	27.78	24.72	26.51
M ₄	21.25	22.50	22.70	21.65	22.03	22.03	24.53	23.90	21.85	23.08	21.64	23.52	23.30	21.75	22.55
Mean	21.19	24.80	23.78	22.11		21.76	25.33	24.18	22.98		21.48	25.07	23.98	22.54	
	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%		F- test
M	0.512		1.543		SIG	0.323		0.974		SIG	0.367		1.106		SIG
B	0.512		1.543		SIG	0.323		0.974		SIG	0.367		1.106		SIG
M X B	1.024		3.086		SIG	0.646		1.948		SIG	0.734		2.212		SIG

Table 4: Effect of organic manures and biofertilizers on number of branches of holy basil at second harvest (150 DAT)

Number of branches at second harvest (150 DAT)														
Treatment	2023-24					2024-25					Pooled			
	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄
M ₁	11.53	13.58	13.33	12.83	12.81	14.63	16.78	16.03	15.95	15.84	13.08	15.18	14.68	14.39
M ₂	15.30	16.35	15.98	15.83	15.86	18.48	19.83	19.55	19.05	19.23	16.89	18.09	17.76	17.44
M ₃	16.13	20.93	17.08	16.93	17.76	18.85	22.00	20.80	19.80	20.36	17.49	21.46	18.94	18.36
M ₄	14.68	16.28	15.93	14.83	15.43	18.05	18.73	18.53	17.35	18.16	16.36	17.50	17.23	16.09
Mean	14.41	16.78	15.58	15.10		17.50	19.33	18.73	18.04		15.95	18.06	17.15	16.57
	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%	
M	0.263		0.794		SIG	0.156		0.469		SIG	0.195		0.587	
B	0.263		0.794		SIG	0.156		0.469		SIG	0.195		0.587	
MXB	0.527		1.587		SIG	0.311		0.939		SIG	0.390		1.174	

Treatment Details						
M ₁ :	Control	M ₂ :	FYM (10 t/ha)	M ₃ :	Vermicompost (5 t/ha)	M ₄ : Biogas slurry (5 t/ha)
B ₁ :	PSB (6 kg/ha)	B ₂ :	<i>Azospirillum</i> (6 kg/ha)	B ₃ :	<i>Azotobacter</i> (6 kg/ha)	B ₄ : VAM (6 kg/ha)

stimulates lateral bud development and branching ([Rahman et al., 2014](#))^[14]. The ability of the M₃B₂ combination to consistently outperform individual treatments highlights the efficacy of integrated nutrient management in maximizing the vegetative architecture of holy basil. Consistent with previous research, these findings align with those of Kumar (2007)^[15] in lemon tulsi and Makkizadeh *et al.* (2012)^[16] in sweet basil with the combined application of vermicompost and *Azospirillum*, thereby validating the current results.

3. Plant spread

3.1. Effect of organic manures on plant spread of holy basil (M):

The experimental results demonstrated that the application of M₃ (Vermicompost at 5 t/ha) significantly promotes the plant spread throughout harvesting stages compared to the M₁ (absolute control) across both seasons and in the pooled analysis. In the 2023-24 trial, M₃ recorded highest plant spread of 115.62 cm and 55.78 cm at 90 and 150 DAT, respectively,

whereas M₁ yielded lowest plant spread of 73.44 cm and 43.72 cm. During the 2024-25 season, M₃ maintained superiority with plant spread of 115.94 cm and 59.65 cm, significantly outperforming M₁ (76.58 cm and 44.08 cm). The pooled data confirmed these trends, with M₃ achieving highly significant mean plant spread of 112.34 cm and 57.86 cm, while M₁ remained the least effective, recording mean values of 75.57 cm and 43.90 cm. The increase in plant spread is attributed to the application of vermicompost, which significantly enhances nitrogen availability in the soil. As a fundamental component of proteins, nitrogen is vital for protoplasm synthesis, cell division and cell enlargement. This growth response is fundamentally linked to the critical role of nitrogen in amino acid metabolism; these amino acids are subsequently integrated into proteins and nucleic acids, thereby boosting photosynthetic efficiency and ultimately resulting in greater horizontal growth or plant spread ([Prajapati, 2025](#))^[17]. These findings highlight the efficacy of vermicompost in optimizing vegetative canopy development in holy basil. These results align with the findings of Kumar

(2007)^[15] in lemon tulsi and Prabu and Arumugam (2013)^[21] in Japanese mint. The convergent evidence from these studies strongly validates the beneficial effects of vermicompost on plant spread.

3.2 Effect of biofertilizers on plant spread of holy basil (B):

The experimental results consistently demonstrated that the treatment B₂ (*Azospirillum* at 6 kg/ha) effectively maximizes the plant spread, significantly outperforming B₁ (PSB at 6 kg/ha), which recorded the lowest values across both seasons and the pooled analysis. In the 2023-24 trial, B₂ achieved highest plant spread of 100.58 cm and 52.61 cm, performing at par with B₃ (*Azotobacter* at 6 kg/ha) at first harvest. Similar

results were seen in 2024-25, where B₂ maintained superiority with plant spread of 102.95 cm and 57.38 cm. The pooled data validates these findings, showing that B₂ reached highly significant mean plant spread of 103.03 cm and 54.99 cm, while B₁ remained the least effective with values of 90.29 cm and 48.08 cm. The application of *Azospirillum* at 6 kg/ha significantly increased the plant spread of holy basil owing to its multifaceted role as a plant growth promoting rhizobacterium. The bacterium colonizes the rhizosphere and root surfaces, improving plant growth primarily through biological nitrogen fixation, phytohormone production, enhanced

Table 5: Effect of organic manures and biofertilizers on plant spread (cm) of holy basil at first harvest (90 DAT)

Treatment	Plant spread (cm) at first harvest (90 DAT)														
	2023-24					2024-25					Pooled				
	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄	Mean
M ₁	70.16	76.93	74.01	72.67	73.44	74.59	77.40	77.71	76.62	76.58	74.63	76.67	75.86	75.15	75.57
M ₂	95.11	104.05	100.89	98.65	99.68	97.60	110.68	110.60	103.58	105.61	96.61	111.81	109.07	101.12	104.65
M ₃	95.93	126.00	121.50	119.05	115.62	106.32	125.05	119.23	113.15	115.94	97.13	123.88	123.77	104.60	112.34
M ₄	82.61	95.32	92.59	89.22	89.94	94.52	98.69	97.89	94.71	96.45	92.82	99.76	98.49	88.97	95.01
Mean	85.95	100.58	97.25	94.90		93.26	102.95	101.36	97.02		90.29	103.03	101.80	92.46	
	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%		F- test
M	1.560		4.702		SIG	1.046		3.153		SIG	0.571		1.721		SIG
B	1.560		4.702		SIG	1.046		3.153		SIG	0.571		1.721		SIG
M X B	3.120		9.404		SIG	2.092		6.307		SIG	1.142		3.441		SIG

Table 6: Effect of organic manures and biofertilizers on plant spread (cm) of holy basil at second harvest (150 DAT)

Treatment	Plant spread (cm) at second harvest (150 DAT)														
	2023-24					2024-25					Pooled				
	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄	Mean
M ₁	41.10	45.45	43.06	45.27	43.72	40.52	47.89	44.05	43.88	44.08	40.81	46.67	43.55	44.58	43.90
M ₂	48.84	52.76	51.41	49.85	50.72	51.75	58.95	57.89	55.67	56.07	50.29	55.86	54.65	52.76	53.39
M ₃	50.90	62.21	57.15	52.85	55.78	53.51	67.48	61.46	57.34	59.95	52.21	64.85	59.31	55.10	57.86
M ₄	46.90	50.01	49.76	47.81	48.62	51.09	55.18	54.65	50.34	52.82	49.00	52.59	52.21	49.08	50.72
Mean	46.93	52.61	50.35	48.95		49.22	57.38	54.51	51.81		48.08	54.99	52.43	50.38	
	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%		F- test
M	0.620		1.867		SIG	0.595		1.794		SIG	0.452		1.363		SIG
B	0.620		1.867		SIG	0.595		1.794		SIG	0.452		1.363		SIG
MXB	1.239		3.735		SIG	1.190		3.587		SIG	0.904		2.726		SIG

Treatment Details					
M ₁ :	Control	M ₂ :	FYM (10 t/ha)	M ₃ :	Vermicompost (5 t/ha)
B ₁ :	PSB (6 kg/ha)	B ₂ :	<i>Azospirillum</i> (6 kg/ha)	B ₃ :	<i>Azotobacter</i> (6 kg/ha)
					B ₄ : VAM (6 kg/ha)

Nutrient uptake and the stimulation of lateral root development. Specifically, *Azospirillum* converts atmospheric nitrogen (N₂) into plant available forms through the activity of the nitrogenase enzyme complex, thereby increasing nitrogen availability within the root zone. This enhanced nitrogen supply accelerates chlorophyll synthesis, amino acid formation and protein metabolism, which ultimately promotes vigorous vegetative growth, increased branching and a wider canopy spread in the holy basil plants (Dobereiner and Day, 1976)^[22]. Correspondingly, the outcome of this study aligns closely with the findings of Manjunatha *et al.* (2002)^[23] in patchouli.

3.3 Interaction effect of organic manures and biofertilizers on plant spread of holy basil (M X B)

The interaction effect between organic manures and biofertilizers demonstrated a significant influence on the plant spread of holy basil, with the M₃B₂ (Vermicompost at 5 t/ha + *Azospirillum* at 6 kg/ha) combination consistently producing the

highest plant spread, while M₁B₁ (Absolute control + PSB at 6 kg/ha) resulted the lowest. In the 2023-24 trial, M₃B₂ achieved highest plant spread of 126.00 cm (90 DAT) and 62.21 cm (150 DAT), significantly outperforming M₁B₁. Similar results were observed in the 2024-25 season, where M₃B₂ reached the highest plant spread of 125.05 cm and 67.48 cm, consistently surpassing other treatments. The pooled analysis confirmed this trend, with M₃B₂ attaining highly significant mean plant spread of 123.88 cm (90 DAT) and 64.85 cm (150 DAT). Conversely, the M₁B₁ combination consistently recorded the lowest values across these intervals. Notably, while the interaction effect was significant at 90 and 150 DAT. The combined application of vermicompost at 5 t/ha and *Azospirillum* at 6 kg/ha in treatment M₃B₂ significantly increased the plant spread in holy basil, surpassing treatment M₁B₁ (Absolute control + PSB at 6 kg/ha). Vermicompost provides a readily available pool of macro and micronutrients facilitated by its low C:N ratio, which accelerates the mineralization process. It also contains

endogenous plant growth regulators such as auxins and cytokinins synthesized during earthworm digestion, which directly trigger cell division and lateral branching. Furthermore, the high microbial activity and improved soil porosity associated with this treatment enhance root respiration and moisture retention, ensuring the necessary structural and metabolic support to maximize the plant's canopy dimensions. The results of the current study align with the findings of Sudhakar (2005)^[24] in coleus and Kumar (2007)^[15] in lemon tulsi. This convergence of evidence validates the current results, underscoring the positive impact of the integrated application of vermicompost and *Azospirillum* on the plant spread of holy basil.

4. Leaf area (cm²)

4.1 Effect of organic manures on leaf area of holy basil (M)

At second harvest (150 DAT), the results from the both experimental trial (2023-24 and 2024- 25) and in pooled analysis for leaf area showed that the treatment M₃ (Vermicompost at 5 t/ha) recorded the largest leaf area with values of 8.96 cm², 10.12cm² and 9.54cm² during 2023-24, 2024-25 and in pooled analysis, respectively, significantly surpassing all other treatments. Meanwhile, the treatment M₁ (Absolute control) recorded the smallest leaf area with values of 4.36 cm², 5.17cm² and 4.76cm² during the same period. (Table 4). This increase in leaf area is attributed to the beneficial impact of vermicompost on soil physical properties, specifically by reducing bulk density and compaction, which expands the surface area for nutrient adsorption and enhances long-term bioavailability. Furthermore, vermicompost is rich in humic acids and endogenous growth promoting substances such as NAA, cytokinins and gibberellins which directly stimulate cell division and leaf expansion (Prajapati, 2025)^[17]. These combined soil-improving and physiologically stimulating effects facilitate superior foliar development in holy basil. Similar results were reported by Kumar (2004)^[25] in krishna tulsi, Befrozfar *et al.* (2013)^[26] in french basil, Prabu and Arumugam (2013)^[21] in Japanese mint and Beleri *et al.* (2024)^[20] in *Ocimum sanctum* L. These convergent findings reinforce the beneficial effects of vermicompost on the vegetative development of holy basil, particularly in maximizing total leaf area.

4.2 Effect of biofertilizers on leaf area of holy basil (B)

The data from the both experimental season (2023-24 and 2024-25) and pooled analysis indicated that the leaf area showed significant differences within treatments. The highest leaf area was observed in B₂ (*Azospirillum* at 6 kg/ha) (7.29 cm², 9.06 cm² and 8.17cm²) and it was at par with treatment B₃ (*Azotobacter* at 6 kg/ha) with 8.22cm² and 7.62cm² leaf area during second season and in pooled analysis. However, the lowest was noticed in B₁ (PSB at 6 kg/ha) (5.55cm², 6.71cm² and 6.13cm²) during 2023-24, 2024-25 and pooled analysis, respectively. (Table 4). The increased leaf area observed in the present study may be attributed to the presence of endogenous plant growth promoters, such as auxins and cytokinins, within earthworm exudates and their associated microbial communities. Concurrently, *Azospirillum* efficiently colonizes the rhizosphere and root surfaces, where it fixes atmospheric nitrogen (N₂). This biological nitrogen fixation improves the vegetative growth of the host plant, directly expanding the total leaf area by increasing both the length and breadth of the leaves. Similar findings were reported by Manjunatha *et al.* (2002)^[23] and Harishkumar *et al.* (2019)^[13] in tulsi.

4.3 Interaction effect of organic manures and biofertilizers on leaf area of holy basil (M X B)

The statistical analysis indicated that the interaction effect of organic manures and biofertilizers exhibited non-significant results for leaf area, in the year 2023-24 and in the pooled analysis at 150 DAT except during 2024-25. The maximum leaf area (10.17cm² and 11.54cm²) was found in treatment M₃B₂ (Vermicompost at 5 t/ha and *Azospirillum* at 6 kg/ha) and the minimum leaf area (3.40cm² and 3.71 cm²) was recorded in M₁B₁ (Absolute control and PSB at 6 kg/ha) (Table 4). The data from second experimental trial indicated that treatment M₃B₂ (Vermicompost at 5 t/ha and *Azospirillum* at 6 kg/ha) recorded the significantly larger leaf area at 150 DAT (12.90cm²). However, the smaller leaf area (4.03cm²) was recorded in M₁B₁ (Absolute control and PSB at 6 kg/ha). The non-significant interaction effect of organic manures and biofertilizers on leaf area at the second harvest stage (150 DAT) across first experimental year 2023-24 and the pooled analysis indicates that these inputs functioned independently rather than synergistically during this late growth phase. This lack of significance can be primarily attributed to crop phenology and shifted source-sink dynamics.

Table 7: Effect of organic manures and biofertilizers on leaf area (cm²) of holy basil at second harvest (150 DAT)

Treatment	Leaf area (cm ²) at second harvest (150 DAT)														
	2023-24					2024-25					Pooled				
	B1	B2	B3	B4	Mean	B1	B2	B3	B4	Mean	B1	B2	B3	B4	Mean
M1	3.40	5.16	4.83	4.05	4.36	4.03	6.00	5.60	5.05	5.17	3.71	5.58	5.21	4.55	4.76
M2	5.81	7.35	7.29	6.70	6.79	7.78	8.68	8.49	8.99	8.48	6.79	8.01	7.89	7.85	7.63
M3	7.63	10.17	9.91	8.13	8.96	7.96	12.90	10.96	8.67	10.12	7.79	11.54	10.44	8.40	9.54
M4	5.35	6.46	6.09	5.78	5.92	7.08	8.68	7.83	6.22	7.45	6.22	7.57	6.96	6.00	6.69
Mean	5.55	7.29	7.03	6.16		6.71	9.06	8.22	7.23		6.13	8.17	7.62	6.70	
	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%		F- test
M	0.281		0.847		SIG	0.297		0.896		SIG	0.219		0.659		SIG
B	0.281		0.847		SIG	0.297		0.896		SIG	0.219		0.659		SIG
M X B	0.562		-		NS	0.595		1.793		SIG	0.437		-		NS

Table 8: Effect of organic manures and biofertilizers on leaf area index of holy basil at second harvest (150 DAT)

Leaf area index at second harvest (150 DAT)														
Treatment	2023-24					2024-25					Pooled			
	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄	Mean	B ₁	B ₂	B ₃	B ₄
M ₁	0.0831	0.1141	0.1130	0.0895	0.0999	0.0997	0.1250	0.1274	0.1159	0.1170	0.0914	0.1197	0.1204	0.1025
M ₂	0.1188	0.1388	0.1416	0.1352	0.1336	0.1502	0.1468	0.1465	0.1616	0.1512	0.1351	0.1435	0.1444	0.1488
M ₃	0.1497	0.1635	0.1734	0.1537	0.1600	0.1487	0.1910	0.1778	0.1511	0.1671	0.1493	0.1780	0.1760	0.1526
M ₄	0.1134	0.1289	0.1212	0.1210	0.1211	0.1388	0.1574	0.1435	0.1238	0.1409	0.1268	0.1438	0.1331	0.1224
Mean	0.1162	0.1363	0.1373	0.1248		0.1343	0.1550	0.1488	0.1381		0.1256	0.1462	0.1434	0.1316
	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%		F- test	S.Em ±		CD at 5%	
M	0.0062		0.0188		SIG	0.0057		0.0171		SIG	0.0049		0.0147	
B	0.0062		-		NS	0.0057		-		NS	0.0049		-	
M X B	0.0125		-		NS	0.0114		-		NS	0.0098		-	

Treatment Details					
M ₁ :	Control	M ₂ :	FYM (10 t/ha)	M ₃ :	Vermicompost (5 t/ha)
B ₁ :	PSB (6 kg/ha)	B ₂ :	<i>Azospirillum</i> (6 kg/ha)	B ₃ :	<i>Azotobacter</i> (6 kg/ha)
					M ₄ : Biogas slurry (5 t/ha)
					B ₄ : VAM (6 kg/ha)

5 Leaf area index

5.1 Effect of organic manures on leaf area index of holy basil (M)

The results from the both experimental trial (2023-24 and 2024-25) and in pooled analysis regarding leaf area index showed that the treatment M₃ (Vermicompost at 5 t/ha) achieved the highest leaf area index at 150 DAT (0.1600, 0.1671 and 0.1639) and it was found significantly superior to other treatments, while M₁ (Absolute control) exhibited the lowest leaf area index (0.0999, 0.1170 and 0.1085) during 2023-24, 2024-25 and in pooled analysis, respectively. (Table 5). The leaf area index was significantly influenced by the application of different organic manures. The maximum leaf area index at 150 DAT was recorded with the application of vermicompost at 5 t/ha. This elevated leaf area index in holy basil under the vermicompost treatment might be attributed to the increased supply of organic carbon and nitrogen provided by the organic input. Furthermore, these structural and chemical improvements in the soil physicochemical properties at a micro-level contribute to enhanced vegetative growth (Beleri, 2021)^[27]. These results are in conformity with the findings of Beleri *et al.* (2024)^[20], which strengthen the validity of the current data and underscore the beneficial effects of vermicompost on maximizing the leaf area index.

5.2 Effect of biofertilizers on leaf area index of holy basil (B)

The data from the both experimental season (2023-24 and 2024-25) and pooled analysis indicated that the leaf area index at 150 DAT showed non-significant differences within treatments. Leaf area index varied from 0.1162 to 0.1373 during 2023-24, 0.1343 to 0.1550 during 2024-25 and 0.1256 to 0.1462 during pooled analysis. The maximum leaf area index was observed in B₃ (*Azotobacter* at 6 kg/ha) (0.1373) during 2023-24 and B₂ (*Azospirillum* at 6 kg/ha) (0.1550 and 0.1462) during 2024-25 and pooled analysis, respectively. While the minimum leaf area index was noticed in B₁ (PSB at 6 kg/ha) (0.1162, 0.1343 and 0.1256) during 2023-24 and 2024-25, respectively. (Table 5). The leaf area index was significantly influenced by the application of different organic manures. The maximum leaf area index at 150 DAT was recorded with the application of vermicompost at 5 t/ha. This elevated leaf area index in holy basil under the vermicompost treatment might be attributed to the increased supply of organic carbon and nitrogen provided by the organic input. Furthermore, these structural and chemical improvements in the soil physicochemical properties at a micro-level contribute to enhanced vegetative growth (Beleri,

2021)^[27]. These results are in conformity with the findings of Beleri *et al.* (2024)^[20], which strengthen the validity of the current data and underscore the beneficial effects of vermicompost on maximizing the leaf area index.

5.3 Interaction effect of organic manures and biofertilizers on leaf area index of holy basil (M X B)

At 150 DAT, the interaction effect of organic manures and biofertilizers on the leaf area index was non-significant during 2023-24, 2024-25 and in the pooled analysis, with values ranging from 0.0831 to 0.1635, 0.0997 to 0.1910 and 0.0914 to 0.1780, respectively. The maximum values for LAI (0.1635, 0.1910 and 0.1780) were observed under treatment M₃B₂ (Vermicompost at 5 t/ha + *Azospirillum* at 6 kg/ha), while the minimum LAI (0.0831, 0.0997 and 0.0914) was noticed under treatment M₁B₁ (Absolute control + PSB at 6 kg/ha) during 2023-24, 2024-25 and in the pooled analysis, respectively. (Table 5). The non-significant interaction effect of organic manures and biofertilizers was observed with respect to leaf area index at 150 DAT across both experimental years (2023-24 and 2024-25) and the pooled analysis indicates that these inputs functioned independently rather than synergistically during this late growth stage. This lack of significance can be primarily attributed to crop phenology and shifted source-sink dynamics.

Conclusion

Based on the two-year experimental results, it could be concluded that the application of vermicompost at 5 t/ha significantly enhanced the growth of holy basil. With respect to biofertilizers, treatment B₂ (*Azospirillum* at 6 kg/ha) enhanced the growth of holy basil. The combined effect of vermicompost at 5 t/ha + *Azospirillum* at 6 kg/ha (M₃B₂) significantly enhanced the growth of holy basil, outperforming other treatment combinations.

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