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Enhancing Morpho-Physiological Traits and Quality of Soybean (*Glycine max* L.) through Organic Manures and Biofertilizers in Gird Region of Madhya Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

A field experiment was conducted during the kharif season of 2025 at the Crop Research Centre, ITM University, Gwalior, Madhya Pradesh, India, to evaluate the effect of organic manures and biofertilizer seed inoculation on the morpho-physiological traits, yield and quality of soybean (*Glycine max* L.) variety JS-335.

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The experiment was laid out in a factorial randomized block design with three replications. The treatments comprised three organic manure sources, namely farmyard manure at 5 t ha^{-1}, vermicompost at 2 t ha^{-1} and poultry manure at 1.5 t ha^{-1}, and three biofertilizer treatments, namely *Rhizobium* at 30 ml kg^{-1} seed, phosphate-solubilising bacteria at 30 ml kg^{-1} seed and potassium-solubilising bacteria at 30 ml kg^{-1} seed, along with an absolute control. Observations were recorded on plant height, branches per plant, trifoliate leaves per plant, leaf area index, dry matter accumulation, crop growth rate, relative growth rate, grain yield, straw yield, harvest index, protein content and oil content. Among the organic manures, vermicompost at 2 t ha^{-1} produced the highest plant height, branching, leaf area index and dry matter accumulation, and recorded grain yield of 1732.5 kg ha^{-1}, straw yield of 2857.0 kg ha^{-1}, protein content of 41.59% and oil content of 21.12%. Among the biofertilizers, *Rhizobium* seed treatment recorded the highest grain yield (1694.0 kg ha^{-1}), straw yield (2790.2 kg ha^{-1}), protein content (41.26%) and oil content (20.67%). The interaction between organic manures and biofertilizers was statistically non-significant. The results indicate that vermicompost application and *Rhizobium* seed inoculation improved soybean performance under the experimental conditions.

Keywords: Soybean; Glycine max; organic manure; vermicompost; farmyard manure; poultry manure; Rhizobium; biofertilizer; growth indices; grain yield; protein content; oil content.

1. Introduction

Soybean is an important leguminous crop cultivated during the kharif season in India for its high protein and oil content. It is used for edible oil, food products and livestock feed, and it is an essential raw material for processing industries and trade. It enhances soil fertility by fixing atmospheric nitrogen, thereby reducing the need for external nitrogen fertilizers in subsequent crops. The productivity and quality of soybean are influenced by the use of organic and biological sources. Worldwide, soybean is cultivated on 1,394 lakh hectares, with production of 3950 lakh tonnes and an average yield of 2840 kg per hectare. India ranks fourth globally in soybean area coverage, with 1230 lakh hectares, and fifth in production, with 14.3 million tonnes and an average yield of 11.55 quintals per hectare. Madhya Pradesh is called the Soya State, as it produces about 58% of India's soybean production (Directorate of Economics and Statistics, 2025).

There is a wide gap between world and Indian productivity because of limited nutrient availability to the crop. Organic manures such as farmyard manure, vermicompost and poultry manure improve soil structure, microbial activity and nutrient supply. Biofertilizers such as *Rhizobium*, phosphorus-solubilising bacteria (PSB) and potassium-solubilising bacteria (KSB) enhance nutrient availability by fixing and mobilising unavailable nutrients in the soil (Gaikwad et al., 2025). However, information on their effect on soybean under specific agro-ecological conditions of the Gird region of Madhya Pradesh is limited, and most previous research has focused mainly on combinations of chemical fertilizers and biofertilizers rather than on organic manures with biofertilizer seed inoculation. This gap indicates the need to evaluate organic manure sources and biofertilizer treatments for soybean under local field conditions. Therefore, an experimental study was conducted to examine the influence of organic manures and biofertilizers on soybean.

2. Materials and Methods

The experiment was conducted at the Crop Research Centre, ITM University, Gwalior, Madhya Pradesh. The research site recorded an average maximum temperature of 34.2°C, a minimum temperature of 23°C and relative humidity of 89% in the morning, while the total rainfall received during the crop period was 369 mm. The experimental field had sandy loam soil with a neutral reaction (pH = 7.7), EC of 0.42 dS m^{-1} and organic carbon content of 0.35%. The available nitrogen, phosphorus and potassium in the soil were 162.2, 17.8 and 282 kg ha^{-1}, respectively. The experiment was conducted in a factorial randomized block design with nine treatments, comprising one absolute control and two factors: organic manures (farmyard manure [FYM] at 5 t ha^{-1}, vermicompost [VC] at 2 t ha^{-1} and poultry manure [PM] at 1.5 t ha^{-1}) and biofertilizers as seed treatments (*Rhizobium* at 30 ml kg^{-1}, phosphorus-solubilising bacteria [PSB] at 30 ml kg^{-1} and potassium-solubilising bacteria [KSB] at 30 ml kg^{-1}). The gross plot size was 4.5 m × 3.6 m, and the net plot size was 2.7 m × 3 m. The variety 'JS-335' was sown at a seed rate of 75 kg ha^{-1} with spacing of 45 cm × 10 cm. The crop was sown on 06 August 2025 and harvested on 11 November 2025. Organic manures were incorporated into the soil 20 days before sowing to allow decomposition and mineralisation. The seeds were inoculated before sowing with liquid formulations containing *Bradyrhizobium japonicum* (*Rhizobium*), *Bacillus megaterium* (PSB) and *Frateuria aurantia* (KSB).

The observations recorded included plant height (cm), number of branches plant^{-1}, number of trifoliate leaves plant^{-1} and dry matter accumulation (g m^{-2}).
The leaf area of sampled plants was measured, and the leaf area index (LAI) was calculated using the formula proposed by Watson (1947).

$$\text{Leaf Area Index} = \frac{\text{Leaf Area (m}^2\text{)}}{\text{Ground Area (m}^2\text{)}}$$

Crop growth rate and relative growth rate were calculated using the formulae proposed by Watson (1952) and Blackman (1919), respectively.

$$\overline{\text{CGR}} = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{A}$$

where W1 and W2 are weights taken at times t1 and t2, respectively, and A is the ground area (m2).

$$\overline{\text{RGR}} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

where log is the natural logarithm, and W1 and W2 are the dry weights taken at times t1 and t2, respectively.

The harvest index was calculated using the formula:

$$\text{Harvest Index (\%)} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Biological Yield (kg ha}^{-1}\text{)}}$$

where biological yield (kg ha^{-1}) = grain yield (kg ha^{-1}) + straw yield (kg ha^{-1}).

After estimating nitrogen content (%) in the grain, protein content was calculated using the following formula:

Protein content (%) = Nitrogen content (%) × 6.25

Oil content was estimated using the standard Soxhlet extraction technique and calculated using the following formula:

$$\text{Oil content} = \frac{\text{Weight of oil extracted (g)}}{\text{Weight of seed sample (g)}} \times 100$$

The recorded data were analysed using analysis of variance (ANOVA) appropriate for a factorial randomized block design, as described by Gomez and Gomez (1984). Statistical analysis was performed using OPSTAT statistical software. Treatment means were compared using the F-test at the 5% probability level. The standard error of the mean and critical difference at the 5% level of significance were calculated for comparison of treatment means.

3. Result and Discussion

3.1 Growth Attributes

Different organic manure and biofertilizer options significantly influenced growth attributes (Table 1). Among the manures, vermicompost at 2 t ha^{-1} recorded higher plant height (56.8 cm), total branches per plant (6.5), trifoliate leaves per plant at 60 DAS (32.4), LAI (4.15) and dry matter accumulation (48.7, 172.6, 364.2 and 458.7 g m^{-2} at the respective growth stages) than the other manures. Vermicompost promotes vigorous plant growth by supplying readily available nutrients and releasing natural growth stimulants that enhance cell division, elongation and branching. Its high microbial activity improved root function and nutrient uptake efficiency, resulting in increased plant height, more branches and trifoliate leaves, and greater dry matter accumulation. Similar findings were reported by Mansare et al. (2026), Mohan et al. (2023) and Samad et al. (2024). Among the biofertilizer seed treatments, maximum plant height (56.5 cm), total branches per plant (6.2), trifoliate leaves per plant at 60 DAS (32.1), LAI (4.04) and dry matter accumulation (48.52, 170.1, 359.5 and 450.1 g m^{-2} at the respective growth stages) were recorded with *Rhizobium* at 30 ml kg^{-1} seed inoculation. The lowest growth attributes were recorded in the absolute control treatment. *Rhizobium* enhances plant growth through biological nitrogen fixation in root nodules, converting atmospheric nitrogen into plant-available forms, which results in improved protein synthesis, chlorophyll formation and overall metabolic activity (Gupta et al., 2024). Better nutrition strengthens vegetative growth, resulting in taller plants, increased branching and higher dry weight due to enhanced photosynthetic efficiency and biomass production. Meetu et al. (2023) and Sannagoudar et al. (2025) reported similar observations.

Table 1. Influence of organic manures and biofertilizers on growth attributes of soybean crop

Treatments	**Plant height at harvest (cm)**	**Total branches $plant^{-1}$ at harvest**	**No. of trifoliate leaves $plant^{-1}$ at 60 DAS**	**Leaf Area Index (At 60 DAS)**	**Dry Matter Accumulation (g m^{-2})**			
					20 DAS	**40 DAS**	**60 DAS**	**At harvest**
Absolute control	44.1	4.2	23.6	3.19	42.22	125.9	253.3	305.2
Factor A (Organic Manure)								
M_1- FYM @ 5 t ha^{-1}	51.1	5.0	28.9	3.57	45.49	144.7	305.2	407.9
M_2- VC @ 2 t ha^{-1}	56.8	6.5	32.4	4.15	48.70	172.6	364.2	458.7
M_3- PM @ 1.5 t ha^{-1}	51.6	5.9	30.0	3.82	46.49	156.0	333.3	414.5
SE(m)±	1.3	0.2	0.75	0.09	1.28	4.4	8.9	9.5
CD (P=0.05)	4.0	0.5	2.22	0.27	NS	12.9	26.4	28.2
Factor B (Biofertilizers)								
B_1- Rhizobium @ 30 ml kg^{-1} seed treatment	56.5	6.2	32.1	4.04	48.52	170.1	359.5	450.1
B_2- PSB @ 30 ml kg^{-1} seed treatment	52.1	5.6	29.6	3.76	46.74	154.8	326.6	417.0
B_3- KSB @ 30 ml kg^{-1} seed treatment	51.0	5.5	29.5	3.73	45.41	148.4	316.5	414.0
SE(m)±	1.3	0.2	0.75	0.09	1.28	4.4	8.9	9.5
CD (P=0.05)	4.0	0.5	2.22	0.27	NS	12.9	26.4	28.2
Interaction A × B								
SE(m)±	2.3	0.3	1.30	0.16	2.22	7.5	15.1	16.4
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

3.2 Growth Indices

Growth indices were significantly affected by the various organic manures and biofertilizers (Table 2). Among the organic manures, the maximum $(\overline{\text{CGR}})$ values (6.19, 9.58 and 3.05 at 20-40 DAS, 40-60 DAS and 60 DAS-harvest stage, respectively) were observed in the vermicompost at 2 t ha^{-1} treatment, followed by poultry manure at 1.5 t ha^{-1}. Among the biofertilizer inoculation treatments, *Rhizobium* at 30 ml kg^{-1} seed recorded the highest $(\overline{\text{CGR}})$ (6.08, 9.47 and 2.92 at 20-40 DAS, 40-60 DAS and 60 DAS-harvest stage, respectively). At the earlier stage, CGR increased and then slightly decreased at later stages. The increase in CGR and RGR under vermicompost application may be attributed to the sustained release of essential nutrients and the presence of growth-enhancing bioactive compounds. These factors improve photosynthetic efficiency and carbon assimilation, thereby accelerating dry matter production per unit plant biomass (Mansare et al., 2026; Mohan et al., 2023). In the case of relative growth rate, the maximum $\overline{\text{RGR}}$ at 20-40 DAS (63.19) was recorded in vermicompost at 2 t ha^{-1}, followed by poultry manure at 1.5 t ha^{-1}. Among the biofertilizer options, *Rhizobium* at 30 ml kg^{-1} seed recorded the highest value (62.73), followed by PSB at 30 ml kg^{-1} seed. At later stages, the effects of both factors were found to be non-significant. The absolute control treatment recorded the lowest values at all stages. *Rhizobium* inoculation enhanced CGR and RGR by increasing nitrogen availability through biological nitrogen fixation. This nutritional boost directly stimulates leaf expansion and increases leaf area, resulting in accelerated photosynthetic activity and thereby promoting biomass production. These findings are similar to those reported by Lida et al. (2024).

Table 2. Influence of organic manures and biofertilizers on growth indices of soybean crop

Treatments	Mean Crop Growth Rate (g m^{-2} day^{-1})			Mean Relative Growth Rate (mg g^{-1} day^{-1})		
	20-40 DAS	40-60 DAS	60 DAS-Harvest (91 DAS)	20-40 DAS	40-60 DAS	60 DAS-Harvest (91 DAS)
Absolute control	4.18	6.37	1.67	54.64	34.98	6.08
Factor A (Organic Manure)						
M_1- FYM @ 5 t ha^{-1}	4.96	8.03	3.31	57.77	37.39	9.41
M_2- VC @ 2 t ha^{-1}	6.19	9.58	3.05	63.19	37.37	7.47
M_3- PM @ 1.5 t ha^{-1}	5.48	8.86	2.62	60.47	37.91	7.09
SE(m)±	0.16	0.23	0.10	0.56	0.24	0.31
CD (P=0.05)	0.48	0.69	0.29	1.68	NS	0.91
Factor B (Biofertilizers)						
B_1- Rhizobium @ 30 ml kg^{-1} seed treatment	6.08	9.47	2.92	62.73	37.39	7.27
B_2- PSB @ 30 ml kg^{-1} seed treatment	5.40	8.59	2.91	59.67	37.35	7.96
B_3- KSB @ 30 ml kg^{-1} seed treatment	5.15	8.41	3.15	59.03	37.92	8.73
SE(m)±	0.16	0.23	0.10	0.56	0.24	0.31
CD (P=0.05)	0.48	0.69	NS	1.68	NS	NS
Interaction A × B						
SE(m)±	0.28	0.41	0.17	0.98	0.41	0.53
CD (P=0.05)	NS	NS	NS	NS	NS	NS

3.3 Yield and Quality

Substantial variation in yield and quality parameters was observed due to different manures and biofertilizers (Table 3). With respect to manures, vermicompost at 2 t ha^{-1} recorded higher grain yield (1732.5 kg ha^{-1}), straw yield (2857 kg ha^{-1}), protein content (41.59%) and oil content (21.12%) than the other manures. The rich microbial activity of vermicompost increases nitrogen availability and biological nitrogen fixation efficiency, directly supporting protein synthesis. Better potassium and phosphorus nutrition improves assimilate translocation and seed filling, resulting in higher yield and increased oil content. Similar findings were reported by Lokhande et al. (2023), Malviya et al. (2025), Rao et al. (2024) and Sruthi et al. (2025). Among the biofertilizers, maximum grain yield (1694 kg ha^{-1}), straw yield (2790.2 kg ha^{-1}), protein content (41.26%) and oil content (20.67%) were recorded in *Rhizobium* at 30 ml kg^{-1} seed treatment, followed by PSB at 30 ml kg^{-1} seed treatment. The lowest grain yield (979.1 kg ha^{-1}), straw yield (1851.9 kg ha^{-1}), protein content (39.6%) and oil content (19.4%) were recorded in the absolute control. *Rhizobium* enhances amino acid and protein synthesis, leading to higher seed protein content and better vegetative growth that supports pod formation. Improved nitrogen metabolism also strengthens carbon assimilation and assimilates partitioning to seeds, resulting in higher yield and increased oil accumulation with superior seed quality (Kukreti & Singh, 2024). These results match the observations recorded by Meetu et al. (2023) and Sannagoudar et al. (2025).

Table 3. Influence of organic manures and biofertilizers on yield and quality of soybean crop

Treatments	Yield (Kg ha^{-1}) Grain	Yield (Kg ha^{-1}) Straw	Harvest Index (%)	Protein content (%)	Oil content (%)
Absolute control	979.1	1851.9	34.6	39.60	19.40
Factor A (Organic Manure)					
M_1- FYM @ 5 t ha^{-1}	1498.4	2567.0	36.9	40.65	19.90
M_2- VC @ 2 t ha^{-1}	1732.5	2857.0	37.7	41.59	21.12

Treatments	Yield (Kg ha^{-1}) Grain	Straw	Harvest Index (%)	Protein content (%)	Oil content (%)
M_3- PM @ 1.5 t ha^{-1}	1553.1	2610.9	37.3	41.05	20.41
SE(m)±	40.6	46.9	-	0.28	0.13
CD (P=0.05)	120.7	139.5	-	NS	0.39
Factor B (Biofertilizers)					
B_1- Rhizobium @ 30 ml kg^{-1} seed treatment	1694.0	2790.2	37.8	41.26	20.67
B_2- PSB @ 30 ml kg^{-1} seed treatment	1553.6	2627.8	37.2	41.14	20.51
B_3- KSB @ 30 ml kg^{-1} seed treatment	1536.4	2617.0	37.0	40.89	20.26
SE(m)±	40.6	46.9	-	0.28	0.13
CD (P=0.05)	120.7	139.5	-	NS	NS
Interaction A × B					
SE(m)±	70.4	81.3	-	0.49	0.23
CD (P=0.05)	NS	NS	-	NS	NS

4. Conclusion

The field experiment indicated that organic manures and biofertilizer seed inoculation influenced the growth, physiological performance, yield and quality parameters of soybean under the Gird region conditions of Madhya Pradesh. Among the organic manure treatments, vermicompost at 2 t ha^{-1} performed better than farmyard manure and poultry manure for most growth and yield attributes, including plant height, number of branches, number of trifoliate leaves, leaf area index, dry matter accumulation, grain yield and straw yield. Among the biofertilizer treatments, *Rhizobium* seed inoculation at 30 ml kg^{-1} seed performed better than phosphate-solubilising bacteria and potassium-solubilising bacteria for growth and yield traits. The highest grain yield was recorded with vermicompost among the organic manures and with *Rhizobium* among the biofertilizer treatments. The interaction effect between organic manures and biofertilizers was statistically non-significant, indicating that the individual effects of the tested inputs were more evident than their combined interaction under the conditions of this study. Based on the recorded responses, vermicompost application and *Rhizobium* seed inoculation may be considered useful nutrient-management options for improving soybean performance in the study region under comparable field conditions in future. These findings should be interpreted within the limits of the experimental season, location and treatment levels evaluated.

5. Limitations

The study was conducted during a single kharif season at one experimental location; therefore, the findings may not fully represent soybean performance across different years, soil types, rainfall patterns or soybean-growing regions. The experiment included selected doses of three organic manures and three biofertilizer seed treatments only, and other nutrient-management combinations were not evaluated. The interaction between organic manures and biofertilizers was statistically non-significant, which limits the interpretation of combined treatment effects. Some quality parameters showed limited statistical response; therefore, conclusions related to seed quality should be interpreted with care. The study did not include a detailed economic analysis, soil biological assessment or post-harvest soil fertility evaluation, which would have strengthened the practical interpretation of the results. Further multi-location and multi-season trials across comparable agro-ecological conditions and seasons are required to confirm the consistency of the observed treatment effects and to refine recommendations for soybean production under similar agro-ecological conditions.

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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