



Plant Archives

Journal homepage: <http://www.plantarchives.org>

DOI Url : <https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.143>

GROWTH ANALYSIS AND YIELD RESPONSE OF SOYBEAN TO CONSORTIA BIOFERTILIZER APPLICATION UNDER *KHARIF* CONDITIONS

P.M. Patil¹, R.S. Shaikh², Suraj N Gund^{3*} and V.R. Awari³

¹Department of Botany, Mahatma Phule Krishi Vidyapeeth, Rahuri - 413 722, Ahilyangar, Maharashtra, India.

²Department of Agricultural Botany College of agriculture Muktainagar, Jalgaon, Maharashtra, India.

³Department of Agricultural Botany, M.P.K. V., Rahuri, Ahilyanagar, Maharashtra, India.

*Corresponding author E-mail : sgund3930@gmail.com

(Date of Receiving-22-06-2025; Date of Acceptance-05-09-2025)

ABSTRACT

A field experiment was done during the *Kharif* season of 2023 at Post Graduate Institute Farm, MPKV, Rahuri, for identify the physiological traits and yield responses of soybean to different biofertilizer application. A split plot design with three replications, included 14 treatment combinations involving seven biofertilizer treatments and two varieties (KDS-726 and KDS-753) are used for the experiment. The results showed that KDS-726 outperformed KDS-753 by a significant margin. The highest (yield trait) plant height (57.44 cm), number of primary (3.84) and secondary branches (9.54), leaf area, AGR, LAI, NAR, dry matter content, CGR, and SCMR were all recorded by treatment T5 (seed inoculation with Rhizobium + PSB + KMB @ 25 g/kg seed + 100% RDF). The potential of biofertilizers in enhancing soybean growth and promoting sustainable agriculture was demonstrated by Treatment T6 (same inoculation + 75% RDF), which displayed somewhat lower values but remained statistically equivalent to T5.

Key words : Physiology of Soybean, Biofertilizer, Growth, yield traits, Sustainable agriculture.

Introduction

In India, where it receives an average of 850 to 900 mm of seasonal rainfall, soybeans (*Glycine max* L. Merr.), which are members of the Leguminosae (Fabaceae) family, are grown mainly as rainfed crops on vertisols and related soils. Since its introduction, traditional cropping systems have undergone significant change. A soybean–wheat/chickpea rotation has replaced the earlier rainy season fallow–post-rainy wheat/chickpea system. This change has increased land productivity and cropping intensity, which has improved economic returns, especially for small and marginal farmers. In rainfed areas, soybeans are a dependable kharif crop due to their ability to withstand low input requirements and climatic uncertainties.

In terms of geography, Madhya Pradesh, Maharashtra, Rajasthan, Chhattisgarh, Andhra Pradesh,

and Karnataka are all included in the latitudinal belt of 15° to 25°N, where soybeans are grown. Together, these states account for roughly 98% of the nation's output.

Soybean (*Glycine max* L. Merr.), a member of the Leguminosae (Fabaceae) family, is primarily cultivated as a rainfed crop on vertisols and associated soils in India, receiving an average seasonal rainfall of approximately 900 mm. Its introduction has significantly altered traditional cropping systems, replacing the earlier rainy season fallow–post-rainy wheat/chickpea system with a soybean–wheat/chickpea rotation. This shift has enhanced cropping intensity and land productivity, leading to improved economic returns, particularly for small and marginal farmers. Soybean's adaptability to minimal inputs and climatic uncertainties has made it a reliable kharif crop in rainfed regions.

Geographically, soybean cultivation spans the

latitudinal belt of 15°–25°N, covering Madhya Pradesh, Maharashtra, Rajasthan, Chhattisgarh, Andhra Pradesh and Karnataka. These states collectively contribute about 98% of national production. With 59% of both area and output, Madhya Pradesh continues to be the top producer. Maharashtra comes in second (28% of area and 26% of production). Notably, in recent years, the area planted to soybeans has increased significantly in southern states.

By means of biological nitrogen fixation and phosphorus solubilisation, biofertilizers—which are made up of advantageous microorganisms—are essential for improving soil fertility. By lowering dependency on chemical fertilisers and minimising environmental pollution, these environmentally friendly inputs enhance agro-ecological sustainability in addition to enhancing plant nutrition (Parr *et al.*, 2002). Biofertilizers have been shown to cut the need for chemical fertilisers by 25–50%, making them economically feasible for farmers (Vance, 1997; Rana *et al.*, 2012). By enhancing nutrient availability and maintaining soil health, their adoption supports sustainable agriculture (Pandey and Pandey, 1995).

Material and Methods

Experimental details

1	Crop	Soybean (<i>Glycine max</i> L. Merrill)
2	Season	Kharif 2023
3	Location of experiment	Post Graduate Institute Farm, MPKV, Rahuri
4	Design	Split Plot Design
5	Number of replications	03
6	Spacing	30 x 10 cm
7	Plot Size	3.00 x 2.75 m
8	Fertilizer dose	50:75:45 NPK Kg ha ⁻¹
9	Treatments	A. Varieties: 1. KDS 726 (Phule Sangam) 2. KDS 753 (Phule Kimaya) B. Biofertilizer treatments: Seven as given in Table 1

Results and Discussion

Growth Parameters

Plant height

The plant height is influenced by significantly due to different treatments is presented in Table 2. The plant height increased progressively up to harvesting. The mean plant height at 30, 60, 90 DAS and at maturity was 23.73, 40.97, 49.09 and 52.00 cm, respectively

Table 1 : Different biofertilizer treatments.

T ₁	Recommended Dose of fertilizer NPK
T ₂	Seed inoculation of <i>Rhizobium</i> @ 25 g/kg + 100% RDF.
T ₃	Seed inoculation of PSB @ 25 g/kg + 100% RDF.
T ₄	Seed inoculation of KMB @ 25 g/kg + 100% RDF.
T ₅	Seed inoculation of <i>Rhizobium</i> + PSB + KMB @ 25g each/kg + 100% RDF
T ₆	Seed inoculation of <i>Rhizobium</i> + PSB + KMB @ 25g each/kg + 75% RDF
T ₇	Control Absolute

The data collected on individual characters were subjected to the method of analysis of variance commonly applicable to the Split plot design (Panse and Sukhatme, 1985).

Effect of varieties

From the data, it is revealed that, there was statistically significant difference in plant height at all growth stages between two varieties. At 30, 60, 90 DAS and at maturity KDS-726 was found statistically significantly superior plant height of 24.63, 41.90, 50.50 and 53.74 cm over KDS-753, respectively.

The wide variation in plant height was observed due to genetical characters of the genotypes and also might be influenced by agronomical and environmental factors (Jadhav *et al.*, 2021). Similar results were reported by Manjaya and Bapat (2008).

Effect of Biofertilizers

At every stage of growth, the height of soybean plants was greatly impacted by the use of biofertilizers. The highest plant heights, 27.61, 47.65, 55.33, and 57.44 cm at 30, 60, 90 DAS and at maturity, respectively, were recorded by treatment T₅ (*Rhizobium* + PSB + KMB @ 25 g/kg seed + 100% RDF), which was statistically superior to all other treatments with the exception of T₆. With heights of 19.38, 34.27, 42.92, and 46.87 cm, Treatment T₆ (same biofertilizers + 75% RDF) performed similarly. The absolute control (T₇) had the smallest plant height.

The synergistic effect of biofertilizers and the nutrient supply from RDF, which improves nutrient uptake and photosynthate translocation, may be the reason for T₅ and T₆'s superior performance. KMB aided in potassium mobilization, PSB improved phosphorus solubilization, and *Rhizobium* helped fix nitrogen—collectively improving plant growth.

Interaction

The interaction effect between different varieties and biofertilizer treatments were found non-significant in

Table 2 : Plant height (cm), Number of primary branches plant⁻¹ and Number of secondary branches plant⁻¹ as influenced by different treatments in soybean.

Factors		Plant height (cm)				Number of primary branches plant ¹		Number of secondary branches plant ¹	
		30 DAS	60 DAS	90 DAS	At Maturity	90 DAS	At Maturity	90 DAS	At Maturity
A.	Main plots: Variety (V)								
V ₁	KDS-726	24.63	41.90	50.50	53.74	3.27	3.34	7.93	8.26
V ₂	KDS-753	22.83	40.04	47.69	50.27	3.13	3.23	7.77	8.23
	S.E. (m) ±	0.04	1.71	0.42	0.46	0.03	0.03	0.09	0.08
	CD at 5%	0.27	3.15	2.56	2.78	NS	NS	NS	NS
B.	Sub plots: Treatments (T)								
T ₁	Recommended Dose of fertilizer NPK	21.67	37.49	45.91	48.53	2.68	2.74	6.61	6.94
T ₂	Seed inoculation of <i>Rhizobium</i> @ 25gkg ⁻¹ + 100% RDF	24.48	41.16	49.27	52.06	3.35	3.51	8.26	8.62
T ₃	Seed inoculation of PSB @ 25 gkg ⁻¹ + 100% RDF	23.53	41.01	48.01	51.80	3.36	3.46	8.11	8.63
T ₄	Seed inoculation of KMB @ 25 gkg ⁻¹ + 100% RDF	23.85	40.64	49.03	52.04	3.23	3.32	7.96	8.33
T ₅	Seed inoculation of <i>Rhizobium</i> + PSB + KMB @ 25g each kg ⁻¹ + 100% RDF	27.61	47.65	55.33	57.44	3.75	3.84	9.12	9.54
T ₆	Seed inoculation of <i>Rhizobium</i> + PSB + KMB @ 25g each kg ⁻¹ + 75% RDF	25.61	44.60	53.21	55.29	3.57	3.65	8.82	9.26
T ₇	Absolute Control	19.38	34.27	42.92	46.87	2.43	2.48	6.07	6.38
	S.E. (m) ±	1.29	1.41	2.03	1.72	0.12	0.10	0.26	0.23
	CD at 5%	3.75	4.12	5.93	5.02	0.35	0.29	0.76	0.71
C.	Interaction (V x T)								
	S.E. (m) ±	1.82	1.99	2.87	2.43	0.17	0.14	0.37	0.37
	CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
	General Mean	23.73	40.97	49.09	52.00	3.20	3.28	7.85	8.24

respect of plant height at all stages of growth.

Number of primary branches and number of secondary branches

The number of primary branches of soybean as influenced significantly due to different treatments is presented in Table 2. The number of primary branches increased progressively up to maturity. The mean number of primary branches at 90 DAS and at maturity was 3.20 and 3.28, respectively.

The number of secondary branches of soybean as influenced significantly due to different treatments is presented in Table 2. The number of secondary branches

increased progressively up to maturity. The mean number of secondary branches at 90 DAS and at maturity was 7.85 and 8.24, respectively.

Effect of varieties

The comparison between two varieties were found non-significant in respect of Number of primary branches and Number of secondary branches at 90 DAS and at maturity of soybean.

Effect of biofertilizers

The number of primary and secondary branches at 90 DAS and at maturity was significantly influenced by

different biofertilizer treatments. The treatment T_5 (seed inoculation with Rhizobium + PSB + KMB @ 25 g each kg^{-1} + 100% RDF – 50:75:45 N:P₂O₅:K₂O kg ha^{-1}) recorded the highest number of primary branches (3.75 at 90 DAS and 3.84 at maturity) and secondary branches (9.12 at 90 DAS and 9.54 at maturity). This was statistically at par with T_6 (same inoculation + 75% RDF), which recorded 3.57 and 3.65 primary branches and 8.82 and 9.26 secondary branches at respective stages. The lowest number of both branch types was observed in the absolute control (T_7).

The significantly higher number of branches under T_5 may be attributed to enhanced root development, nutrient uptake, and overall plant metabolism stimulated by combined biofertilizer application and recommended nutrient dose (Islam *et al.*, 2017). These results align with the findings of Jaga and Sharma (2005).

Interaction

The interaction effect between different varieties and biofertilizer treatments were found non-significant in respect of number of primary and secondary branches at 90 DAS and at maturity of soybean.

Leaf area

The leaf area of soybean as influenced statistically significant due to different treatments is presented in Table 3. The leaf area increased progressively up to 90 DAS. The mean leaf area at 30, 60, 90 DAS and at maturity were 2.67, 20.72, 24.31 and 22.69 dm^2 , respectively.

Effect between varieties

At every stage of growth, a notable variation in leaf area was noted between the two types of soybeans. In comparison to KDS-753, variety KDS-726 had greater leaf area values at 30, 60, 90 and maturity, respectively, of 2.76, 21.36, 25.28 and 23.61 dm^2 . Its wider canopy, effective root system, and improved nutrient uptake, which promotes increased photosynthetic activity, may be the cause of this superiority. These outcomes are consistent with Vyas and Khandwe's (2014) research.

Effect of biofertilizers

Biofertilizer treatments had a big effect on leaf area at all stages of growth. The treatment T_5 (Rhizobium + PSB + KMB @ 25g/kg seed + 100% RDF) had the most leaf area (3.05, 22.63, 26.93 and 25.74 dm^2) at 30, 60, 90 DAS, and maturity. T_6 (the same inoculation + 75% RDF) was very close behind, with values that were statistically the same. The Absolute Control (T_7) had the smallest leaf area.

Herliana *et al.* (2019) say that higher leaf area in Rhizobium-inoculated treatments means better nitrogen

fixation, which means more chlorophyll and greener leaves. Singh *et al.* (2018) also saw similar trends.

Interaction

The interaction effect between different varieties and biofertilizer treatments were found non-significant in respect of leaf area at all stages of growth.

Leaf area Index

The leaf area index of soybean as influenced statistically significant due to different treatments is presented in Table 3. The leaf area index increased progressively up to 90 DAS. The mean leaf area index at 30, 60, 90 DAS and at maturity was 0.79, 6.09, 7.15 and 6.67, respectively.

Effect between varieties

At each phase of growth, a significant difference in the two soybean varieties' leaf area index (LAI) was noted. In compared with KDS-753, variety KDS-726 frequently showed higher LAI values of 0.81, 6.28, 7.44, and 6.94 at 30, 60, 90 DAS, and maturity, respectively. Greater leaf area, more branches, and generally vigorous growth are the reasons for this superiority. Jadhav *et al.* (2021) reported similar results, observing that KDS-726 grew more vigorously than KDS-753.

Effect of biofertilizers

Treatments with biofertilizer had a major impact on LAI at every growth stage. With the highest LAIs of 0.90, 6.65, 7.92 and 7.57 at 30, 60, 90 DAS, and maturity, respectively, treatment T_5 (seed inoculation with Rhizobium + PSB + KMB @ 25 g kg^{-1} seed + 100% RDF) was statistically comparable to treatment T_6 (same inoculants + 75% RDF). The absolute control (T_7) had the lowest LAI.

Improved root development and nutrient availability from biofertilizer application, which improves light interception and vegetative growth, could be the cause of the increased LAI under T_5 (Aduloju *et al.*, 2009).

The combined effect of biofertilizer's and chemical fertilizers produced higher leaf area index (LAI) in soybean plants. There was synergistic effect of biofertilizers with each other leads to more nutrient availability to plants, that leads to higher leaf area index (LAI) in soybean. Results are in agreement with Banerjee *et al.* (2012).

Interaction

The interaction effect between different varieties and biofertilizer treatments were found non-significant in respect of leaf area index at all stages of growth.

Table 3 : Leaf area (LA) ($\text{dm}^2 \text{ plant}^{-1}$) and Leaf area index (LAI) as influenced by different treatments in soybean.

Factors		Leaf area (LA) dm ² plant ⁻¹				Leaf area index (LAI)			
		30 DAS	60 DAS	90 DAS	At Maturity	30 DAS	60 DAS	90 DAS	At Maturity
A.	Main plots: Variety (V)								
V ₁	KDS-726	2.76	21.36	25.28	23.61	0.81	6.28	7.44	6.94
V ₂	KDS-753	2.59	20.10	23.35	21.78	0.76	5.90	6.87	6.41
	S.E. (m) ±	0.02	0.09	0.29	0.28	0.01	0.02	0.09	0.08
	CD at 5%	0.11	0.54	1.78	1.73	0.03	0.14	0.52	0.51
B.	Sub plots: Treatments (T)								
T ₁	Recommended Dose of fertilizer NPK	2.55	19.59	23.59	21.57	0.75	5.76	6.94	6.34
T ₂	Seed inoculation of <i>Rhizobium</i> @ 25gkg ⁻¹ + 100% RDF.	2.68	20.43	24.07	22.42	0.79	6.01	7.08	6.59
T ₃	Seed inoculation of PSB @ 25 gkg ⁻¹ + 100% RDF.	2.65	20.36	23.97	22.38	0.78	5.99	7.04	6.57
T ₄	Seed inoculation of KMB @ 25 gkg ⁻¹ + 100% RDF.	2.57	20.37	23.96	22.36	0.76	5.97	7.05	6.58
T ₅	Seed inoculation of <i>Rhizobium</i> + PSB + KMB @ 25g each kg ⁻¹ + 100% RDF	3.05	22.63	26.93	25.74	0.90	6.65	7.92	7.57
T ₆	Seed inoculation of <i>Rhizobium</i> + PSB + KMB @ 25g each kg ⁻¹ + 75% RDF	2.89	22.15	26.41	25.21	0.85	6.51	7.77	7.42
T ₇	Absolute Control	2.33	19.56	21.24	19.15	0.68	5.71	6.25	5.63
	S.E. (m) ±	0.11	0.73	0.92	0.91	0.03	0.22	0.27	0.26
	CD at 5%	0.32	2.14	2.69	2.65	0.09	0.63	0.79	0.78
C.	Interaction (V x T)								
	S.E. (m) ±	0.16	1.04	1.30	1.28	0.05	0.30	0.38	0.36
	CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
	General Mean	2.67	20.72	24.31	22.69	0.79	6.09	7.15	6.67

Crop Growth Rate (CGR)

The crop growth rate of soybean as influenced significantly due to different treatments is presented in Table 4. The crop growth rate increased progressively up to 60 DAS. The mean crop growth rate at 30-60, 60-90 DAS and 90 DAS-at maturity was 1.04, 0.63 and 0.069, respectively.

Effect between varieties

From the data it is revealed that, there was statistically significant difference of crop growth rate up to 60 DAS between two varieties. Between 30-60 and 60-90 DAS, KDS-726 has shown significantly higher crop growth rate 1.08 and 0.65 g cm⁻² day⁻¹ over KDS-753, respectively.

The variety KDS 726 has produced more dry matter content as compare to other variety KDS 753, so the higher crop growth rate was showed by the variety KDS 726. Also, it might be due to environmental variation.

Effect of biofertilizer treatment

Up to 60 DAS, notable variations in the growth rate of soybean crops were noted as a result of biofertilizer treatments. Treatment T₅ (seed inoculation with *Rhizobium* + PSB + KMB @ 25 g kg⁻¹ + 100% RDF) had the highest crop growth rate (1.19 g cm⁻² day⁻¹) between 30 and 60 DAS. T₆ (1.11 g cm⁻² day⁻¹) was the next best treatment. T₇ (absolute control) had the lowest rate. T₆ exhibited numerically greater growth than the others after 60 DAS.

Table 4 : Crop Growth Rate (CGR) ($\text{g cm}^{-2}\text{day}^{-1}$) and Absolute Growth Rate (AGR) ($\text{g plant}^{-1}\text{day}^{-1}$) as influenced by different treatments in soybean.

Factors		Crop Growth Rate (CGR) ($\text{g cm}^{-2}\text{day}^{-1}$)			Absolute Growth Rate (AGR) ($\text{g plant}^{-1}\text{day}^{-1}$)		
		30-60 DAS	60-90 DAS	90-At Maturity	30-60 DAS	60-90 DAS	90-At Maturity
A. Main plots: Variety (V)							
V ₁	KDS-726	1.08	0.65	0.06	0.397	0.234	0.127
V ₂	KDS-753	1.00	0.57	0.07	0.385	0.221	0.084
	S.E. (m) $\pm$	0.01	0.01	0.01	0.004	0.005	0.021
	CD at 5%	0.07	0.04	NS	NS	NS	NS
B. Sub plots: Treatments (T)							
T ₁	Recommended Dose of fertilizer NPK	0.93	0.56	0.065	0.363	0.236	0.085
T ₂	Seed inoculation of <i>Rhizobium</i> @ 25 g kg ⁻¹ + 100% RDF.	1.08	0.64	0.064	0.409	0.218	0.094
T ₃	Seed inoculation of PSB @ 25 g kg ⁻¹ + 100% RDF.	1.04	0.59	0.056	0.393	0.211	0.089
T ₄	Seed inoculation of KMB @ 25 g kg ⁻¹ + 100% RDF.	1.05	0.56	0.061	0.396	0.208	0.088
T ₅	Seed inoculation of <i>Rhizobium</i> + PSB + KMB @ 25 g each kg ⁻¹ + 100% RDF	1.19	0.69	0.075	0.440	0.239	0.099
T ₆	Seed inoculation of <i>Rhizobium</i> + PSB + KMB @ 25 g each kg ⁻¹ + 75% RDF	1.11	0.72	0.076	0.407	0.263	0.109
T ₇	Absolute Control	0.88	0.52	0.060	0.332	0.217	0.078
	S.E. (m) $\pm$	0.04	0.06	0.016	0.018	0.027	0.039
	CD at 5%	0.12	NS	NS	0.054	NS	NS
C. Interaction (V x T)							
	S.E. (m) $\pm$	0.06	0.09	0.02	0.038	0.006	0.038
	CD at 5%	NS	NS	NS	NS	NS	NS
	General Mean	1.04	0.63	0.069	0.228	0.10	0.228

With comparable results published by Ghosh *et al.* (2020), Bhardwaj *et al.* (2014) and Ramesh *et al.* (2019), the improvement may be ascribed to nitrogen fixation, nutrient mobilization, and soil structure enhancement through biofertilizer application (Sharma *et al.*, 2021).

Interaction

Interaction was not observed between the varieties and biofertilizer treatments in respect of crop growth rate.

Absolute Growth Rate (AGR) ($\text{g plant}^{-1}\text{day}^{-1}$)

The absolute growth rate of soybean as influenced significantly due to different treatments is presented in Table 4. The absolute growth rate increased progressively upto 60 DAS. The mean absolute growth rate at 30-60, 60-90 DAS and 90 DAS-at maturity was 0.396, 0.228 and 0.10 $\text{g plant}^{-1}\text{day}^{-1}$, respectively.

Effect between varieties

Between varieties, there was statistically non-

significant difference in absolute growth rate of soybean.

Effect of biofertilizer treatment

Biofertilizers play a significant role in enhancing the absolute growth rate of soybean (*Glycine max*) by improving various physiological and biochemical processes. There was statistically significant difference had seen in different treatments of biofertilizer. The treatment T₅ i.e. seed inoculation of *Rhizobium* + PSB + KMB @ 25g each kg⁻¹ + 100% RDF has shown statistically significant superior absolute growth rate of 0.440 $\text{g plant}^{-1}\text{day}^{-1}$ upto 60 DAS among the other treatments except treatment T₆. Treatment T₆ i.e. Seed inoculation of *Rhizobium* + PSB + KMB @ 25 g each kg⁻¹ + 75% RDF has absolute growth rate of 0.407 $\text{g plant}^{-1}\text{day}^{-1}$, which was at par with treatment T₅. After 60 DAS treatment T₆ i.e. seed inoculation of *Rhizobium* + PSB + KMB @ 25g each kg⁻¹ + 75% RDF had shown the numerically higher absolute growth rate of 0.263, 0.109

Table 5 : Net Assimilation Rate (NAR) ($\text{g dm}^{-2} \text{ day}^{-1}$) as influenced by different treatments in soybean.

Factors		Net Assimilation Rate (NAR) (g cm ⁻² day ⁻¹)				Dry Matter Content (DMC) (g plant ⁻¹)		
		30-60 DAS	60-90 DAS	90-At Maturity	30 DAS	60 DAS	90 DAS	At Maturity
A.	Main plots: Variety (V)							
V ₁	KDS-726	0.044	0.014	0.0096	3.13	15.04	22.07	24.01
V ₂	KDS-753	0.045	0.014	0.0106	2.85	14.42	21.05	22.69
	S.E. (m) ±	0.0004	0.0002	0.0003	0.04	0.09	0.16	0.18
	CD at 5%	NS	NS	NS	0.26	0.57	0.98	1.07
B.	Sub plots: Treatments (T)							
T ₁	Recommended Dose of fertilizer NPK	0.043	0.0124	0.0094	2.53	13.43	20.52	22.30
T ₂	Seed inoculation of <i>Rhizobium</i> @ 25 g kg ⁻¹ + 100% RDF.	0.046	0.0138	0.0100	2.57	14.85	21.39	22.91
T ₃	Seed inoculation of PSB @ 25 g kg ⁻¹ + 100% RDF.	0.045	0.0137	0.0098	3.03	14.81	21.14	22.90
T ₄	Seed inoculation of KMB @ 25 g kg ⁻¹ + 100% RDF.	0.042	0.0125	0.0096	2.88	14.75	21.00	22.69
T ₅	Seed inoculation of <i>Rhizobium</i> + PSB + KMB @ 25 g each kg ⁻¹ + 100% RDF	0.048	0.0171	0.0122	3.83	17.02	24.18	26.29
T ₆	Seed inoculation of <i>Rhizobium</i> + PSB + KMB @ 25 g each kg ⁻¹ + 75% RDF	0.047	0.0147	0.0109	3.72	15.93	23.82	25.89
T ₇	Absolute Control	0.041	0.0122	0.0087	2.37	12.32	18.84	20.47
	S.E. (m) ±	0.0013	0.0009	0.0006	0.13	0.66	0.93	1.05
	CD at 5%	0.0037	0.0025	0.0017	0.38	1.93	2.71	3.07
C.	Interaction (V x T)							
	S.E. (m) ±	0.002	0.0012	0.0008	0.18	0.93	1.31	1.49
	CD at 5%	NS	NS	NS	NS	NS	NS	NS
	General Mean	0.044	0.0138	0.0095	2.99	14.73	21.55	23.35

$\text{g plant}^{-1} \text{ day}^{-1}$. The lowest absolute growth rate was observed in treatment T₇ i.e. absolute control.

The results shown during the experiment might be due to effect of *mycorrhizal* biofertilizers which enhance the uptake of essential nutrients such as phosphorus and potassium, which are vital for root development, energy transfer, and photosynthesis. Improved nutrient uptake directly contributes to increased biomass and growth rates (Bhardwaj *et al.*, 2014). Similar results were obtained by Islam *et al.* (2017).

Interaction

The interaction effect between varieties and biofertilizer treatments were non-significant in respect

of absolute growth rate.

Net Assimilation Rate (NAR) ($\text{g dm}^{-2} \text{ day}^{-1}$)

The data revealed that there were statistically significant differences in the net assimilation rate of soybean influenced by different treatments. Between 30-60, 60-90 and 90-at maturity the mean values of net assimilation rate were 0.044, 0.0138 and 0.01 $\text{g dm}^{-2} \text{ day}^{-1}$, respectively. NAR presented in Table 5.

Effect of varieties

The difference between net assimilation rate of KDS-726 and KDS-753 were found non-significant at all stages of growth.

Effect of biofertilizer treatment

Biofertilizer treatments had a significant impact on the net assimilation rate (NAR) during 30–60, 60–90, and 90 DAS–maturity. The highest NAR (0.048, 0.0171, and 0.0122 g dm⁻² day⁻¹, respectively) was recorded by treatment T₅ (Rhizobium + PSB + KMB @ 25 g kg⁻¹ seed + 100% RDF). T₆ (same inoculation + 75% RDF) had values that were comparable (0.047, 0.0147, and 0.0109 g dm⁻² day⁻¹). The absolute control had the lowest NAR. The improvement can be ascribed to the synergistic effect of fertilizers and biofertilizers, which increase nutrient availability through nitrogen fixation, phosphate solubilization and potash mobilization (Ravnskov *et al.*, 2019). Comparable results were documented by Munda *et al.* (2013) and Pote (2020).

Interaction

The interaction effect between varieties and biofertilizer treatments were non-significant in respect of net assimilation rate.

Total dry matter content (g plant⁻¹)

The total dry matter content of soybean as influenced statistically significant due to different treatments is presented in Table 5. The dry matter content increased progressively up to harvesting. The mean dry matter content at 30, 60, 90 DAS and at maturity were 2.99, 14.73, 21.55 and 23.35 g, respectively.

Effect of varieties

From the data, it is revealed that, there was significant difference of dry matter content at all growth stages between two varieties. At 30, 60, 90 DAS and at maturity KDS-726 was found significantly superior in dry matter content 3.13, 15.04, 22.07, 24.01 g, respectively over KDS-753.

KDS 726 is specifically bred for higher biomass production and better adaptation to certain climates, which can lead to increased dry matter accumulation compared to KDS 753. KDS 726 may have a more efficient root system or better nutrient uptake capability, allowing it to utilize soil nutrients more effectively, resulting in higher dry matter content. Differences in flowering and maturation times can influence how long the plant has to accumulate biomass before harvest, potentially favouring the KDS 726 variety.

Effect of biofertilizer treatment

The total dry matter content, significantly influenced by different biofertilizer treatments, was recorded as 3.83, 17.02, 24.18 and 26.29 g at 30, 60, and 90 DAS, and at maturity, respectively, were found to be statistically and

significantly superior in treatment T₅ (seed inoculation with Rhizobium + PSB + KMB @ 25 g each kg⁻¹ seed + 100% RDF [50:75:45 N:P₂O₅:K, O kg ha⁻¹]) compared to the rest of the treatments, except T₆. Treatment T₆ (seed inoculation with Rhizobium + PSB + KMB @ 25 g each kg⁻¹ seed + 75% RDF) recorded dry matter content values of 3.72, 15.93, 23.82, and 25.89 g at 30, 60, 90 DAS and at maturity, respectively, which were statistically at par with T₅. The lowest total dry matter content was observed in the absolute control (T₇).

The beneficial effect of Rhizobium, PSB and KMB can be attributed to improved nutrient availability in the soil. In addition, mycorrhizal fungi form symbiotic associations with soybean roots, enhancing root structure and function, which in turn improves water and nutrient uptake, leading to higher dry matter accumulation (Rai *et al.*, 2018). These findings are in close agreement with the results reported by Singaravel *et al.* (2008).

Interaction

The interaction effect between different varieties and biofertilizer treatments were found non-significant in respect of total dry matter content at all stages of growth.

SPAD chlorophyll meter reading (SCMR)

The SCMR reading of soybean as influenced significantly due to different treatments is presented in Table 6. The SCMR increased progressively up to 90 DAS. The mean values of SCMR at 30, 60, 90 DAS and at maturity were 34.76, 43.82, 28.58 and 21.55 cm, respectively.

Effect of varieties

From the data it is revealed that, there was statistically non-significant difference in SCMR at all growth stages between two varieties.

Effect of biofertilizer treatment

The SCMR at 30, 60, 90 DAS and at maturity were influenced significantly due to different biofertilizer treatments. The SCMR at 30, 60, 90 DAS and at maturity 40.01, 50.52, 32.84 and 24.95, respectively, were recorded statistically significantly superior in treatment T₅ (seed inoculation *Rhizobium* + PSB + KMB @ 25g each kg⁻¹ + 100% RDF (50:75:45 N:P₂O₅:K₂O) kg ha⁻¹) than rest of the treatments except treatment T₆. At 30, 60, 90 DAS and at maturity treatment T₆ (seed inoculation of *Rhizobium* + PSB + KMB @ 25g each kg⁻¹ + 75% RDF) recorded the SCMR index of 39.12, 49.02, 31.86 and 23.85, respectively and it was at par with treatment T₅. The lowest chlorophyll content was observed in Absolute Control (T₇).

Table 6 : SPAD chlorophyll meter reading (SCMR) as influenced by different treatments in soybean.

Factors		SCMR values			
		30 DAS	60 DAS	90 DAS	At Maturity
A.	Main plots: Variety (V)				
V ₁	KDS-726	35.39	44.38	28.84	21.63
V ₂	KDS-753	34.14	43.27	28.32	21.46
	S.E. (m) ±	0.31	0.21	0.09	0.06
	CD at 5%	NS	NS	NS	NS
B.	Sub plots: Treatments (T)				
T ₁	Recommended Dose of fertilizer NPK	30.97	39.65	25.77	19.33
T ₂	Seed inoculation of <i>Rhizobium</i> @ 25gkg ⁻¹ + 100% RDF.	37.01	46.65	30.32	22.74
T ₃	Seed inoculation of PSB @ 25 gkg ⁻¹ + 100% RDF.	32.38	40.82	26.53	19.90
T ₄	Seed inoculation of KMB @ 25 gkg ⁻¹ + 100% RDF.	33.69	41.82	27.18	20.39
T ₅	Seed inoculation of <i>Rhizobium</i> + PSB + KMB @ 25g each kg ⁻¹ + 100% RDF	40.01	50.52	32.84	24.95
T ₆	Seed inoculation of <i>Rhizobium</i> + PSB + KMB @ 25g each kg ⁻¹ + 75% RDF	39.12	49.02	31.86	23.85
T ₇	Absolute Control	30.17	38.29	25.56	19.67
	S.E. (m) ±	1.55	2.17	1.51	1.03
	CD at 5%	4.52	6.33	4.41	3.00
C.	Interaction (V x T)				
	S.E. (m) ±	2.19	3.07	2.14	1.45
	CD at 5%	NS	NS	NS	NS
	General Mean	34.76	43.82	28.58	21.55

Rhizobium forms symbiotic relationships with soybean roots, fixing atmospheric nitrogen and making it available to the plant. Increased nitrogen levels enhance chlorophyll synthesis, leading to greener, more vigorous plants (Ghosh *et al.*, 2021).

PSB solubilize phosphorus in the soil, making it more accessible to plants. Phosphorus is essential for energy transfer and chlorophyll synthesis thus; higher availability leads to increased chlorophyll production (Rai *et al.*, 2018).

KMB help in the solubilization of potassium, an essential nutrient that plays a vital role in various physiological processes, including photosynthesis and chlorophyll formation. Adequate potassium levels enhance overall plant health and chlorophyll content (Ahlawat *et al.*, 2019). Similar results were obtained by Shete *et al.* (2019) and Chauhan *et al.* (2023).

Conclusion

The current study specifically documented that the combination of *Rhizobium*, PSB, and KMB in consortia,

along with 100% RDF, markedly improved the growth attributes, physiological traits and yield parameters of soybean under *Kharif* conditions. Among the seven different treatments, T₅ (seed inoculation with *Rhizobium* + PSB + KMB @ 25 g each kg⁻¹ seed + 100% RDF) consistently exceptional results in terms of plant height, branching pattern, leaf area, physiological traits (LAI, CGR, AGR, NAR, SCMR), dry matter accumulation and yield parameters, followed closely by T₆ (Seed inoculation of *Rhizobium* + PSB + KMB @ 25g each/kg + 75% RDF), which was statistically at par for most parameters. The rate of nutrient absorption, photosynthetic efficiency, and biomass production were significantly accelerated by the stimulating effects of biological nitrogen fixation, phosphorus solubilization, and potassium mobilization. Higher yield and productivity resulted from this. These findings suggested that using consortium biofertilizer technology could reduce the need for chemical fertilizers while maintaining or enhancing crop performance in an environmentally friendly and economical manner. Such integrated nutrient management techniques can be crucial

for maintaining soil health, optimizing resource utilization, and ensuring the long-term productivity of soybean-based production systems in the absence of rainfall.

Author's contribution

P. M. Patil: Conducted research trial, observations, data collection, review collection, data analysis, interpretation of results, draft manuscript preparation and study conception and design.

Dr. R. S. Shaikh: Served as research guide and scientific advisor

Suraj Gund: Reviewed the manuscript.

Dr. V.R. Awari: Reviewed the manuscript.

All authors reviewed the results and approved the final version of the manuscript.

Acknowledgments

I extend my sincere thanks to Dr. R. S. Shaikh (major advisor) and to my advisory committee members for giving me proper guidance throughout the research. The co-operation provided by the entire staff of Agricultural Botany is sincerely acknowledged. All the respondents of the study area who helped me directly or indirectly are greatly acknowledged.

References

- Aduloju, M.O., Mahmood J. and Abayomi Y.A. (2009). Evaluation of soybean (*Glycine max* L.) genotypes for adaptability to Southern Guinea Savanna environment with and without P fertilizer application in north Central Nigeria. *Afr. J. Agricult. Res.*, **4**, 556-563.
- Ahlawat, I.P.S., Kumar R. and Singh A. (2019). Effect of integrated nutrient management on growth and yield of soybean (*Glycine max* L.). *Indian J. Agron.*, **64**(1), 16-21.
- Aslam, M. and Mirza M.S. (1995). Crop Production Bulletin No.6, *Pakistan Agricultural Research Council*, Islamabad, Pakistan. pp. 1- 20.
- Banerjee, A., Jayantha K.D. and Naba K. Mondal (2012). Changes in morpho physiological traits of mustard under the influence of different fertilizers and plant growth regulators cycocel. *J. Saudi Soc. Agricult. Sci.*, **11**, 89-97.
- Bansal, R.K. (2015). Synergistic effect of *Rhizobium*, PSB and PGPR on nodulation and seed yield of mung bean. *Int. J. Agricult. Biol.*, **15**.
- Bhardwaj, S.K., Jha P.N. and Singh S. (2014). Role of mycorrhizal fungi in improving nutrient uptake and growth of soybean. *Afr. J. Microbiol. Res.*, **8**(9), 932-939.
- Chauhan, A., Singh V.K., Sharma A. and Jeena K. (2023). Effect of organic and bio fertilizer on growth and yield of soyabean (*Glycine max*) in doon valley of Uttarakhand.
- Ghosh, D., Saha S. and Bhattacharya A. (2021). Impact of biofertilizers on growth and yield of soybean. *Plant Growth Regulation*, **93**(1), 37-49.
- Ghosh, S., Singh S. and Kumar A. (2020). Effect of biofertilizers on growth and yield of soybean (*Glycine max* L. Merr.) in rainfed conditions. *Int. J. Chem. Stud.*, **8**(1), 205-208.
- Herliana, O., Harjoso T., Anwar A.H.S. and Fauzi A. (2019). The Effect of *Rhizobium* and N Fertilizer on Growth and Yield of Black Soybean (*Glycine max* L Merrill). *Earth Environ. Sci.*, **255**, 012015.
- Islam, M.S., Ahmed M., Hossain M.S., Akter H. and Aktar S. (2017). Response of soybean to *Rhizobium* biofertilizer under different levels of phosphorus. *Progressive Agriculture*, **28**(4), 302-315, ISSN: 1017 – 8139.
- Jadhav, V., Karjule A., Gagare K. and Shelar V. (2021). Screening for morphophysiological, seed yield and quality parameters in soybean genotypes (*Glycine max* (L.) Merrill). *The Pharma Innov. J.*, **10**(12), 49-53.
- Jaga, P.K. and Sharma S. (2015). Effect of biofertilizer and fertilizers on productivity of soybean. *Annals Plant Soil Res.*, **17**(2), 171-174.
- Manjaya, J.G. and Bapat V.A. (n.d.). Studies on genetic divergence in soybean, *Glycine max* (L). *J. Oilseeds Res.*, **25**(2), 178-180.
- Munda, S., Shivakumar B.G., Gangaiah B., Rana D.S., Manjaiah K.M., Lakshman K. and LAYEK J. (2013). Response of soybean (*Glycine max*) to phosphorus with or without biofertilizers. *Indian J. Agron.*, **58**(1), 86-90.
- Pandey, V.P. and Pandey M.P. (1995). Biofertilizers as the cheapest source of nitrogen. *Farmer and Parliament*, **30**(8), 9-10.
- Panse, V.G. and Sukhatme P.V. (1985). *Statistical methods for agricultural workers*, ICAR publications, New Delhi, India. 359.
- Parr, J.F. (2002). Beneficial and effective microorganisms for a sustainable agriculture and environment. *Int. Nature Farming Res. Center* (INFRC), Atami, Japan.
- Pote, C.K. (2020). Effect of liquid biofertilizers on morpho-physiology and yield attributes of soybean [*Glycine max* (L.) Merrill] (*Doctoral dissertation*, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani).
- Rai, A.K., Singh S. and Kumar A. (2018). Effect of biofertilizers on growth, yield and nutrient uptake of soybean (*Glycine max* L.). *J. Agricult. Sci. Technol.*, **20**(3), 543-554.
- Ramesh, P., Reddy G. and Rao R. (2019). Impact of biofertilizers on soil properties and growth of soybean. *Journal of Soil Sci. Plant Nutr.*, **19**(3), 1-10.
- Rana, A., Joshi M., Prasanna R., Shivay Y.S. and Nain L. (2012). Biofortification of wheat through inoculation of plant growth promoting *Rhizobacteria* and *cyanobacteria*. *Europ. J. Soil Biol.*, **50**, 118-26.
- Ravnskov, S. et al. (2019). Mycorrhizal fungi and nutrient uptake in plants: A review. *Fungal Ecology*, **38**, 116-123.
- Sharma, A., Vyas M.D., Gulaiya S., Singh P.P., Kochle P. and Sharma B.K. (2021). Effect of liquid biofertilizer and

- inorganic nutrients application on growth, physiology and productivity of soybean (*Glycine max* L. Merrill).
- Shete, M.H., Murumkar D.R., Tirmali A.M. and Landge K.B. (2019). Formulation of culture media for growth of nitrogen fixing, phosphate solubilizing and potash mobilizing bacteria in a consortium. *J. Plant Dis. Sci.*, **14(1)**, 41-46.
- Singaravel, R., Suhatiya K., Vembu G. and Kamaraj S. (2008). Effect of liquid biofertilizer on the nutrient content and uptake of okra. *Asian J. Soil. Sci.*, **3(2)**, 217-219.
- Singh, N., Joshi E., Sasode D.S., Sikarwar R.S. and Rawat G.S. (2018). Liquid biofertilizer and inorganic nutrients effect on physiological, quality parameters and productivity of *kharif* groundnut (*Arachis hypogaea* L.). *Int. J. Curr. Microbiol. Appl. Sci.*, **7(9)**, 729-735.
- Vance, C.P. (1997). *Biological fixation of N₂ for ecology and sustainable agriculture*. Springer-Verlag, p. 179.
- Vyas, M.D. and Khandwe R. (2014). Effect of row spacing and seed rate on morphophysiological parameters, yield attributes and productivity of soybean (*Glycine max* L. Merrill) cultivars under rainfed condition of Vindhyan plateau of Madhya Pradesh. *Soybean Research*, **12(1)**, 82-91.