



Influence of Different Microbial Strains and Their Consortia on Yield and Nutrient Uptake in Soybean Grown on Vertisol

Shubhashree Jena ^{a++*}, A.L. Dhamak ^{a#},
Sravanthi Yelagada ^{b++} and Hrusikesh Patra ^{c†}

^a Department of Soil Science, Vasantrya Naik Marathwada Krishi Vidyapeeth, Parbhani 431 402, Maharashtra, India.

^b Department of Soil Science, Punjab Agricultural University, Ludhiana, 141027, Punjab, India.

^c Department of Soil Science, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, 741252, India.

Authors' contributions

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

Article Information

DOI: <https://doi.org/10.9734/ijpss/2025/v37i85651>

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://pr.sdiarticle5.com/review-history/141744>

Original Research Article

Received: 30/05/2025
Published: 05/08/2025

ABSTRACT

The present field experiment was undertaken at Research Farm, Department of Soil Science, College of Agriculture, Vasantrya Naik Marathwada Krishi Vidyapeeth, Parbhani during *kharif* season of 2023. Ten different treatment combinations were used in the experiment which included different microbial cultures and their consortia *i.e* *Rhizobium spp.* + *Bacillus megaterium* (Consortia -I), *Rhizobium spp.* + *Frateuria aurantia* (Consortia-II), *Rhizobium spp.* + *Thiobacillus thiooxidans*

⁺⁺M.Sc. Research Scholar;

[#]Associate Professor;

[†]Ph.D. Research Scholar;

*Corresponding author: E-mail: shubhashreejena2000@gmail.com;

Cite as: Jena, Shubhashree, A.L. Dhamak, Sravanthi Yelagada, and Hrusikesh Patra. 2025. "Influence of Different Microbial Strains and Their Consortia on Yield and Nutrient Uptake in Soybean Grown on Vertisol". *International Journal of Plant & Soil Science* 37 (8):506-14. <https://doi.org/10.9734/ijpss/2025/v37i85651>.

(Consortia-III), *Rhizobium spp.* + *Pseudomonas striata* (Consortia-IV), *Rhizobium spp.* + *Bacillus megaterium* + *Frateuria aurantia* (Consortia- V), *Rhizobium spp.* + *Bacillus megaterium* + *Thiobacillus thiooxidans* (Consortia- VI), *Rhizobium spp.* + *Bacillus megaterium* + *Pseudomonas striata* (Consortia- VII) and control replicated thrice in RBD (Randomized Block Design). Seed treatment of soybean was done with microbial consortia @ 10 ml kg⁻¹ seed before sowing with recommended dose of fertilizers. Among all the treatments, *Rhizobium spp.* + *Bacillus megaterium* + *Frateuria aurantia* (Consortia- V) higher seed and straw yield of soybean (1863.26 and 2999.84 kg ha⁻¹ respectively). Furthermore, total uptake of NPK was found significantly higher (130.65, 24.71 and 57.81 kg ha⁻¹) with consortia -V. Study concludes that recommended dose of fertilizers with microbial consortia helped in improving yield and nutrient content in plants and seeds of soybean grown in Vertisol. It emphasises the use of microbial inoculants—which are economical and environmentally friendly than synthetic fertilisers, which have detrimental effects on the soil and environment, this research is significant for sustainable agriculture.

Keywords: Microbial consortia; soybean; yield; nutrient uptake; Vertisol.

1. INTRODUCTION

Soybean (*Glycine max*) annual legume of the pea family *Fabaceae* with the subfamily *Papilionaceae*. It is also known as the “wonder bean” and “gold of the 21st century”. The origins of the soybean plant are obscure, but many botanists believe it was first domesticated in central China as early as 7000 BCE. An ancient crop, the soybean has been used in China, Japan, and Korea for thousands of years as food and a component of medicines. Soybean is also known as an oilseed crop. It contains 20% oil with 40% protein content. It is common knowledge that soybean, as a legume crop, fixes atmospheric nitrogen into the soil and it also adds roughly 32 to 35 Qt/ha of crop residue at harvest season, which not only increases soil fertility but also keeps the soil in good shape. In India, during *Kharif* 2023, the area under soybean was 118.54 lakh hectares with a production of 118.74 lakh MT. Among the states, Madhya Pradesh stood first with 52.647 Lakh MT production followed by Maharashtra with 46.91 Lakh MT. The average yield was higher in Maharashtra and Madhya Pradesh at 1028 and 1008 kg/ha during the same period SOPA (SOPA, 2023). The increase in the human population is expected to lead to an increase in global crop demand in the future, however, agricultural production cannot be sufficient for the estimated demand Tilman et al. (2011). Soybean is used to make a variety of fresh, fermented and dried foods such as milk, bean sprouts, and soy sauce. Additionally, soybean oil is extracted and used in several industrial and food-related operations.

However, traditional farming methods that mostly rely on inorganic inputs raise issues since they

affect the nutritional value of product, farmers' livelihoods, and customers. Kumar et al. (2021). In response to these issues, using the consortium of microorganisms as an inoculant has a lot of significance because each microorganism has its own plant growth-promoting properties; hence, evaluating their performance in the field environment had paramount importance in validating efficient microbial inoculants that can be used for improving the productivity of soybean. Crop productivity and soil fertility have been shown to be improved by inoculation with microbial strains such as *Rhizobium* and phosphate-solubilizing microorganisms Sahu et al. (2023). Although rhizobia, which are known for their capacity to colonise the rhizosphere and produce nodules in plant roots, are used as conventional inoculants, new research indicates that combining *Rhizobium* in consortia with other advantageous microbes result in greater advantages. These include enhancement the growth of the host plant and its associated microorganisms; in contrast to conventional fertilizers and pesticides, PGPMS breakdown extremely quickly; resistance development is minimal; and it can be used in conventional or integrated management systems. Berg (2009); Kaur et al. (2020). Additionally, this research is important for sustainable agriculture because it focuses on using microbial inoculants, which are environmentally friendly and cost-effective, instead of chemical fertilizers that negatively impact the soil and environment.

2. MATERIALS AND METHODS

2.1 Experimental Site

The field experiment was carried at Research Farm, Department of Soil Science, Vasantrao

Naik Marathwada Agricultural University, Parbhani (MAH), during *kharif* 2023, which is situated at the Parbhani district in the Godawari drainage basin in the heart of India between 76°46' East longitude and 19°16' North latitude and Marathwada division of Maharashtra state which is elevated to 410 m above mean sea level. The area experiences semi- arid weather, with an average annual precipitation of 1017 mm, it is in an agro- climatic zone with assured monsoon rains. The mean daily maximum temperature varied from 28.0 to 34.5°C. The mean daily minimum temperature varied from 18.6 to 34.5°C. The mean daily maximum relative humidity varied from 74 to 100% and the mean daily minimum relative humidity varied from 33 to 80%. The soils of the region are medium to deep black (Vertisol). The soil had a clay-like texture, was moderately alkaline in response, had low levels of readily accessible nitrogen, available phosphorus and high levels of readily available potassium, but had deficient in Fe and Zn and sufficient in Cu and Mn.

2.2 Experimental Design

Ten treatments were used in the experiment, viz. T₁ Absolute control, T₂ Recommended Dose of Fertilizer (RDF), T₃ Recommended Dose of Fertilizer (RDF) + *Rhizobium spp.*, T₄ Recommended Dose of Fertilizer RDF + *Rhizobium spp.* + *Bacillus megaterium* (PSB), T₅ Recommended Dose of Fertilizer (RDF) + *Rhizobium spp.* + *Frateuria aurantia* (KSB), T₆ Recommended Dose of Fertilizer (RDF) + *Rhizobium spp.* + *Thiobacillus thiooxidans* (SSB), T₇ Recommended Dose of Fertilizer (RDF) + *Rhizobium spp.* + *Pseudomonas striata* (ZnSB), T₈ Recommended Dose of Fertilizer (RDF) + *Rhizobium spp.* + *Bacillus megaterium* (PSB) + *Frateuria aurantia* (KSB), T₉ Recommended Dose of Fertilizer (RDF) + *Rhizobium spp.* + *Bacillus megaterium* (PSB) + *Thiobacillus thiooxidans* (SSB), T₁₀ Recommended Dose of Fertilizer (RDF) + *Rhizobium spp.* + *Bacillus megaterium* (PSB) + *Pseudomonas striata* (ZnSB), the experiment was laid out in a Randomized Block Design (RBD) with ten treatments and three replications. plot size of field was 4.5 m x 4.0 m and a total number of plots 30. Row to Row and Plant to plant spacing was 45 x 5 cm.

2.3 Seed Inoculation and Sowing

Rhizobium spp. with *Bacillus megaterium* (Consortia-I), *Rhizobium spp.* with *Frateuria*

aurantia (Consortia-II), *Rhizobium spp.* with *Thiobacillus thiooxidans* (Consortia-III), *Rhizobium spp.* with *Pseudomonas striata* (Consortia-IV), *Rhizobium spp.* with *Bacillus megaterium* and *Frateuria aurantia* (Consortia-V), *Rhizobium spp.* with *Bacillus megaterium* and *Thiobacillus thiooxidans* (Consortia-VI), *Rhizobium spp.* with *Bacillus megaterium* and *Pseudomonas striata* (Consortia-VII) were obtained from ICAR - All India Network Project on Soil Biodiversity – Biofertilizers, Parbhani Center and used for seed treatment @ 10 ml per kg of soybean seed. Seed treatment was done before sowing. Seeds were dried in shed and used for sowing as dibbling. The variety of soybean is MAUS-158. method of sowing was dibbling and Seeds were sown at the rate of 65 kg ha⁻¹ for soybean. The fertilizers were applied @ N: P₂O₅ : K₂O 30:60:30 kg ha⁻¹ respectively. Urea, single super phosphate and muriate of potash were used as fertilizer sources. The soybean crop MAUS-158 was seeded on 5 th July, 2023 and harvested on 17th October, 2023 by adopting all the recommended package of practices. After threshing individually seed and stover samples were weighed (kg ha⁻¹) and data were recorded plot-wise. Samples were collected from each plot for further NPK and micronutrients analyses in seed and straw. The seed and straw of soybean was taken to determine nutritional consistence. For the determination of nitrogen content in soybean crop micro Kjeldahl method was used AOAC (1990), for phosphorus content of the seed and dry matter was estimated spectro-photometrically by the vanado molybdate phosphoric acid yellow color method Piper (1966) and potassium content in seed and dry matter was determined from the diluted di - acid extract on a Flame Photometer Jackson (1973). On the basis on nutrient content the nutrient uptake of soybean was calculated in kg ha⁻¹. The total zinc, total iron, total manganese and total copper from seed and dry matter samples were estimated from di-acid extract digest with proper dilution using an Atomic Absorption Spectrophotometer with different wavelengths after proper dilution Lindsay and Norvell (1978). Uptake of nutrients was calculated by considering biological dry matter yield (*i.e.* grain and whole plant) and concentration of the particular nutrient.

Nutrient uptake of seed and straw for major nutrients (NPK):

$$\text{Uptake (kg ha}^{-1}\text{)} = (\text{Nutrient content (\%)} \times \text{Yields of seed or dry matter (kg ha}^{-1}\text{)}) / 100.$$

Total uptake (kg ha⁻¹) = Seed uptake (kg ha⁻¹) + Dry matter uptake (kg ha⁻¹)

Nutrient uptake of seed and straw for micro nutrients (Fe, Mn, Zn and Cu):

Uptake (kg ha⁻¹) = (Nutrient content (%) x Yields of seed or dry matter (kg ha⁻¹)) / 1000.
Total uptake (kg ha⁻¹) = Seed uptake (kg ha⁻¹) + Dry matter uptake (kg ha⁻¹)

3. RESULTS AND DISCUSSION

3.1 Seed and Straw Yield

The seed yield of soybean was observed maximum *ie.*, 1863.26 kg ha⁻¹ in treatment T₈ RDF + *Rhizophos* + KSB, (Consortia-V), followed by treatment T₉ RDF + *Rhizophos* + ZnSB, (Consortia-VII), (1840.00 kg ha⁻¹). Significantly lowest seed yield was observed in T₁ (absolute control). And straw yield significantly highest (2999.84 kg ha⁻¹) was obtained from treatment receiving T₈ RDF + *Rhizophos* + KSB (Consortia-V) followed by treatment T₁₀ RDF + *Rhizophos* + ZnSB (Consortia-VII), (2944.00 kg ha⁻¹) (Table 1). Increase in seed and straw yield due to the combined effects of NPK fertiliser and biofertilizers helped to fit the necessary pattern of soybean absorption by releasing nutrients into the soil solution at a slow and consistent rate, increasing yield. The results closely match those of Ekta Joshi et al. (2018) and Jaga and Sharma (2015), who found that NPK + VAM + *Rhizobium* + PSB increased soybean production. Navasare et al. (2019) also observed in soybeans. Along with the release of indole acetic acid, which aids in the mobilization of fixed phosphorus, potassium and improves the supply of nutrients to plants and root nodulation, may be the cause of the higher seed yield in biofertilizer-inoculated treatments. Jaybhay et al. (2017) and Virk et al. (2017).

3.2 Major Nutrient (NPK) Uptake in Seed and Straw (kg ha⁻¹) of Soybean

Nutrient uptake (NPK) of soybean was significantly influenced by microbial inoculants and their consortia with RDF. The seed N uptake ranges from 57.33 to 102.04 kg ha⁻¹, straw N uptake 10.96 to 29.60 kg ha⁻¹ and total uptake of N was ranged from 68.29 to 131.64 kg ha⁻¹ (Table 2). Nutrient uptake observed maximum in treatment T₈ RDF + *Rhizophos* + KSB, (Consortia-V). These results align with those of Nimnoi et al. (2014), who highlighted the advantages of endophytic actinomycetes as co-

inoculants with *Bradyrhizobium japonicum*. Furthermore, the study that reaffirmed the importance of microbial inoculation in enhancing soybean plants' uptake of nutrients was corroborated by Kumar et al. (2021). The phosphorus uptake of seed 3.80 to 11.06 kg ha⁻¹, straw 4.93 to 15.09 kg ha⁻¹ and total uptake was 8.73 to 26.15 kg ha⁻¹ (Table 2) was recorded Nutrient uptake observed maximum in treatment T₈ RDF + *Rhizophos* + KSB. Nirmal et al. (2006) state that when *Rhizobium* and PSB were infected simultaneously, their associative effects and solubilization of non-exchangeable to labile form increased the availability of P in the soil. Aechra et al. (2017) stated that co-inoculation of *Rhizobium* and PSB improved phosphorous uptake. However, the highest uptake of K by seed 15.65 to 31.61 kg ha⁻¹, straw 10.41 to 26.20 kg ha⁻¹ and total uptake was 26.06 to 57.81 kg ha⁻¹ (Table 2). The release of organic acids mediated by soil microorganisms and the possible enhancement of K nutrition made possible by the inoculation of PGPR as a biofertilizer are probably responsible for this result Sahu et al. (2023). Sahu et al. (2021) discovered that KSB seed inoculation enhanced crop growth, yield, plant height, and grain and shoot weight, all of which contributed to a superior crop's uptake of potassium from the soil.

3.3 Iron and Manganese Uptake (g ha⁻¹)

The highest uptake values of iron in soybean seed *ie* 124.32 g ha⁻¹, straw-137.83 g ha⁻¹ and total- 262.15 g ha⁻¹ were found statistically significantly high showing maximum values in treatment T₈ (RDF + *Rhizophos*+ KSB) was at par with treatment T₁₀ (RDF + *Rhizophos* + ZnSB) has iron uptake seed-123.58 g ha⁻¹, straw-136,54 g ha⁻¹ and total- 260.12 g ha⁻¹. Whereas, uptake of iron noticed lowest in treatment T₁ (absolute control) *ie.*, seed- 61.80 g ha⁻¹, straw-63.07 g ha⁻¹ and total-124.87 g ha⁻¹ (Table 3). Kumar et al. (2016) showed that co inoculation of *Rhizobium* and *Trichoderma viride* along with RDF enhanced the yield, nutrient content, nutrient uptake and quality of soybean crop. Bagmare, (2019) reported that inoculation of *Pseudomonas spp.* and *Azospirillum spp.* produced the most siderophores, which enhanced uptake of iron in green gram. The maximum uptake of manganese in seed 99.89 g ha⁻¹, straw- 132.15 g ha⁻¹ and total 232.04 kg ha⁻¹ by soybean were found statically significant showing maximum values in treatment T₈ (RDF+ *Rhizophos* + KSB), was at par with treatment T₁₀ (RDF+ *Rhizophos* + ZnSB) seed- 99.76 g ha⁻¹, straw- 131.63 g ha⁻¹ and total- 231.38 g ha⁻¹.

Table 1. Effect of different microbial cultures and their consortia on seed and straw yield of soybean

Treatment detail	Seed yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)
T ₁ : Absolute control	1117.67	1826.50
T ₂ :RDF	1563.63	2345.44
T ₃ :RDF+ <i>Rhizobium</i> inoculation	1640.02	2525.63
T ₄ :RDF+ <i>Rhizophos</i> inoculation	1786.26	2822.29
T ₅ :RDF + <i>Rhizobium</i> + KSB inoculation	1683.19	2608.94
T ₆ : RDF + <i>Rhizobium</i> + SSB inoculation	1687.85	2633.04
T ₇ : RDF + <i>Rhizobium</i> + ZnSB inoculation	1689.44	2652.42
T ₈ : RDF + <i>Rhizophos</i> + KSB inoculation	1863.26	2999.84
T ₉ : RDF + <i>Rhizophos</i> + SSB inoculation	1825.00	2901.75
T ₁₀ : RDF + <i>Rhizophos</i> + ZnSB inoculation	1840.00	2944.00
SE(m) ±	7.30	13.55
C.D at 5%	21.68	40.27

Table 2. Effect of different microbial cultures and their consortia on uptake of macronutrients by soybean

Treatment detail	N uptake (kg ha ⁻¹)			P uptake (kg ha ⁻¹)			K uptake (kg ha ⁻¹)		
	Seed	Straw	Total	Seed	Straw	Total	Seed	Straw	Total
T ₁ : Absolute control	57.33	10.96	68.29	3.80	4.93	8.73	15.65	10.41	26.06
T ₂ :RDF	81.79	16.42	98.20	5.99	7.27	13.26	23.09	15.25	38.33
T ₃ :RDF+ <i>Rhizobium</i> inoculation	86.76	19.19	105.95	6.95	8.84	15.79	24.93	17.34	42.27
T ₄ :RDF+ <i>Rhizophos</i> inoculation	96.28	24.37	120.64	8.93	12.14	21.07	28.58	21.73	50.31
T ₅ :RDF + <i>Rhizobium</i> + KSB inoculation	89.88	21.14	111.02	7.63	9.91	17.54	26.59	19.57	46.17
T ₆ : RDF + <i>Rhizobium</i> + SSB inoculation	90.58	22.12	112.70	8.21	11.06	19.28	26.05	18.70	44.75
T ₇ : RDF + <i>Rhizobium</i> + ZnSB inoculation	90.89	22.55	113.44	8.05	10.88	18.93	26.36	19.37	45.72
T ₈ : RDF + <i>Rhizophos</i> + KSB inoculation	102.04	29.60	131.64	11.06	15.09	26.15	31.61	26.20	57.81
T ₉ : RDF + <i>Rhizophos</i> + SSB inoculation	99.61	26.50	126.11	10.55	14.80	25.35	30.25	23.79	54.04
T ₁₀ :RDF + <i>Rhizophos</i> + ZnSB inoculation	101.58	29.15	130.73	9.88	13.84	23.72	30.73	24.73	55.46
SE(m) ±	0.88	0.20	0.96	0.20	0.20	0.31	0.22	0.19	0.26
C.D at 5%	2.63	0.60	2.85	0.59	0.59	0.91	0.65	0.55	0.77

Table 3. Effect of different microbial cultures and their consortia on uptake of iron and manganese by soybean

Treatment detail	Fe uptake (g ha ⁻¹)			Mn uptake (g ha ⁻¹)		
	Seed	Straw	Total	Seed	Straw	Total
T ₁ :Absolute control	61.80	63.07	124.87	47.93	60.98	108.91
T ₂ :RDF	92.85	90.56	183.41	71.65	85.16	156.81
T ₃ :RDF+ <i>Rhizobium</i> inoculation	100.09	101.71	201.79	77.35	95.17	172.44
T ₄ :RDF+ <i>Rhizophos</i> inoculation	115.25	123.48	238.72	91.50	117.77	209.28
T ₅ :RDF + <i>Rhizobium</i> + KSB inoculation	103.80	106.71	210.50	79.74	98.80	178.55
T ₆ : RDF + <i>Rhizobium</i> + SSB inoculation	104.65	108.55	213.20	84.39	106.64	191.03
T ₇ : RDF + <i>Rhizobium</i> + ZnSB inoculation	107.50	113.93	221.44	85.85	109.60	195.45
T ₈ :RDF + <i>Rhizophos</i> + KSB inoculation	124.32	137.83	262.15	99.89	132.15	232.04
T ₉ : RDF + <i>Rhizophos</i> + SSB inoculation	119.91	129.97	249.88	95.35	123.50	218.84
T ₁₀ :RDF + <i>Rhizophos</i> + ZnSB inoculation	123.58	136.54	260.12	99.76	131.63	231.38
SE(m) ±	2.30	2.98	3.61	2.06	0.57	2.06
C.D at 5%	6.83	8.87	10.72	6.12	1.71	6.11

Table 4. Effect of different microbial cultures and their consortia on uptake of zinc and copper by soybean

Treatment detail	Zn uptake (g ha ⁻¹)			Cu uptake (g ha ⁻¹)		
	Seed	Straw	Total	Seed	Straw	Total
T ₁ :Absolute control	34.27	35.38	69.65	30.58	25.63	56.11
T ₂ :RDF	55.17	56.29	111.46	45.72	37.22	82.95
T ₃ :RDF+ <i>Rhizobium</i> inoculation	63.96	69.96	133.92	50.18	43.54	93.73
T ₄ :RDF+ <i>Rhizophos</i> inoculation	78.80	92.60	171.40	60.13	57.24	117.36
T ₅ :RDF + <i>Rhizobium</i> + KSB inoculation	68.45	76.62	145.07	53.13	47.46	100.59
T ₆ : RDF + <i>Rhizobium</i> + SSB inoculation	69.76	79.07	148.84	53.64	48.47	102.11
T ₇ : RDF + <i>Rhizobium</i> + ZnSB inoculation	71.34	82.04	153.38	54.63	50.26	104.89
T ₈ :RDF + <i>Rhizophos</i> + KSB inoculation	88.27	107.65	195.92	72.78	74.79	147.57
T ₉ : RDF + <i>Rhizophos</i> + SSB inoculation	82.76	98.41	181.17	68.81	72.33	141.14
T ₁₀ :RDF + <i>Rhizophos</i> + ZnSB inoculation	87.58	106.87	194.45	72.11	73.96	146.07
SE(m) ±	1.03	0.88	1.28	1.35	0.30	1.25
C.D at 5%	3.06	2.61	3.80	4.00	0.88	3.72

However, uptake of manganese recorded lowest value in treatment T₁ (absolute control) ie, seed- 47.93 g ha⁻¹, straw- 60.98 g ha⁻¹ and total- 108.91 g ha⁻¹ (Table 3). Gamit and Tank (Gamit & Tank, 2014) reported that inoculating *Cajanas cajan* with *Pseudomonas pseudoalcaligenes* which produces siderophore, due to acidification of PGPR it enhances the uptake of Fe, Cu, Mn, Zn, Co, Ni and Al. The role of microbial isolates boosts the growth of plants. Soliman et al. (2012) stated that the supply of Mn through organics as a result of mineralization may be responsible for the rise in Mn uptake.

3.4 Zinc and Copper Uptake (g ha⁻¹)

The highest uptake of zinc in seed - 88.27 g ha⁻¹, straw- 107.65 g ha⁻¹ and total- 195.92 kg ha⁻¹ by soybean were found statistically significant showing maximum values in treatment T₈ (RDF + *Rhizophos* + KSB) which was at par with treatment T₁₀ (RDF *Rhizophos* + ZnSB) has zinc uptake in seed- 87.58g ha⁻¹, straw- 106.87g ha⁻¹ and total- 194.45 g ha⁻¹. However, uptake of zinc was recorded lowest value in treatment T₁ ie., absolute control in seed 34.27g ha⁻¹, straw- 35.38g ha⁻¹ and total 69.65g ha⁻¹ (Table 4). According to Jadhav (2021) there was a statistically significant interaction between zinc solubilizers and zinc levels. The results showed that *Pseudomonas striata* treatment with 30 kg ZnSO₄ ha⁻¹ had the maximum seed, straw, and total Zn uptake of pigeon pea. Significantly highest uptake of copper seed 72.78 g ha⁻¹, straw- 74.79 g ha⁻¹ and total 147.57 kg ha⁻¹ by soybean were found statistically significant showing maximum values in treatment T₈ (RDF + *Rhizophos*+ KSB) was at par with treatment T₁₀ (RDF + *Rhizophos* + ZnSB) has copper uptake in seed – 72.11 g ha⁻¹, straw- 73.96 g ha⁻¹ and total- 146.07g ha⁻¹. Whereas, uptake of copper recorded lowest value in treatment T₁ absolute control seed- 30.58 g ha⁻¹, straw 25.63 g ha⁻¹ and total- 56.11 g ha⁻¹ (Table 4). According to Gurumurthy et al. (2009), The PSB seed inoculation to soybean with N, P, and K treatment increased grain and straw Cu uptake. According to the results of Jayant Raman's (Raman, 2012) experiment, a combination of *Pseudomonas striata*, *Trichoderma viride*, and *Azotobacter chroococcum* inoculation produced the maximum quantity of copper.

4. CONCLUSION

The results of the investigation showed that the application of the *Rhizobium spp.* + *Bacillus*

megaterium + *Frateuria aurantia* (Consortia -V) as seed inoculation along with 100 per cent recommended dose of fertilizers performed as the best consortium for enhancing seed and stover yield of soybean. Similarly for nutrient uptake of N, P and K, micronutrients viz., Fe, Mn Cu and Zn.

By enhancing biological nitrogen fixation, solubilising nutrients, and promoting root development, the use of microbial strains and their consortia improves soybean production and nutrient uptake in Vertisols. A sustainable substitute for chemical fertilisers is the integrated use of microbial consortia, particularly in black soils that lack nutrients mostly.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

- A.O.A.C. (1990). *Official methods of analysis* (15th ed.). Association of Official Analytical Chemists.
- Aechra, Yadav, B. L., Ghosalya, B. D., & Bamboriya. (2017). Effect of soil salinity, phosphorus and biofertilizers on physical properties of soil, yield attributes and yield of cowpea (*Vigna unguiculata* (L.) Wilczek). *Journal of Pharmacognosy & Phytochemistry*, 6(4), 1691–1695.
- Bagmare, R. R. (2019). *Growth promoting influence of siderophore producing microorganism in green gram* (Master's thesis). Vasantarao Naik Marathwada Krishi Vidyapeeth, Parbhani.
- Berg, G. (2009). Plant–microbe interactions promoting plant growth and health: Perspective for controlled use of microorganisms in agriculture. *Applied Microbial Biotechnology*, 84, 11–18.
- Gamit, D. A., & Tank, S. K. (2014). Effect of siderophore producing microorganisms on plant growth of *Cajanas cajan* (pigeon pea). *International Journal of Research in Pure and Applied Microbiology*, 4(1), 20–27.

- Gurumurthy, K. T., Leena, N., & Prakasha, H. C. (2009). Micronutrient uptake and yield of soybean (*Glycine max* (L.) Merrill) as influenced by integrated nutrient management practices. *Mysore Journal of Agriculture Science*, 23, 883–886.
- Jackson, M. L. (1973). *Soil chemical analysis*. Prentice Hall of India Pvt. Ltd.
- Jadhav, S. M. (2021). *Investigation on effect of zinc solubilizing microorganisms on growth, yield and nutrient availability in pigeonpea (Cajanus cajan) on Vertisol* (Ph.D. thesis). Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani.
- Jaga, P. K., & Sharma, S. (2015). Effect of bio-fertilizer and fertilizers on productivity of soybean. *Annals of Plant and Soil Research*, 17(2), 171–174.
- Jaybhay, S. A., Taware, S. P., & Varghese, P. (2017). Microbial inoculation of *Rhizobium* and phosphate-solubilizing bacteria along with inorganic fertilizers for sustainable yield of soybean (*Glycine max* (L.) Merrill). *Journal of Plant Nutrition*, 40(2), 209–216.
- Joshi, E., Gupta, V., Sasode, D. S., Tiwari, S., Sikarwar, R. S., & Singh, N. (2018). Liquid biofertilizer and inorganic nutrients application impact on quality traits and physiology of Kharif groundnut. In *National Conference "Current Trends in Plant Science and Molecular Biology for Food Security and Climate Resilient Agriculture" Proceedings* (pp. 67–74).
- Kaur, D., Rana, K., Lata, K., Yadav, A., Kumar, M., Kumar, V., Vyas, P., Singh, D. H., & Kumar, S. A. (2020). Microbial biofertilizers: Bio sources and eco-friendly technologies for agricultural and environmental sustainability. *Biocatalysis and Agricultural Biotechnology*, 23, 10487.
- Kumar, B., Kranthi, Ismail, S., Pawar, A., & Manasa, K. (2016). Effect of Zn solubilizing microbial cultures on yield, nutrient uptake and quality of soybean. *Ecology Environment and Conservation*, 22, 339–346.
- Kumar, S., Sahu, R. K., Thakur, R. K., Yaduwanshi, B., & Mitra, N. G. (2021). Effect of microbial inoculants on plant attributes and nutrients uptake by soybean in vertisols. *International Journal of Plant & Soil Science*, 33(18), 102–109.
- Lindsay, W. L., & Norvell, W. A. (1978). Development of DTPA soil testing for Zn, Fe, Mn and Cu. *Soil Science Society of America Journal*, 42(10), 421–428.
- Navasare, G. J., Aglave, B. N., & Sathe, R. K. (2019). Effect of nodulation and quality of soybean (*Glycine max* (L.) Merrill) as influenced by biofertilizers. *International Journal of Chemical Studies*, 7(2), 670–672.
- Nimnoi, P., Pongsilp, N., & Lumyong, S. (2014). Co-inoculation of soybean (*Glycine max*) with actinomycetes and *Bradyrhizobium japonicum* enhances plant growth, nitrogenase activity and plant nutrition. *Journal of Plant Nutrition*, 37(3), 432–446.
- Nirmal, D., Singh, R. K., Kumar, A., & Singh, J. (2006). Effect of organic inputs and biofertilizers on biomass, quality and yield parameters of vegetable pea (*Pisum sativum* L.). *International Journal of Agriculture Science*, 2, 618–620.
- Piper, C. S. (1966). *Soil plant analysis*. Hans Publication.
- Raman, J. (2012). Response of *Azotobacter*, *Pseudomonas* and *Trichoderma* on growth and apple seedling. In *International Conference on Biology Life Science* (IPCBE, Vol. 40, pp. 83–90).
- Sahu, R. K., Kumar, S., Thakur, R., & Mitra, N. G. (2023). Effects of bioinoculants on total chlorophyll content, yield of soybean and fertility status of a vertisols. *Journal of Experimental Agriculture International*, 45(12), 250–256.
- Sahu, S. K., Singh, A. K., & Gupta, S. B. (2021). Effect of K solubilizing bacteria isolates on performance of maize in Inceptisol of Chhattisgarh. *The Pharma Innovation Journal*, 10(10), 1496–1498.
- Soliman, A. H., Abeer, A., Mahmoud, & Gendy, A. (2012). Effect of fertilizers on growth, yield and active ingredients of safflower plant under sandy soil condition. *Journal of Applied Science Research*, 8, 5572–5578.
- SOPA. (2023). *The Soybean Processors Association of India*. Indore, Madhya Pradesh. <https://www.sopa.org>
- Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture.

Proceedings of the National Academy of Sciences, 108(50), 20260–20264.

Virk, H. K., Singh, G., & Sharma, P. (2017). Productivity, nutrient uptake, energy indices and profitability of soybean (*Glycine max*) as influenced by planting methods, *Bradyrhizobium* and plant growth promoting rhizobacteria. *Indian Journal of Agronomy*, 62, 341–347.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2025): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:

<https://pr.sdiarticle5.com/review-history/141744>