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# Effect of Different Bio-Fertilizer on Plant and Soil in Different Stages of Rice in *Vertisol* of Chhattisgarh Plain, India

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.*

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## ABSTRACT

**Background:** The extensive use of chemical fertilizers and agrochemicals has led to soil degradation, reduced microbial diversity, increased vulnerability to pests and diseases, and adverse environmental consequences. The excessive dependence on chemical inputs in rice cultivation has resulted in declining soil fertility and environmental concerns, necessitating a shift toward sustainable alternatives.

**Aim:** This research seeks to provide insights into sustainable agricultural practices that can mitigate the adverse effects of chemical fertilizers while ensuring food security and environmental sustainability.

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**Methods:** A field experiment was conducted at the Department of Agricultural Microbiology, Instructional Cum Research Farm, College of Agriculture, IGKV, Raipur (C.G.), India during the *Kharif* season of 2023-24. The study aimed to evaluate the impact of bio-fertilizers on rice growth, yield, and soil properties under different nutrient management treatments. The experiment comprised seven treatments, including control ($T_1$), 100% RDF ($T_2$), 75% RDF ($T_3$), and combinations of 75% RDF with bio-fertilizers such as *Azospirillum* ($T_4$), phosphate-solubilizing bacteria (PSB) ($T_5$), potassium-solubilizing bacteria (KSB) ($T_6$), and an integrated approach combining PSB, KSB, and *Azospirillum* ($T_7$).

**Results:** The study indicated that bio-fertilizer treatments significantly influenced plant height, tiller number, panicle count, biomass accumulation, and grain yield. At 30, 60, and 90 days after transplanting (DAT), $T_7$ consistently recorded the tallest plants (86.92 cm at 90 DAT), followed by $T_2$ (87.31 cm), highlighting the role of *Azospirillum* and KSB in enhancing plant growth. Similarly, $T_7$ exhibited the highest tiller count (5.33 at 90 DAT) and maximum panicle number (5.13 at 90 DAT), underscoring the beneficial effects of bio-fertilizers in promoting tillering and panicle formation. Grain yield was highest in $T_2$ (40.60 Q/ha), followed closely by $T_7$ (40.51 Q/ha), while the control ($T_1$) had the lowest yield (23.40 Q/ha), demonstrating the importance of nutrient supplementation in rice productivity. The straw yield was significantly higher in $T_7$ (52.82 Q/ha), further validating the effectiveness of integrating bio-fertilizers with reduced chemical fertilizers. Test weight was also improved, with $T_7$ (27.43 g) and $T_4$ (27.03 g) recording the highest values, emphasizing enhanced seed quality.

**Discussion:** Soil analysis at different growth stages indicated no significant changes in pH and organic matter content but revealed notable improvements in soil nitrogen, phosphorus, and potassium levels at harvest, particularly in bio-fertilizer-treated plots. The microbial inoculation of bio-fertilizers enhanced rhizosphere activity, thereby improving soil-plant interactions, nutrient uptake, and overall crop performance.

**Conclusion:** The study concludes that the application of bio-fertilizers in combination with 75% RDF ($T_7$) significantly improves rice growth, yield, and soil health, offering a sustainable alternative to full chemical fertilization.

*Keywords: Bio-fertilizers; rice growth and yield; soil nutrient availability; plant height and tillers; grain and straw yield.*

## 1. INTRODUCTION

Rice (*Oryza sativa L.*) is a staple food crop that sustains a significant portion of the global population, particularly in Asia, where it forms the dietary foundation for nearly half of the region's inhabitants. Asia contributes over 90% of the world's rice production and consumption, with India being one of the leading producers (Bandumula, 2018). The increasing global demand for rice necessitates advancements in cultivation practices to enhance productivity while ensuring sustainability.

However, the extensive use of chemical fertilizers and agrochemicals has led to soil degradation, reduced microbial diversity, increased vulnerability to pests and diseases, and adverse environmental consequences. These challenges highlight the urgency of adopting eco-friendly and sustainable agricultural practices.

In India, rice is cultivated across 43.86 million hectares, with an annual production of 104.80 million tons, ranking second globally after China. The crop accounts for approximately 40–43% of the country's total food grain production, playing a pivotal role in food security and rural livelihoods (Pavithra *et al.,* 2021). Chhattisgarh, often referred to as the "Rice Bowl of India," is a major rice-producing state, with over 70% of its agricultural land dedicated to rice cultivation. The predominant cultivation systems include monocropping in rainfed areas and rice-rice cropping in perennially irrigated regions (Karamchedu, 2024).

Despite its importance, the excessive dependence on chemical inputs in rice cultivation has resulted in declining soil fertility and environmental concerns, necessitating a shift toward sustainable alternatives.

Biofertilizer is one of the sources that support chemical fertilizers. Biofertilizers are potential environmentally friendly supplemental inputs for healthy plant growth. It is a component made up of living, helpful bacteria that, when added to soil, surfaces, or plant seeds, colonize the plant's rhizosphere and promote development by giving the host plant more essential nutrients or by giving it phytohormones. With their host plants, biofertilizers engage in symbiotic and associative microbial interactions (Nguyen Hoang et al., 2025; Gehlot et al., 2024).

Biofertilizers, composed of beneficial microorganisms such as nitrogen-fixing bacteria (Rhizobium, *Azospirillum*), phosphate-solubilizing bacteria (Pseudomonas), and mycorrhizal fungi, have emerged as a promising solution to address these challenges. These microorganisms enhance nutrient availability, improve soil health, and contribute to sustainable agricultural practices.

In Chhattisgarh, where Vertisols dominate the agricultural landscape, the application of biofertilizers offers a viable approach to enhancing rice productivity while minimizing environmental impact. This study aims to evaluate the effectiveness of biofertilizers in rice cultivation, focusing on their role in improving soil properties, nutrient uptake, and overall crop productivity. By analyzing the mechanisms of biofertilizer action and their impact on rice yield, this research seeks to provide insights into sustainable agricultural practices that can mitigate the adverse effects of chemical fertilizers while ensuring food security and environmental sustainability.

## 2. MATERIALS AND METHODS

The research was conducted at the Department of Agricultural Microbiology, Instructional Cum Research Farm, College of Agriculture, IGKV Raipur (C.G.). The study focused on the rice variety Proteozinc, conducted during the Kharif season of 2023–2024 in an open-field experiment at the mid-eastern Chhattisgarh plains. Raipur is situated at 21°23' North latitude and 81°69' East longitude, at an elevation of 289.5 meters above mean sea level. The region experiences a sub-tropical climate with high temperatures reaching above 48°C in summer, monsoon rainfall of about 1,300 mm, and winter temperatures as low as 5°C.

The field experiment followed a Randomized Block Design (RBD) with three replications and seven treatments evaluating biological nitrogen fixation (BNF) biofertilizers—Phosphate Solubilizing Bacteria (PSB), Potash Solubilizing Bacteria (KSB), and *Azospirillum*, in comparison to synthetic NPK fertilizers. The experimental plots measured 7 × 3 $m^2$, with a spacing of 10 × 20 cm. The rice seedlings were transplanted 25 days after sowing (DAS), and cultural operations such as irrigation, weed control, and disease management were carried out following standard agronomic practices.

The biofertilizers *Azospirillum*, PSB, and KSB were procured from the Department of Agricultural Microbiology Repository, College of Agriculture, IGKV Raipur (C.G.). The seven treatments included Control ($T_1$), 100% RDF ($T_2$), 75% RDF ($T_3$), 75% RDF + *Azospirillum* ($T_4$), 75% RDF + PSB ($T_5$), 75% RDF + KSB ($T_6$), and 75% RDF + PSB + KSB + *Azospirillum* ($T_7$). Fertilizer application involved 50% of nitrogen (N) and 100% of phosphorus (P) and potassium (K) applied before transplanting, while the remaining 50% nitrogen was applied at the panicle initiation and flowering stages.

Observations were recorded at 30, 60, and 90 days after transplanting (DAT) and at harvest. Growth parameters included plant height, number of tillers per plant, and panicle count, while yield parameters comprised grain yield, straw yield, 1000-seed weight, and dry shoot weight. Soil samples were analyzed for pH, electrical conductivity, organic carbon content, and available NPK levels before and after harvest. The collected data were statistically analyzed using Analysis of Variance (ANOVA) (Gomez & Gomez, 1984), and treatment means were compared at a 5% probability level ($p \leq 0.05$).

This structured methodology ensures the reliability and reproducibility of results, providing insights into the role of biofertilizers in rice cultivation under *Vertisol* conditions.

## 3. RESULTS AND DISCUSSION

### 3.1 Effect of Bio-Fertilizers on Plant Growth Parameters

**Plant height (cm) at different growth stages:** Plant height was recorded at 30, 60, and 90 days after transplanting (DAT) (Table 1, Fig. 1). At 30 DAT, the tallest plants were observed in T7 (75% RDF + PSB + KSB + *Azospirillum*) (52.18 cm), followed by $T_2$ (RDF 100%) (51.63 cm), whereas the control ($T_1$) had the shortest height (43.84 cm). The positive influence of *Azospirillum* on early plant growth was evident, particularly in $T_4$ and $T_7$.

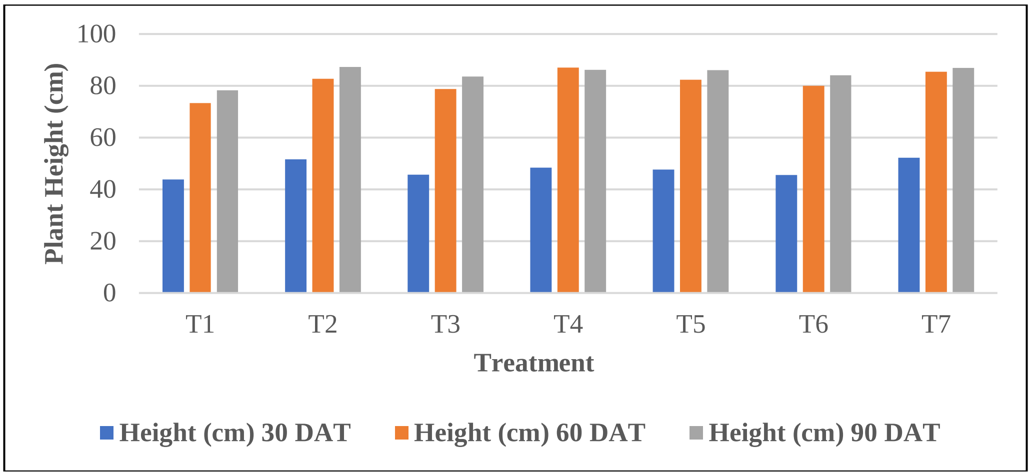


**Fig. 1. Effect of different biofertilizer on plant height of paddy grown in *Vertisol* under Chhattisgarh plain**

**Table 1 Effect of different biofertilizer on plant height of paddy grown in *Vertisol under* Chhattisgarh plain**

| | | Plant Height (cm) | | |
|---|---|---|---|---|
| **Notations** | **Treatments** | **30 DAT** | **60 DAT** | **90 DAT** |
| $T_1$ | CONTROL | 43.84 | 73.37 | 78.32 |
| $T_2$ | RDF 100% | 51.63 | 82.77 | 87.31 |
| $T_3$ | 75% RDF | 45.68 | 78.82 | 83.60 |
| $T_4$ | 75% RDF + *AZOSPIRILIUM* | 48.37 | 87.03 | 86.23 |
| $T_5$ | 75% RDF + PSB | 47.72 | 82.40 | 86.06 |
| $T_6$ | 75% RDF + KSB | 45.54 | 80.00 | 84.05 |
| $T_7$ | 75% RDF + PSB + KSB + *AZOSPIRILIUM* | 52.18 | 85.47 | 86.92 |
| | **S E m (±)** | **1.448** | **2.593** | **1.703** |
| | **C.D. (P=0.05)** | **4.461** | **7.990** | **5.248** |

At 60 DAT, the tallest plants were recorded in $T_4$ (87.03 cm), followed closely by $T_7$ (85.47 cm), both outperforming $T_2$ (82.77 cm) and $T_5$ (82.40 cm). The control remained the shortest (73.37 cm). At 90 DAT, $T_7$ continued to perform well (86.92 cm), slightly higher than $T_2$ (87.31 cm) and $T_4$ (86.23 cm), indicating the cumulative effect of biofertilizers in maintaining plant height. Statistical analysis confirmed significant differences among treatments ($p \leq 0.05$). These results align with Isahak et al. (2012), who reported that biofertilizers enhance rice plant growth by improving nitrogen and phosphorus availability.

**Number of tillers per plant:** The number of tillers per plant at 60 and 90 DAT varied significantly across treatments (Table 2, Fig. 2). At 60 DAT, the highest tiller count was recorded in $T_7$ (5.23 tillers/plant), followed by $T_2$ (5.03 tillers/plant), while the control ($T_1$) had the lowest (3.03 tillers/plant). Similar trends were observed at 90 DAT, where $T_7$ (5.33 tillers/plant) performed best, slightly ahead of $T_2$ (5.10 tillers/plant), whereas $T_1$ remained the lowest (3.37 tillers/plant). Statistical analysis showed a critical difference (C.D.) of 0.598 at 60 DAT and 0.999 at 90 DAT, indicating that biofertilizers significantly enhance tillering ability.

**Number of panicles per plant:** The number of panicles per plant was significantly influenced by treatments (Table 3, Fig. 3). At 60 DAT, $T_7$ had the highest panicle count (4.93 per plant), followed by $T_2$ (4.60 per plant), whereas $T_1$ had the lowest (2.80 per plant). At 90 DAT, $T_7$ continued to perform best (5.13 panicles per plant), followed by $T_2$ (4.90 panicles per plant). The inclusion of PSB, KSB, and *Azospirillum* in $T_7$ contributed to the higher number of panicles by improving nutrient availability and uptake.

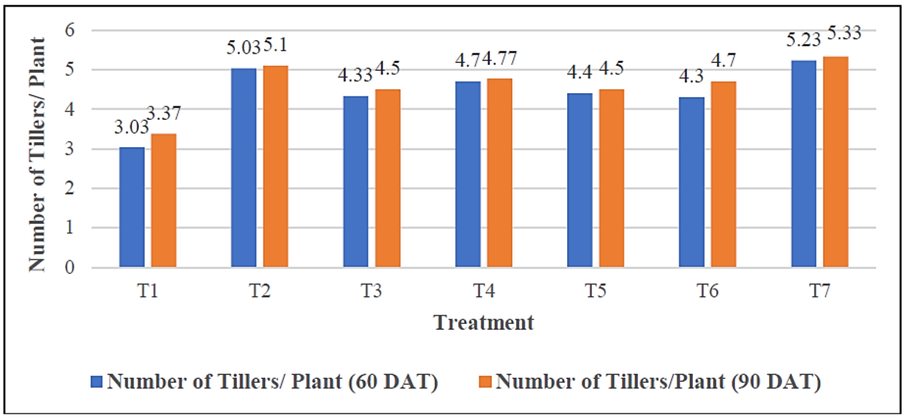


**Fig. 2. Effect of different biofertilizer on number of tillers per plant in paddy grown in *Vertisols* under Chhattisgarh plains**

**Table 2. Effect of different biofertilizer on number of tillers per plant in paddy grown in *Vertisols* under Chhattisgarh plains**

| | | Number of tillers per plant | |
|---|---|---|---|
| **Notations** | **Treatments** | **60 DAT** | **90DAT** |
| **$T_1$** | CONTROL | 3.03 | 3.37 |
| **$T_2$** | RDF 100% | 5.03 | 5.10 |
| **$T_3$** | 75% RDF | 4.33 | 4.50 |
| **$T_4$** | 75% RDF + *AZOSPIRILIUM* | 4.70 | 4.77 |
| **$T_5$** | 75% RDF + PSB | 4.40 | 4.50 |
| **$T_6$** | 75% RDF + KSB | 4.30 | 4.70 |
| **$T_7$** | 75% RDF + PSB + KSB + *AZOSPIRILIUM* | 5.23 | 5.33 |
| | **S E m (±)** | **0.194** | **0.324** |
| | **C.D. (P=0.05)** | **0.598** | **0.999** |

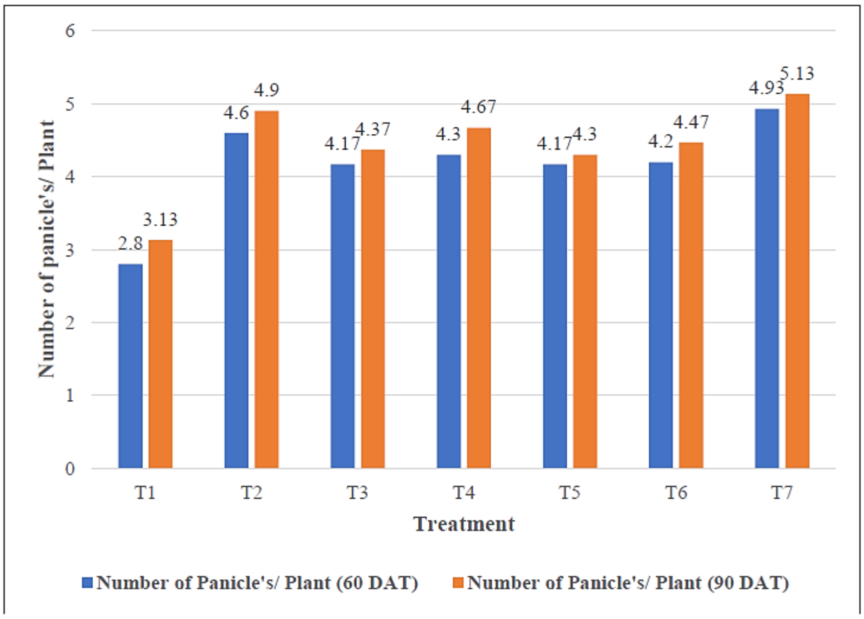


**Fig. 3. Effect of different biofertilizer on number of panicles per plant in paddy grown in *Vertisols* under Chhattisgarh plains**

**Table 3. Effect of different biofertilizer on number of panicles per plant in paddy grown in *Vertisols* under Chhattisgarh plains**

| | | Number of Panicle's per Plant | |
|---|---|---|---|
| **Notations** | **Treatments** | **60 DAT** | **90DAT** |
| **$T_1$** | CONTROL | 2.80 | 3.13 |
| **$T_2$** | RDF 100% | 4.60 | 4.90 |
| **$T_3$** | 75% RDF | 4.17 | 4.37 |
| **$T_4$** | 75% RDF + *AZOSPIRILIUM* | 4.30 | 4.67 |
| **$T_5$** | 75% RDF + PSB | 4.17 | 4.30 |
| **$T_6$** | 75% RDF + KSB | 4.20 | 4.47 |
| **$T_7$** | 75% RDF + PSB + KSB + *AZOSPIRILIUM* | 4.93 | 5.13 |
| | **S E m (±)** | **0.235** | **0.224** |
| | **C.D. (P=0.05)** | **0.723** | **0.690** |

**Table 4. Effect of different biofertilizer on shoot dry weight and seed weight biomass of paddy grown in *Vertisol* under Chhattisgarh plain**

| **Notations** | **Treatments** | **Dry Weight/ Plant (gm/plant)** | **Seed Weight/ Plant (gm/plant)** |
|---|---|---|---|
| **$T_1$** | CONTROL | 6.10 | 5.16 |
| **$T_2$** | RDF 100% | 7.27 | 8.60 |
| **$T_3$** | 75% RDF | 7.63 | 7.37 |
| **$T_4$** | 75% RDF + *AZOSPIRILIUM* | 7.97 | 8.20 |
| **$T_5$** | 75% RDF + PSB | 7.73 | 7.60 |
| **$T_6$** | 75% RDF + KSB | 7.80 | 7.43 |
| **$T_7$** | 75% RDF + PSB + KSB + *AZOSPIRILIUM* | 8.20 | 8.06 |
| | **S E m (±)** | **0.382** | **0.324** |
| | **C.D. (P=0.05)** | **1.178** | **0.999** |

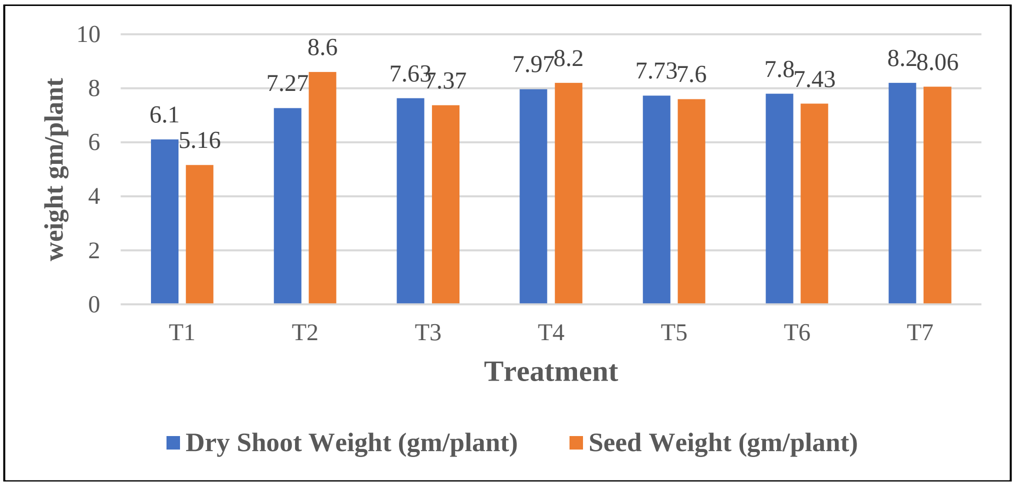


**Fig. 4. Effect of different biofertilizer on shoot dry weight and seed weight biomass of paddy grown in *Vertisol* under Chhattisgarh plains**

### 3.2 Crop Yield Parameters

**Shoot dry weight and grain weight:** The dry weight per plant was significantly affected by treatments (Table 4, Fig. 4). T7 recorded the highest dry weight (8.20 g/plant), significantly higher than the control (6.10 g/plant). T4 (7.97 g/plant) and $T_6$ (7.80 g/plant) also showed notable improvements over $T_3$ (75% RDF). Grain weight followed a similar trend, with $T_2$ (8.60 g/plant) achieving the highest value, followed by $T_4$ (8.20 g/plant) and $T_7$ (8.06 g/plant). The lowest grain weight was observed in the control (5.16 g/plant), confirming that biofertilizers enhance grain development.

**Grain and straw yield:** Grain yield varied significantly among treatments (Table 5, Fig. 5). $T_2$ (RDF 100%) produced the highest grain yield (40.60 Q/ha), closely followed by $T_7$ (40.51 Q/ha). The control had the lowest yield (23.40 Q/ha), underscoring the importance of balanced nutrient management. Straw yield was highest in $T_7$ (52.82 Q/ha), followed by $T_2$ (49.87 Q/ha). These findings align with studies by Simarmata et al*.*, (2016), Marlina et al., (2014), and Nahar et al*.*, (2016), which support the positive role of biofertilizers in improving crop yield.

### 3.3 Soil Properties

**Soil pH and organic carbon content:** Soil pH remained relatively stable across treatments, with no significant differences at 30, 60 DAT, and post-harvest (Table 6, Fig.6) & (Table 6, Fig. 6). Similarly, organic carbon content showed no significant variations, indicating that biofertilizers did not alter these parameters considerably.

**Soil nutrient availability:** Significant differences were observed in available nitrogen (N), phosphorus (P), and potassium (K) levels at harvest (Table 8, Fig. 8). $T_2$ recorded the highest residual nitrogen (271.73 kg/ha), followed closely by $T_7$ (267.61 kg/ha) and $T_4$ (263.42 kg/ha), confirming that biofertilizers improve nitrogen retention. Phosphorus was highest in $T_5$ (22.13 kg/ha), demonstrating the effectiveness of PSB in solubilizing phosphorus. Potassium levels remained statistically unchanged, with $T_7$ recording the highest value (471.36 kg/ha).

### 3.4 Microbial Growth and Soil Enzymatic Activity

**Microbial population:** The microbial population varied significantly among treatments (Table 9, Fig. 9). $T_7$ consistently supported higher bacterial (56.00 $\times 10^7$ cfu/g soil), fungal (14.00 $\times 10^4$ cfu/g soil), and actinomycete (44.00 $\times 10^6$ cfu/g soil) populations, confirming the positive role of biofertilizers in sustaining microbial diversity.

**Table. 5 Effect of different biofertilizer on grain yield and straw yield on paddy grown in *Vertisol* under Chhattisgarh plain**

| | | Grain Yield | | Straw Weight | |
|---|---|---|---|---|---|
| **Notations** | **Treatments** | **Kg/Plot** | **Q/ha** | **Kg/Plot** | **Q/ha** |
| **$T_1$** | CONTROL | 4.91 | 23.40 | 7.09 | 33.78 |
| **$T_2$** | RDF 100% | 8.53 | 40.60 | 10.47 | 49.87 |
| **$T_3$** | 75% RDF | 7.65 | 36.43 | 8.35 | 39.78 |
| **$T_4$** | 75% RDF + *AZOSPIRILIUM* | 8.11 | 38.63 | 10.35 | 49.27 |
| **$T_5$** | 75% RDF + PSB | 8.02 | 38.17 | 9.14 | 43.54 |
| **$T_6$** | 75% RDF + KSB | 7.83 | 37.27 | 8.77 | 41.78 |
| **$T_7$** | 75% RDF + PSB + KSB + *AZOSPIRILIUM* | 8.51 | 40.51 | 11.09 | 52.82 |
| | **S E m (±)** | **0.341** | **1.801** | **0.617** | **2.937** |
| | **C.D. (P=0.05)** | **1.050** | **5.551** | **1.901** | **9.051** |

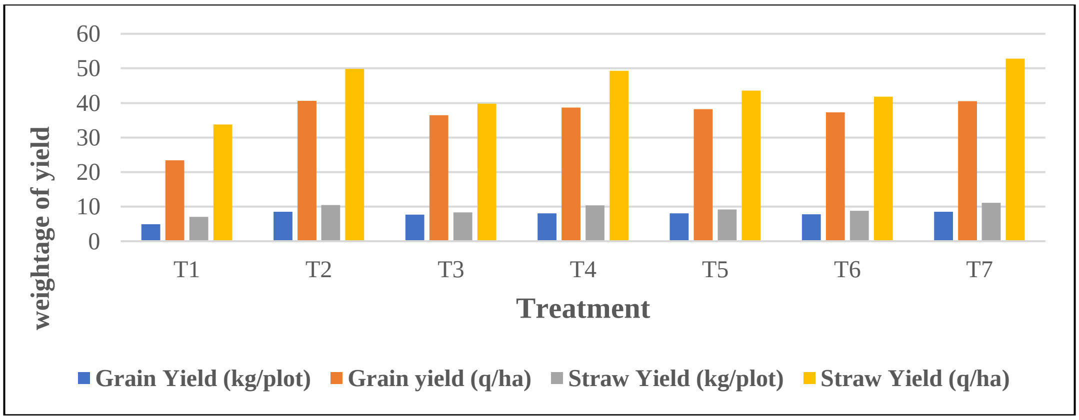


**Fig. 5. Effect of biofertilizer on grain yield and straw yield**

**Table 6. Effect of different bio-fertilizers on soil pH of paddy crop grown in *Vertisols* under Chhattisgarh plain**

| | | pH | | |
|---|---|---|---|---|
| **Notations** | **Treatments** | **30 DAT** | **60 DAT** | **At Harvest** |
| **$T_1$** | CONTROL | 7.40 | 7.43 | 7.50 |
| **$T_2$** | RDF 100% | 7.67 | 7.53 | 7.47 |
| **$T_3$** | 75% RDF | 7.57 | 7.67 | 7.53 |
| **$T_4$** | 75% RDF + *AZOSPIRILIUM* | 7.53 | 7.43 | 7.50 |
| **$T_5$** | 75% RDF + PSB | 7.50 | 7.53 | 7.43 |
| **$T_6$** | 75% RDF + KSB | 7.50 | 7.60 | 7.63 |
| **$T_7$** | 75% RDF + PSB + KSB + *AZOSPIRILIUM* | 7.30 | 7.57 | 7.57 |
| | **S E m (±)** | **NS** | **NS** | **NS** |
| | **C.D. (P=0.05)** | **NS** | **NS** | **NS** |

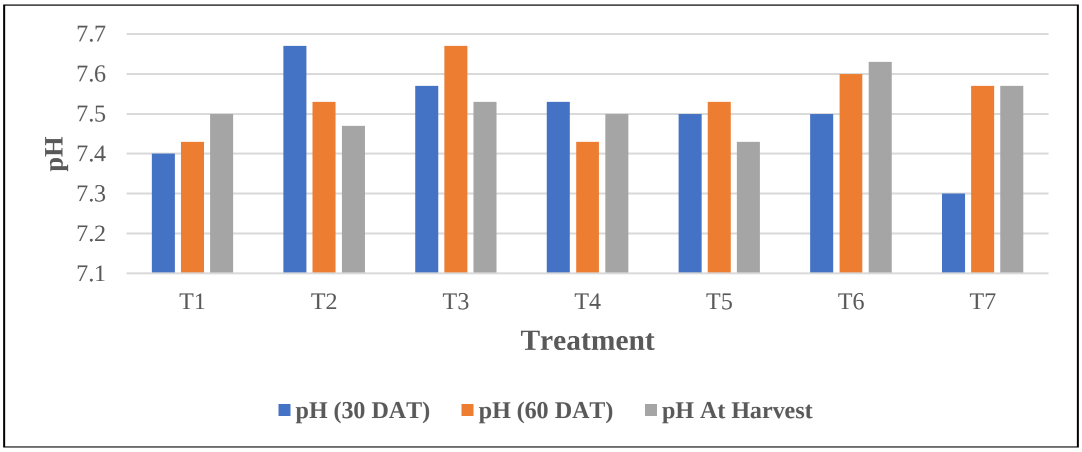


**Fig. 6. Effect of different bio-fertilizer on soil pH of paddy crop grown in *Vertisols* under Chhattisgarh plain**

**Table. 7 Effect of different bio-fertilizer on soil organic carbon content of paddy grown *Vertisols* under Chhattisgarh plain**

| | | SOIL ORGANIC MATTER (%) | | |
|---|---|---|---|---|
| **Notations** | **Treatments** | **30 DAT** | **60 DAT** | **(At Harvest)** |
| **$T_1$** | CONTROL | 0.43 | 0.48 | 0.47 |
| **$T_2$** | RDF 100% | 0.51 | 0.58 | 0.57 |
| **$T_3$** | 75% RDF | 0.54 | 0.58 | 0.54 |
| **$T_4$** | 75% RDF + *AZOSPIRILIUM* | 0.62 | 0.57 | 0.51 |
| **$T_5$** | 75% RDF + PSB | 0.52 | 0.51 | 0.54 |
| **$T_6$** | 75% RDF + KSB | 0.54 | 0.55 | 0.54 |
| **$T_7$** | 75% RDF + PSB + KSB + *AZOSPIRILIUM* | 0.51 | 0.54 | 0.50 |
| | **S E m (±)** | **NS** | **NS** | **NS** |
| | **CD(P=0.05)** | **NS** | **NS** | **NS** |

**Dehydrogenase activity:** Soil enzymatic activity, measured as dehydrogenase activity, varied significantly across treatments (Table 10, Fig. 10). T5 (0.67 µg TPF $g^{-1}$ soil $h^{-1}$ at 60 DAT) and T6 (0.97 µg TPF $g^{-1}$ soil $h^{-1}$ at 90 DAT) showed the highest enzymatic activity, indicating enhanced microbial metabolism in biofertilizer-treated plots.

The results demonstrate that integrating PSB, KSB, and *Azospirillum* with 75% RDF ($T_7$)

enhances plant growth, crop yield, soil nutrient availability, and microbial activity, proving its effectiveness as a sustainable alternative to chemical fertilizers.

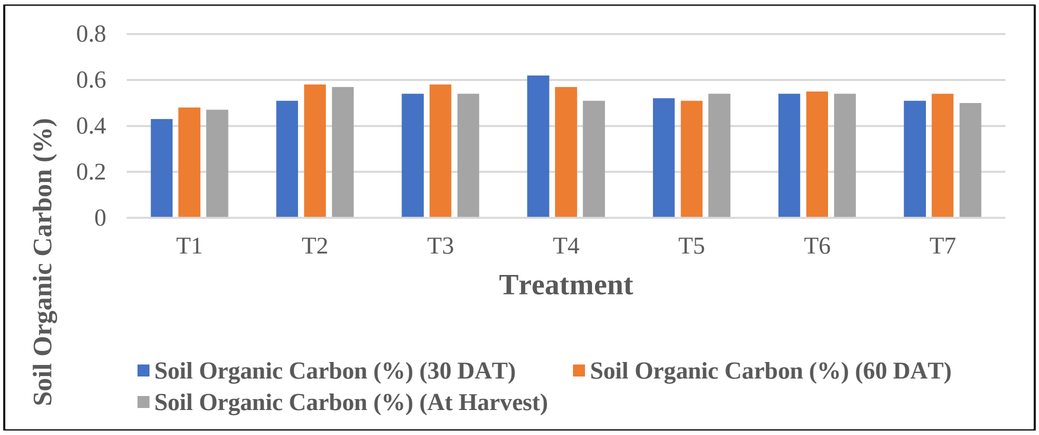


**Fig. 7. Effect of different bio-fertilizers on soil organic carbon content of paddy grown *Vertisols* under Chhattisgarh plain**

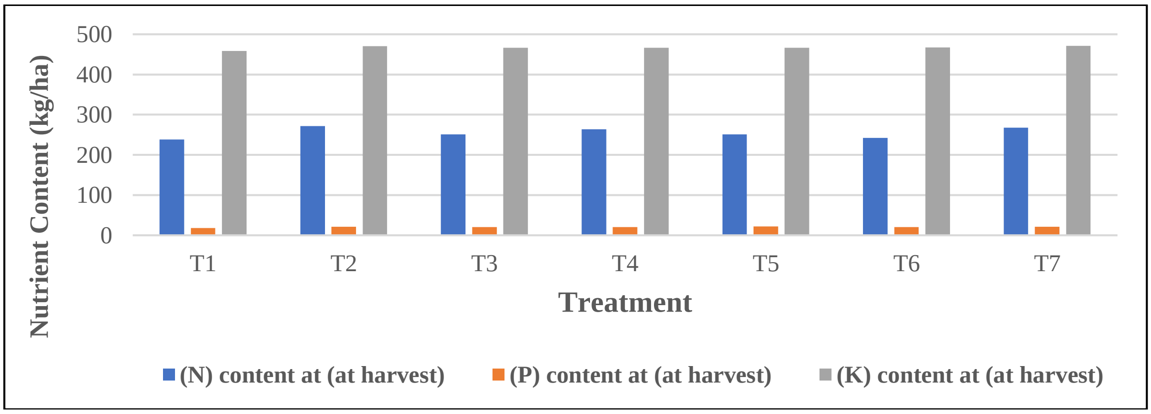


**Fig. 8. Variation in residual nutrient content in soil due to application of different bio-fertilizer**

**Table 8. Variation in residual nutrient content in soil due to application of different bio-fertilizer**

| | | Soil Nutrient Content (Available Form) (kg/ha) | | |
|---|---|---|---|---|
| | | N | P | K |
| **Notations** | **Treatments** | **(at harvest)** | **(at harvest)** | **(at harvest)** |
| **$T_1$** | CONTROL | 238.34 | 18.28 | 458.64 |
| **$T_2$** | RDF 100% | 271.73 | 21.10 | 470.44 |
| **$T_3$** | 75% RDF | 250.88 | 20.22 | 466.72 |
| **$T_4$** | 75% RDF + *AZOSPIRILIUM* | 263.42 | 20.64 | 466.45 |
| **$T_5$** | 75% RDF + PSB | 250.88 | 22.13 | 466.30 |
| **$T_6$** | 75% RDF + KSB | 242.52 | 20.25 | 467.33 |
| **$T_7$** | 75% RDF + PSB + KSB + *AZOSPIRILIUM* | 267.61 | 21.46 | 471.36 |
| | **S E m (±)** | **8.103** | **0.667** | **NS** |
| | **CD(P=0.05)** | **24.969** | **2.055** | **NS** |

**Table 9. Variation in microbial growth in paddy crop due to application of different bio-fertilizers**

| | | Microbial Population (cfu/gm soil) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Bacteria(x10$^7$) | | | Fungi (x10$^4$) | | | Actinomycetes(x10$^{6)}$ | | |
| **Notations** | **Treatments** | **30 DAT** | **60 DAT** | **POST HARVEST** | **30 DAT** | **60 DAT** | **POST HARVEST** | **30 DAT** | **60 DAT** | **POST HARVEST** |
| **$T_1$** | CONTROL | 54.33 | 53.67 | 46.00 | 18.00 | 18.00 | 11.00 | 36.33 | 41.33 | 39.00 |
| **$T_2$** | RDF 100% | 49.00 | 43.67 | 39.33 | 18.33 | 19.33 | 14.33 | 41.67 | 46.00 | 43.00 |
| **$T_3$** | 75% RDF | 46.67 | 61.67 | 44.00 | 22.33 | 21.33 | 15.67 | 42.67 | 41.67 | 46.00 |
| **$T_4$** | 75% RDF + *AZOSPIRILIUM* | 52.33 | 67.00 | 52.67 | 17.67 | 22.33 | 16.33 | 45.33 | 45.67 | 45.33 |
| **$T_5$** | 75% RDF + PSB | 51.00 | 66.67 | 52.00 | 19.67 | 19.33 | 16.00 | 36.00 | 48.67 | 42.67 |
| **$T_6$** | 75% RDF + KSB | 55.00 | 62.00 | 50.00 | 15.67 | 17.00 | 14.33 | 44.33 | 43.33 | 46.33 |
| **$T_7$** | 75% RDF + PSB + KSB + *AZOSPIRILIUM* | 58.33 | 66.33 | 56.00 | 19.33 | 21.00 | 14.00 | 46.67 | 44.00 | 44.00 |
| | **S E m (±)** | 2.204 | 2.118 | 1.864 | 2.084 | 1.318 | 1.723 | 4.291 | 2.553 | 2.212 |
| | **CD(P=0.05)** | 6.792 | 6.526 | 5.743 | 6.420 | 4.062 | 5.309 | 13.222 | 7.867 | 6.817 |

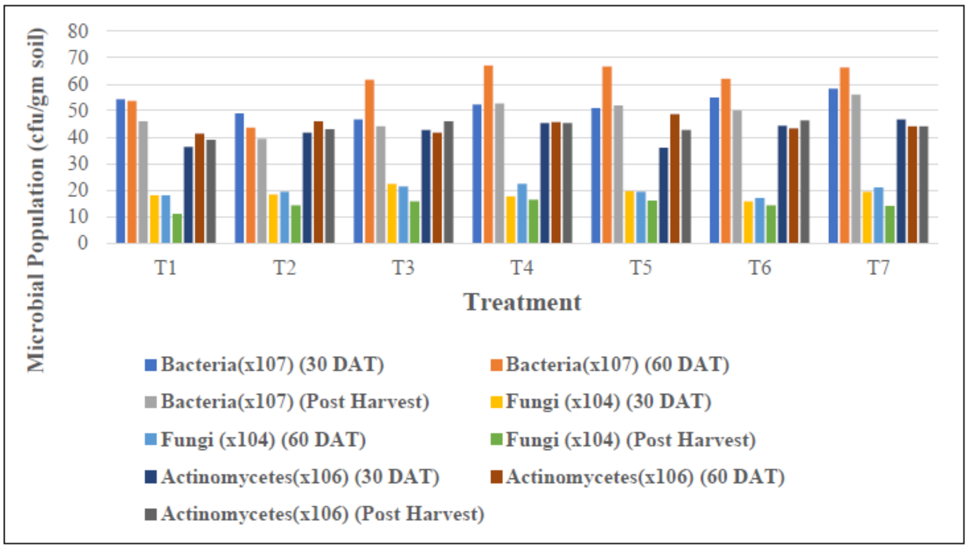


**Fig. 9. bar graph showing variation in microbial population with different treatments**

**Table 10. Variation in Dehydrogenase Activity by microbes in paddy crop due to application of different bio-fertilizers**

| | | Dehydrogenase Activity ($\mu g$ TPF $g^{-1}$ soil $h^{-1}$) | | |
|---|---|---|---|---|
| **Notations** | **Treatments** | **30 DAT** | **60 DAT** | **90 DAT** |
| **$T_1$** | CONTROL | 0.06 | 0.12 | 0.14 |
| **$T_2$** | RDF 100% | 0.14 | 0.12 | 0.13 |
| **$T_3$** | 75% RDF | 0.06 | 0.13 | 0.14 |
| **$T_4$** | 75% RDF + *AZOSPIRILIUM* | 0.11 | 0.34 | 0.18 |
| **$T_5$** | 75% RDF + PSB | 0.09 | 0.67 | 0.37 |
| **$T_6$** | 75% RDF + KSB | 0.05 | 0.09 | 0.97 |
| **$T_7$** | 75% RDF + PSB + KSB + *AZOSPIRILIUM* | 0.11 | 0.23 | 0.66 |
| | **S E m (±)** | **0.033** | **0.140** | **0.148** |
| | **CD(P=0.05)** | **0.101** | **0.433** | **0.456** |

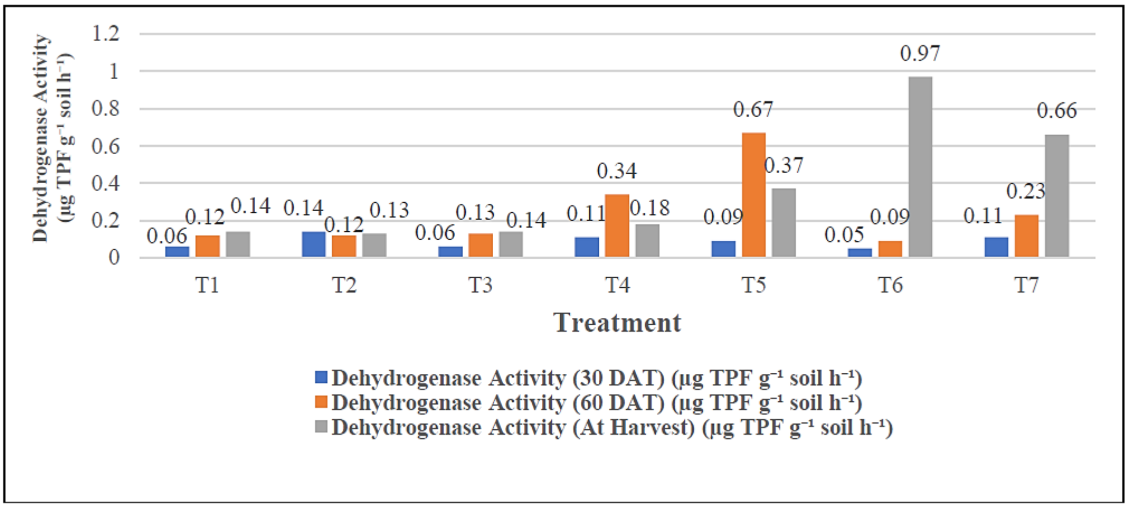


**Fig. 10. Variation in Dehydrogenase Activity by microbes in paddy crop due to application of different bio-fertilizers**

The study demonstrated the significant role of biofertilizers in enhancing rice growth, yield, and soil health. The application of 75% RDF supplemented with PSB, KSB, and *Azospirillum* ($T_7$) consistently outperformed other treatments, showing improvements in plant height, tiller count, panicle formation, and overall biomass accumulation.

Among the treatments, $T_7$ exhibited superior growth performance, producing the highest number of tillers (5.33 per plant at 90 DAT) and achieving a grain yield of 40.51 q/ha, which was nearly equivalent to the 100% RDF treatment (40.60 q/ha). Additionally, $T_7$ significantly contributed to soil nutrient retention, particularly in potash content (471.36%), highlighting the potential of biofertilizers in maintaining soil fertility while reducing reliance on synthetic fertilizers.

## 4. CONCLUSION

The microbial activity in biofertilizer-treated plots was notably higher, with $T_7$ fostering an enriched microbial ecosystem, promoting beneficial bacterial, fungal, and actinomycete populations. Enhanced dehydrogenase activity, a key indicator of microbial enzymatic function, further reinforced the positive influence of biofertilizers on soil health.

Overall, the findings affirm that biofertilizers serve as a sustainable and eco-friendly alternative to conventional chemical fertilizers. The integration of PSB, KSB, and *Azospirillum* with 75% RDF not only supports high crop productivity but also ensures long-term soil health and microbial stability. These results underscore the importance of biofertilizers in achieving sustainable rice production while minimizing environmental impact.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares 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.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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