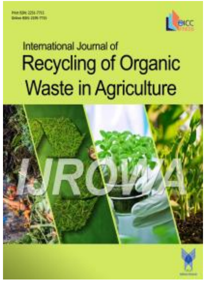

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Research Article

The Effect of Slow-Release Fertilizer (SRF) and Biofertilizer Application on Rice Growth and Yield in a Paddy Field

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Abstract

Purpose: Paddy fields in Indonesia have experienced a stagnation in productivity, where increasing fertilizer applications no longer result in higher yields. To address this, various strategies, including ameliorants, have been employed to enhance rice production. This study investigates the potential of biofertilizers to improve the efficiency of inorganic fertilizers, specifically slow-release fertilizers (SRF). The aim is to evaluate the impact of biofertilizer application on rice production when combined with inorganic fertilizers.

Method: The experiment was conducted using a Randomized Complete Block Design (RCBD) with 10 treatments and 3 replications on 5m x 5m plots. The treatments included different combinations of inorganic fertilizers (NPK) and biofertilizers: P1 [SRF NPK 20-10-15 + Zn 0.2]; P2 [SRF NPK 20-10-15 + Cu 0.4 + Fe 0.4]; P3 [SRF NPK 15-15-10 + Cu 0.4 + Fe 0.4]; P4 [SRF NPK 15-15-10]; P5 [SRF NPK 15-15-10 + S 0.4 + Zn 0.2]; and P6-P10, which corresponded to P1-P5 combined with biofertilizer. In the biofertilizer treatments, the inorganic fertilizer dose was reduced to one-third of the original amount. Growth parameters and rice yield were measured.

Results: The results showed that applying SRF at 60% of the standard fertilizer rate achieved comparable yields to full-dose conventional applications. Additionally, the integration of biofertilizers allowed for a 70% reduction in SRF usage without compromising rice production.

Conclusion: The study shows that combining biofertilizers with SRF allows for a 70% reduction in SRF usage while supporting rice yields, offering an effective and sustainable solution to enhance rice production.

Keywords: Inorganic fertilizer, SRF NPK, Micronutrients, Biofertilizer, Rice productivity

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1. Introduction

Rice (*Oryza sativa* L.) is a staple food for more than half of the world's population, especially in Southeast Asia, where it plays a vital role in the economy, culture, and nutrition.

In Indonesia, rice is essential not only for ensuring food security but also for supporting the livelihoods of millions of farmers.

With the increasing demand for food, boosting rice production is essential to meet the needs of the growing population (Pingali & Stringer, 2017).

However, challenges such as soil degradation, nutrient depletion, and the impacts of climate change have made it difficult to sustain high rice yields (Ansari et al., 2023; Algarni et al., 2025).

Ciherang is one of Indonesia's leading rice varieties, valued for its high yield potential, stress tolerance, and superior grain quality (Susiyanti et al., 2020). This variety can produce up to 8.5 tons per hectare and thrives in various environments, including in Oxisol soils, which are common in tropical regions but often suffer from low fertility and high weathering (Brady & Weil, 2016; Santosa & Suryanto, 2015).

Fertilization plays a critical role in addressing these soil limitations and enhancing rice productivity.

Inorganic fertilizers, particularly NPK, are widely used because they provide essential nutrients quickly to the soil (Barker & Pilbeam, 2015; Dobermann & Fairhurst, 2000). However, the overuse of inorganic fertilizers can lead to environmental concerns, such as soil acidification and water contamination (Guo et al., 2010; Rashmi et al., 2020). To mitigate these problems, slow-release fertilizers (SRF) have been developed. Previous studies have used activated carbon impregnated with Cu, Fe, and Zn as slow-release fertilizer.

It found that zinc was the element released from activated carbon the easiest out of the three (Prastiwi et al., 2019). When nutrients are unevenly concentrated, leaching can occur, contaminating groundwater and degrades soil, resulting in environmental degradation. As a result, plants in some regions will not receive any micronutrients, while plants in other areas will experience an excess of micronutrients. Therefore, developing fertilizer with a progressive release rate is one approach to solving this problem. The trace metal was trapped inside the activated carbon when the nutrient and water came into contact, making it impossible for it to escape (Muchtar et al., 2025). SRFs release nutrients gradually, allowing crops to absorb them more efficiently while reducing nutrient loss to the environment (Bindraban et al., 2020; Bo et al., 2025).

Another promising approach to improving soil health and crop productivity is the use of biofertilizers, which have beneficial microorganisms such as *Azotobacter sp.*, *Corynebacterium sp.*, *Pseudomonas sp.*, and *Bacillus sp.* These microorganisms enhance nutrient solubilization, improve soil structure, and stimulate microbial activity, resulting in healthier plants and more productive soils (Nosheen et al., 2021; Rosa-Núñez et al., 2023; Timofeeva et al., 2023).

Biofertilizers are increasingly recognized as a sustainable alternative to chemical fertilizers, as they enhance soil fertility and plant growth while reducing the need for synthetic inputs (Bashan et al., 2014; Singh et al., 2016).

While both inorganic fertilizers and biofertilizers offer clear advantages, their combined effects on rice production have not been fully explored.

This study aims to investigate the impact of applying slow-release NPK fertilizers and biofertilizers, both individually and in combination, on rice growth, yield, and soil health.

The hypothesis is that the combined application of biofertilizers and slow-release fertilizers will enhance nutrient uptake, minimize environmental impacts, and support rice productivity, thereby providing a more sustainable and efficient fertilization strategy.

Therefore, this study evaluates the effects of slow-release NPK fertilizers and biofertilizers on rice growth and yield.

2. Materials and methods

2.1. Experimental site

The study was conducted in Cikampek Subdistrict, Karawang Regency, West Java Province, Indonesia. The area is characterized by lowland physiography, with an elevation ranging from 0 to 1200 meters above sea level. The region experiences an average annual temperature of 28.87 °C and rainfall between 1100 and 3200 mm. The soil is classified as Oxisol, with a pH range of 4.5 to 6.5 and a clay texture.

2.2. Fertilizer and biological materials

The inorganic fertilizers used in the study were slow-release NPK fertilizers (SRF), urea-prill (as a nitrogen source), diammonium phosphate (DAP), potassium chloride (KCl), zeolite (as a matrix), and clay (as a filler and binder). These fertilizers were formulated to release nutrients gradually, enhancing nutrient use efficiency and minimizing environmental impact.

It demonstrated that Controlled Release Fertilizer (CRF) formulations, particularly those enhanced with zeolite, significantly improve nutrient retention and reduce nitrogen and potassium losses in soils (Suwardi et al., 2023).

Their study showed that zeolite-coated fertilizers slow the release of essential nutrients such as ammonium (NH_4^+) and potassium (K^+), which prolongs nutrient availability for plant uptake and enhances overall crop growth.The primary raw materials used in the NPK fertilizer formulations included urea, DAP, and KCl. Urea provided 46.00% nitrogen and had a moisture content of 3.19%, while DAP supplied 47.37% phosphorus (P_2O_5), 18.00% nitrogen, and 2.59% moisture.

KCl contributed 61.77% potassium (K_2O) and had a moisture content of 0.41%. Table 1 presents the nutrient analysis of these raw materials.

Table 1. Analysis of fertilizer raw materials

Raw Material	Parameters	Value (%)
Urea	Nitrogen	46.00
	H_2O	3.19
DAP	P_2O_5	47.37
	Nitrogen	18.00
	H_2O	2.59
KCl	K_2O	61.77
	H_2O	0.41

Zeolite and clay were used as substrates in the fertilizer formulation, with their properties presented in Table 2. Zeolite had a higher cation exchange capacity (98.72 Meq/100 g) compared to clay (15.63 Meq/100 g). The water content of zeolite was 8.00%, while clay was 5.50%. Other parameters, such as C-organic, N total, and major elements (P, Ca, Mg, K, and Na), are also shown in Table 2, indicating that zeolite and clay contributed to the slow-release characteristics and the nutrient availability of the fertilizer. Zeolite's high cation exchange capacity helped maintain nutrient availability, leading to increased plant height, chlorophyll content, and yield compared to standard fertilization (Suryaningtyas et al., 2024). Oktariani et al. (2024) found that the application of slow-release NPK granule fertilizer enhanced with zeolite and humic acid significantly improved nutrient retention, particularly for nitrogen (N) and potassium (K), leading to higher nutrient use efficiency in plantation crops. The slow-release mechanism reduced the rate of nutrient loss through leaching, enhancing both crop growth and yield.

The application of Controlled-Release Fertilizer (CRF) significantly impacted the availability of essential nutrients such as phosphorus (P), sulfur (S), copper (Cu), iron (Fe), zinc (Zn), and manganese (Mn) (Suwardi et al., 2024). This shows that CRF improves nutrient efficiency and supports increased crop yield, while also reducing the environmental impact associated with fertilizer overuse.

Biofertilizers were produced using a fermentor, each with specific media for targeted bacterial strains. The biofertilizers consisted of *Azotobacter* sp., *Corynebacterium* sp., *Pseudomonas* sp., and *Bacillus* sp., cultivated on Nitrogen Free Mineral (NFM) medium, Nitrogen Free Bromothymol (NFB) medium, Pseudomonas base medium, and Pikovskaya medium, respectively.

These microorganisms were selected for their ability to solubilize phosphorus and fix nitrogen, enhancing nutrient availability in rice fields.

Table 2. Analysis of substrate raw materials

Parameters	Unit	Zeolite	Clay
Particle size	Mesh	60 - 80	60 - 80
Cation exchange capacity	Meq/100 g	98.72	15.63
Water content	%	8.00	5.50
C-organic	%	0.08 – 0.24	0.88
N total	%	0.02 – 0.03	0.10
P	Meq/100 g	12.8	13.9
Ca	Meq/100 g	65.03	24.11
Mg	Meq/100 g	2.90	3.40
K	Meq/100 g	0.82	0.25
Na	Meq/100 g	0.87	1.30

2.3. Characterization of inoculum bacteria

Phosphate Solubilization: Phosphate-solubilizing bacteria were tested using Pikovskaya medium (Safari et al., 2020) and incubated at 28°C for eight days.

The solubilization index (SI) was calculated as follows:

$$SI = (Colony\ diameter + Clear\ zone\ diameter)\ Colony\ diameter$$

Nitrogen-fixing bacteria were grown on NFB medium (Nafisah et al., 2022), with growth showed by a color change from green to blue.

Total Plate Count (TPC) was conducted aseptically, using dilution methods as described by Rupaedah et al. (2014), to quantify the bacterial population in the biofertilizer.

2.4. Application of inoculum bacteria

The bacterial inoculum was diluted to a concentration of 10^8 cells/mL and applied at the time of planting or to young seedlings. The recommended application rate was 2 liters per 100 m² of paddy field to promote best bacterial colonization and enhance nutrient uptake by the plants.

2.5. Slow-release fertilizer (SRF) formulation

The SRF NPK fertilizers were enriched with essential micronutrients, including sulfur (S), zinc (Zn), copper (Cu), and iron (Fe), to enhance nutrient availability and plant growth. The formulations were designed for slow nutrient release, reducing nutrient losses, and improving efficiency. SRF NPK 20-10-15 + Cu + Fe had the highest nitrogen (19.73%) and potassium (14.46%) content among the formulations, while SRF NPK 15-15-10 had the highest phosphorus (21.05%). The raw materials for the NPK fertilizers were processed by drying, crushing, and sieving to achieve the desired particle size, following the method outlined in Patent IDP000049843 (Saputra et al., 2018), with slight modifications to the formulation and binders. Five SRF formulations were tested for both macronutrient and micronutrient content, as shown in Table 3. The table presents the levels of nitrogen (N), phosphorus (P_2O_5), potassium (K_2O), sulfur (S), zinc (Zn), copper (Cu), and iron (Fe) across the different formulations.

2.6. Experimental design and fertilization application

The experiment was arranged in a Randomized Complete Block Design (RCBD) with 10 treatments and 3 replications.
Each treatment plot measured 5m x 5m and received different combinations of SRF NPK and biofertilizer, as detailed in Table 4.
Ciherang rice seeds were used due to their adaptability to the lowland Oxisol soils.
The seedlings were transplanted at 16 days old with a spacing of 22.5 cm x 22.5 cm. Urea was applied in two stages: 0-5 days after sowing (DAS) and 30 DAS. Biofertilizer was applied at planting.

2.7. Data collection and statistical analysis

The number of tillers, plant height, yield components, soil nutrient content, and leaf greenness were recorded. Data were analysed using analysis of variance (ANOVA) at a 95% confidence level, and Duncan's Multiple Range Test (DMRT) was used for comparing treatment means at a 5% significance level.

Table 3. Macronutrient and micronutrient analysis of Slow-Release Fertilizer (SRF) formulations

Samples	Analysis result						
	Macronutrient			Micronutrient			
	N (%)	P_2O_5 (%)	K_2O (%)	S (ppm)	Zn (ppm)	Cu (ppm)	Fe (ppm)
SRF NPK 20-10-15 + Zn	19.27	13.66	11.82	-	0.2	-	-
SRF NPK 20-10-15 + Cu + Fe	19.73	13.78	14.46	-	-	0.4	0.4
SRF NPK 15-15-10+ Cu + Fe	15.18	19.44	10.24	-	-	0.4	0.4
SRF NPK 15-15-10	13.42	21.05	10.24	-	-	-	-
SRF NPK 15-15-10+S+Zn	14.44	20.06	9.64	0.4	0.2	-	-

Table 4. Fertilizer formulations, application rates, and nutrient dosage for different treatments

Code	Fertilizer	Mix Fertilizer (g/25 m²)	Nutrient Dosage (kg/ha)
P0	Positive Control (single NPK)	-	115 N, 36 P_2O_5, 18 K_2O
P1	SRF NPK 20-10-15 + Zn	687.5	55 N, 28 P_2O_5, 41 K_2O
P2	SRF NPK 20-10-15 + Cu + Fe	500	40 N, 20 P_2O_5, 30 K_2O
P3	SRF NPK 15-15-10 + Cu + Fe	625	38 N, 38 P_2O_5, 25 K_2O
P4	SRF NPK 15-15-10	625	38 N, 38 P_2O_5, 25 K_2O
P5	SRF NPK 15-15-10 + S + Zn	625	38 N, 38 P_2O_5, 25 K_2O
P6	P1 + Biofertilizer	206.3	17 N, 8 P_2O_5, 12 K_2O
P7	P2 + Biofertilizer	150	12 N, 6 P_2O_5, 9 K_2O
P8	P3 + Biofertilizer	187.5	11 N, 11 P_2O_5, 8 K_2O
P9	P4 + Biofertilizer	187.5	11 N, 11 P_2O_5, 8 K_2O
P10	P5 + Biofertilizer	187.5	11 N, 11 P_2O_5, 8 K_2O

3. Results and discussion

3.1. Effect of biofertilizer on soil microbial populations

The first assessment of soil microbial populations, presented in Table 5, reveals the presence of phosphate-solubilizing and nitrogen-fixing bacteria in varying concentrations across different soil samples. Sample 1 displayed a particularly high population of *Azotobacter sp.* in NFM Agar, with colony counts ranging from 1 × 10^8 to 2 × 10^8 CFU per gram of soil. Additionally, non-symbiotic nitrogen-fixing bacteria were present, with counts between 1 × 10^7 and 1.5 × 10^8 CFU per gram in NFB Agar. Phosphate-solubilizing bacteria, which play a crucial role in making phosphorus available to plants, were detected at concentrations of 1 × 10^8 to 2 × 10^7 CFU per gram in Pikovskaya Agar.

In contrast, Samples 2 and 3 showed significantly lower microbial populations. Sample 2 had non-symbiotic nitrogen-fixing bacteria in reduced concentrations (2 × 10^7 to 5 × 10^6 CFU per gram) and phosphate-solubilizing bacteria at even lower counts (2 × 10^6 to 1 × 10^6 CFU per gram). Sample 3 had no detectable *Azotobacter sp.* or non-symbiotic nitrogen-fixing bacteria, while phosphate-solubilizing bacteria were present in low counts, ranging from 2 × 10^6 to 5 × 10^6 CFU per gram.

To assess the impact of biofertilizer application on microbial activity, the solubilizing and nitrogen-fixing bacteria were examined.

The solubilizing index (SI) is used to evaluate the capacity of bacteria to convert insoluble phosphates into plant-available forms. Among the isolates, *Bacillus sp.* exhibited the highest solubilizing potential, with an SI of 2.781, followed by *Azotobacter sp.* (2.354), *Pseudomonas sp.* (2.287), and *Corynebacterium sp.* (2.203). These solubilizing abilities are crucial for enhancing phosphate availability in the soil, a vital factor in plant nutrient uptake. The color shift in the NFB medium is used to gauge the nitrogen-fixing activity. While all the bacterial isolates showed the ability to fix nitrogen, *Corynebacterium* sp. had the highest activity (++++), followed by *Bacillus* sp. with moderate activity (++).

The soil-health framework's addition of a biological perspective is crucial for sustainable crop production (Lehmann et al., 2020).

Before planting, a study found low levels of non-symbiotic nitrogen-fixing and phosphate-solubilizing bacteria in paddy fields (Table 6), suggesting reduced microbial biodiversity due to inorganic fertilizer use. Introducing beneficial microbes, like *Azotobacter* and phosphate-solubilizing bacteria, can enhance soil microbial presence and promote plant productivity. This aligns with Mandal (2021), who proved that these microbes significantly improve plant growth and yield.

To address soil microbial biodiversity issues, biofertilizers were produced by combining composted organic materials with bio-stimulants having phosphate-solubilizing bacteria and *Azotobacter*. These bacteria create transparent zones on Pikovskaya media by producing organic acids like citric acid and oxalic acid, which bind to phosphate and chelate cations such as Fe, Al, and Ca. This process converts these cations into soluble phosphate forms that plants can absorb, resulting in the formation of H_2PO_4 and clear zones within the medium (Halimursyadah & Rizva, 2022; Setyowati et al., 2017).

The viability test results for bacteria in granular bioorganic fertilizer are shown in Table 7. The results proved that *Azotobacter sp.*, *Bacillus sp.*, *Pseudomonas sp.*, and *Corynebacterium sp.* kept high cell counts after the granulation process. *Azotobacter sp.* and *Bacillus sp.* showed the highest viability, with cell counts of 4 × 10^8 CFU per gram, suggesting that these bacterial strains were able to withstand the granulation process and remain active in the soil.

Table 5. Types of microbes present in soil samples before biofertilizer treatment

Soil Sample*	Media	Bacteria	Number of colonies/gr Soil sample (CFU)	
Sample 1	NFM Agar	*Azotobacter*	1 x 10^8	2 x 10^8
	NFB Agar	Non-symbiotic N-fixing bacteria	1 x 10^7	1.5 x 10^8
	Pikovskaya Agar	Phosphate solubilizing bacteria	1 x 10^8	2 x 10^7
Sample 2	NFM Agar	*Azotobacter*	0	0
	NFB Agar	Non-symbiotic N-fixing bacteria	2 x 10^7	5 x 10^6
	Pikovskaya Agar	Phosphate solubilizing bacteria	2 x 10^6	1 x 10^6
Sample 3	NFM Agar	*Azotobacter*	0	0
	NFB Agar	Non-symbiotic N-fixing bacteria	0	0
	Pikovskaya Agar	Phosphate solubilizing bacteria	2 x 10^6	5 x 10^6

*Samples were collected from three distinct locations within the experimental field

Table 6. Nitrogen-fixing activity and solubilizing index (SI) of bacteria

Bacterial isolate	Treatment	Activity	Solubilizing index (SI)
			7 days after inoculation
Azotobacter sp.	Media agar NFB	+++	2.354
Pseudomonas sp.	Media agar NFB	+++	2.287
Bacillus sp.	Media agar NFB	++	2.781
Corynebacterium sp.	Media agar NFB	++++	2.203

Table 7. The viability test of bacteria in granular bioorganic fertilizer

No.	Bacterial strains	Cell count per gram of granules		Media
1	*Azotobacter sp.*	4 x 10^8	3 x 10^8	NFM Agar
2	*Pseudomonas sp.*	2 x 10^8	1 x 10^8	NFB Agar
3	*Bacillus sp.*	4 x 10^8	3 x 10^8	Pikovskaya Agar
4	*Corynebacterium sp.*	2 x 10^8	1 x 10^8	NFB Agar

Table 8. Soil microbial population in the rhizosphere of rice plants after harvest

Code	Composition	Bacterial Population per gram of Soil (CFU)			
		Phosphate-solubilizing bacteria	*Azotobacter sp.*	*Pseudomonas sp.*	*Non-symbiotic nitrogen-fixing bacteria*
P0	Positive control	1,1 x 10^{10}	4 x 10^9	2 x 10^7	1 x 10^9
P1	SRF NPK 20-10-15+Zn	1 x 10^9	4 x 10^9	-	1 x 10^9
P2	SRF NPK 20-10-15 + Cu + Fe	6 x 10^7	-	2 x 10^7	-
P3	SRF NPK 15-15-10 + Cu + Fe	4 x 10^8	1,7 x 10^8	3,3 x 10^8	1 x 10^7
P4	SRF NPK 15-15-10	2 x 10^8	1,2 x 10^9	-	1 x 10^7
P5	SRF NPK 15-15-10 + S + Zn	8 x 10^7	3 x 10^7	2,8 x 10^8	2 x 10^7
P6	P1 + Biofertilizer	1,3 x 10^8	2 x 10^8	1,7 x 10^8	1,1 x 10^8
P7	P2 + Biofertilizer	1,3 x 10^8	2 x 10^7	8 x 10^7	9 x 10^7
P8	P3 + Biofertilizer	3 x 10^7	7 x 10^9	-	3 x 10^7
P9	P4 + Biofertilizer	7 x 10^9	2 x 10^9	1 x 10^7	-
P10	P5 + Biofertilizer	4 x 10^9	1 x 10^9	8 x 10^7	2 x 10^7

The post-harvest analysis of microbial populations (Table 8) shows that biofertilizer application had a significant impact on microbial activity in the rhizosphere. In the control treatment (P0), phosphate-solubilizing bacteria were most abundant, reaching 1.1 × 10^{10} CFU per gram of soil, while *Azotobacter sp.* populations were also high at 4 × 10^9 CFU. These results highlight the strong microbial activity present before biofertilizer treatment. In treatments incorporating biofertilizers, a marked increase in microbial populations was observed. For example, treatment P9 [P4 + Biofertilizer] showed an increase in *Azotobacter sp.* to 2 × 10^9 CFU per gram and phosphate-solubilizing bacteria to 7 × 10^9 CFU, demonstrating that biofertilizers significantly promoted microbial growth. Similarly, treatment P10 [P5 + Biofertilizer] resulted in high bacterial counts, particularly for phosphate-solubilizing bacteria (4 × 10^9 CFU) and *Azotobacter sp.* (1 × 10^9 CFU). The results of this study confirm the effectiveness of biofertilizer application in promoting beneficial microbial populations, enhancing soil health, and supporting rice productivity. The comparison of pre- and post-harvest microbial populations (Table 5 vs. Table 8) shows the beneficial effects of biofertilizers on soil microbial dynamics, with treatments incorporating biofertilizers consistently outperforming those without in sustaining microbial populations essential for nutrient cycling and plant growth.

3.2. Effect of SRF NPK fertilizer and biofertilizer on soil organic matter

The application of both SRF NPK and biofertilizers had a significant impact on soil organic carbon (SOC) and soil organic matter (SOM) levels. It can be seen on Table 9 that the highest SOC levels were observed in treatments P2 [SRF NPK 20-10-15 + Cu + Fe] and P3 [SRF NPK 15-15-10 + Cu + Fe], with values of 2.58% and 2.59%, respectively. In contrast, treatment P4 (SRF NPK 15-15-10) showed the lowest SOC content, at 1.41%. Similarly, SOM values followed the same pattern, with treatments

P2 and P3 exhibiting the highest SOM levels (4.45% and 4.47%, respectively). These findings align with studies suggesting that the integration of biofertilizers can enhance soil organic matter by promoting microbial activity and the decomposition of organic residues (Brady & Weil, 2016). The biofertilizer-treated soil (P9) had higher C-organic content (2.25%), indicating that biofertilizer has a favorable influence on organic matter buildup via increased microbial decomposition. Numerous studies have demonstrated that organic fertilizers can increase SOC and soil microbial biomass, ultimately improving soil fertility (Scharlemann et al., 2014; Villa & Ryals, 2021). Biofertilizer treatments showed promising results, with increased SOC levels attributed to enhanced microbial activity and organic matter decomposition (Brady & Weil, 2016). Treatment P3 had the highest C-organic content (2.58%) among the treatments without biofertilizer, while P9, which incorporated biofertilizer, achieved the highest C-organic content (2.25%) among the biofertilizer treatments.

3.3. Effect of SRF NPK fertilizer and biofertilizer on rice growth

The combined application of SRF NPK and biofertilizer had a profound effect on rice growth parameters, including plant height and tiller formation. Statistical analysis revealed no significant increases in plant height in treatments P4 and P9 [P4 + Biofertilizer], as well as P5 and P10 [P5 + Biofertilizer]. These results confirm the synergistic effects of NPK and biofertilizer in promoting vegetative growth, aligning with findings from previous studies (Bharath Kumar et al., 2025; Hosseini et al., 2023). The number of tillers as on Table 10, a critical determinant of rice yield, also showed significant improvements with biofertilizer application.

Table 9. Soil analysis of soil organic matter (SOM)

Samples	Treatments	C-Organic (%)	Organic matter (%)	Soil Fertility*
P0	Control (+)	2.18	3,75	high
P1	SRF NPK 20-10-15 + Zn	1.88	3,24	high
P2	SRF NPK 20-10-15 + Cu + Fe	2.58	4,45	high
P3	SRF NPK 15-15-10 + Cu + Fe	2.59	4,47	high
P4	SRF NPK 15-15-10	1.41	2,43	moderate
P5	SRF NPK 15-15-10 +S + Zn	2.18	3,76	high
P6	P1 + Biofertilizer	1.94	3,34	high
P7	P2 + Biofertilizer	1.79	3,09	high
P8	P3 + Biofertilizer	1.98	3,41	high
P9	P4 + Biofertilizer	2.25	3,88	high
P10	P5 + Biofertilizer	2.03	3,49	high

Table 10. The effect of treatments on vegetative growth

Treatments		Plant height (cm)	Number of tillers
P0	Control (+)	45.4 ab	13.3 ab
P1	SRF NPK 20-10-15 + Zn	43.9 b	11.9 b
P2	SRF NPK 20-10-15 + Cu + Fe	45.4 ab	12.7 ab
P3	SRF NPK 15-15-10 + Cu + Fe	47.5 ab	15.6 ab
P4	SRF NPK 15-15-10	46.7 ab	13.3 ab
P5	SRF NPK 15-15-10 +S + Zn	46.5 ab	13.8 ab
P6	P1 + Biofertilizer	42.9 b	13.3 ab
P7	P2 + Biofertilizer	45.4 ab	13.8 ab
P8	P3 + Biofertilizer	46.7 ab	14.2 ab
P9	P4 + Biofertilizer	44.7 b	13.7 ab
P10	P5 + Biofertilizer	44.5 b	13.7 ab

Note: Values followed by the same letter do not show significant differences based on the 5% DMRT test

Treatments P3 and P8 had the highest number of tillers, with averages of 15.6 and 14.2, respectively. Notably, biofertilizer treatment in P8 resulted in slightly lower tiller numbers compared to P3, suggesting that while biofertilizers enhance microbial activity, they may not always lead to further increases in tiller production beyond optimal levels.

3.4. Effect of SRF NPK fertilizer and biofertilizer on rice production

The application of SRF NPK fertilizer and biofertilizer had a notable impact on rice productivity, as evidenced by the number of panicles per plant, grain quality, and overall yield. Among the treatments, P3 [NPK 15-15-10 + Cu + Fe] and P10 [P5 + Biofertilizer] produced the highest number of panicles, with 15.6 and 14.7 panicles per plant, respectively, surpassing the control group. This highlights the positive effect of biofertilizer application on panicle development, as observed in treatments such as P2-P7, P4-P9, and P5-P10. However, treatments P1-P6 and P3-P8 demonstrated a slight decrease in the number of panicles compared to the control.

The weight of 1000 grains also varied across treatments. The highest grain weight was recorded in the treatment without biofertilizer, specifically P1, at 21.8 grams, compared to 19.1 grams in the control group. Conversely, the lowest grain weight was observed in P4, which yielded only 14.3 grams. Interestingly, adding biofertilizer did not significantly improve the weight of 1000 grains across treatments, as all weights were below the control. Regarding the weight of milled dry grains, treatment P10 [P5 + Biofertilizer] produced results comparable to the control, which had the highest grain weight. Biofertilizer application increased grain weight in treatments such as P2, P7, P4, P9, and P5. However, treatments P1 and P6, as well as P3 and P8, resulted in lower milled grain weights. In terms of grain production, there was no significant difference between P10 and the control group, both achieving yields of 6.2 tons/ha and 6.1 tons/ha, respectively. Biofertilizer was most effective when applied in treatment P10 [P5 + Biofertilizer].

The research showed that both inorganic fertilizers and biofertilizers improved rice growth, yield, and grain quality.

Significant differences in panicle numbers were found in treatments P1-P6, P3-P8, and P5-P10 (Table 11). Treatment P10 [P5 + Biofertilizer] yielded the highest panicle count (14.7) and grain production (6.2 tons/ha) among the treatments of biofertilizer. This is attributed to micronutrients such as sulfur and zinc, which enhance growth, yield, and stress tolerance (Krishna et al., 2023).

Grain quality analysis revealed significant variations in empty grains and the weight of 1000 grains among several treatment pairs.

Although P10 outperformed P9 in grain production, it did so despite having a lower 1000-grain weight, due to the greater abundance of beneficial soil microbes.

The combined application of NPK and biofertilizer improved both rice grain quality and nutrient uptake efficiency (Sofyan et al., 2023; Baghel & Singh, 2025). Research conducted in Indonesia further supports bioorganic fertilization as a viable alternative to inorganic methods for rice production, with both approaches yielding high outputs (Ngui et al., 2024; Dollison, 2023).

The study also identified NPK conversion rates in fertilizer composition with treatment P10 containing 11 kg/ha of N, 11 kg/ha of P_2O_5, and 8 kg/ha of K_2O.

Table 11. The effect of treatments on generative growth

Treatments	Number of panicles/plants	Empty grains (%)	Weight of 1000 grains (gr)	Milled dry grain (gr/plants)	Grain production (ton/ha)
P0 (+)	14.1 abc	30.3 bc	19.1 ab	31.0	6.1
P1	14.1 abc	33.2 abc	21.8 a	27.5	5.4
P2	12.2 bc	34.6 abc	17.6 ab	27.3	5.4
P3	15.6 a	31.1 abc	18.4 ab	27.0	5.3
P4	12.6 abc	51.7 a	14.3 b	20.6	4.1
P5	11.7 c	44.7 ab	17.2 ab	24.2	4.8
P6	12.3 bc	35.8 abc	14.5 b	19.9	3.9
P7	12.9 abc	46.1 ab	15.4 b	27.6	5.5
P8	12.7 abc	33.8 abc	16.1 ab	26.9	5.3
P9	13.1 abc	26.0 bc	17.2 ab	26.8	5.3
P10	14.7 abc	32.2 abc	17.8 ab	31.3	6.2

Note: Values followed by the same letter do not show significant differences based on the 5% DMRT test

Despite the relatively low levels of P and K, P10 achieved the highest yield due to the biofertilizer's contribution, which included beneficial microbes such as phosphate-solubilizing bacteria (4 × 10^9 CFU), *Azotobacter sp.* (1 × 10^9 CFU), *Pseudomonas sp.* (8 × 10^7 CFU), and *Bacillus sp.* (2 × 10^7 CFU). These microbes play a vital role in enhancing nutrient availability and uptake (Maciel-Rodriguez et al., 2025). According to the study, P10 achieved nutrient conversion rates of 90% for nitrogen (N), 69% for phosphorus (P), and 56% for potassium (K), resulting in the highest rice production. The combination of slow-release NPK fertilizer and biofertilizers significantly improved nutrient utilization efficiency, supporting the conclusion that slow-release NPK fertilizers can enhance overall fertilizer efficiency (ME Trenkel, 2021).

4. Conclusion

Rice plants fertilized with inorganic NPK and those treated with slow-release NPK (SRF) combined with biofertilizer achieved similar production outcomes, demonstrating the effectiveness of SRF and biofertilizers as viable alternatives to traditional chemical fertilizers. The results indicate that using SRF at 60% of the standard NPK dose can produce comparable yields, highlighting the potential to reduce chemical fertilizer use. Moreover, adding biofertilizer enabled a 70% reduction in SRF application while supporting equivalent production levels. This highlights the environmental advantages of biofertilizers, which not only support sustained rice production but also promote more sustainable and eco-friendly farming practices by decreasing dependency on chemical inputs and improving soil health.

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Authors Contribution

All authors participated sufficiently in the intellectual content, conception, and design of this work, the analysis and interpretation of the data, as well as the writing of the manuscript.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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