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Effect of Organic Fertilizers and Plant Growth-Promoting Rhizobacteria (PGPR) on Nutrient Residue and Growth of Rice (*Oryza sativa* L.)

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Abstract— *This study aims to evaluate the effects of organic fertilizers and Plant Growth-Promoting Rhizobacteria (PGPR) on rice (Oryza sativa L.) growth and fertilizer residues. The research was conducted at Jatimulyo Experimental Farm, Malang, using a split-plot design with 12 treatment combinations of organic fertilizers and PGPR. The results showed that the application of organic fertilizers increased soil organic carbon content, while PGPR contributed to improving nitrogen and potassium efficiency by reducing nutrient losses. However, the efficiency of phosphorus from inorganic fertilizers remained low, with most of the phosphorus retained in the soil and not absorbed by plants. Principal Component Analysis (PCA) revealed that plant growth parameters were more influenced by inorganic fertilizer treatments than organic ones. This research provides important insights for the development of sustainable agricultural technologies that enhance soil quality and reduce dependence on inorganic fertilizers.*

***Keywords*— organic fertilizer, PGPR, rice production, sustainable agriculture**

I. INTRODUCTION

Rice is a staple food in Indonesia, where the majority of the population depends on it as their primary food source. As the population grows, the demand for rice is expected to remain stable or even increase. In 2022, national rice production was recorded at around 55 million tons. East Java, one of the main rice production centers in Indonesia, has experienced a decline in productivity from 2020 to 2021, from 56.68 ku ha^{-1} in 2020 to 56.02 ku ha^{-1} in 2021 (BPS, 2023). This decline is an issue that needs serious attention, as it can affect food security in Indonesia.

One of the factors contributing to the decline in rice productivity is the excessive use of inorganic fertilizers by farmers. Overuse of fertilizers can result in negative impacts, such as decreased rice yields, soil degradation, greenhouse gas emissions, water pollution, and food insecurity (Smith & Siciliano, 2015). Soil, air, and water pollution caused by inorganic fertilizers can occur through leaching of nutrients, soil property degradation, and accumulation of toxic substances in water sources (Agbede, 2010). Therefore, the excessive use of inorganic fertilizers must be avoided to maintain agricultural sustainability and environmental quality.

As an alternative, the use of organic fertilizers can help improve soil conditions and provide the essential nutrients for plant growth. Organic fertilizers have the ability to enhance soil quality, improve its physical, chemical, and biological properties, and increase the population of soil microorganisms that function as decomposers. One example of organic fertilizers is manure, which contains humic acid, fulvic acid, hormones, and enzymes that are crucial for soil health and plant growth (Atmaja et al., 2019). Furthermore, utilizing baglog waste from the mushroom industry in East Java as an organic fertilizer can reduce environmental pollution caused by waste accumulation, by recycling it for agricultural use.

In recent years, the government has started to shift policies from conventional agriculture to organic farming systems. Organic farming is expected to help restore the environmental quality that has been degraded by excessive use of inorganic fertilizers. Although organic farming systems are often associated with lower productivity per unit area compared to conventional farming (Zhai et al., 2009), organic fertilizers focus more on improving soil properties rather than increasing immediate yields.

One approach to improving organic farming yields is the addition of PGPR (Plant Growth-Promoting Rhizobacteria), which are natural bacteria that colonize plant roots and assist in the decomposition of organic matter, nitrogen fixation, and the provision of other essential nutrients. The use of PGPR can reduce reliance on chemicals and support environmentally friendly and sustainable farming (Prasad et al., 2015)

This study aims to test the combination of organic fertilizers and PGPR as a solution to improve soil quality and avoid excessive use of inorganic fertilizers. During the first planting season, a substitution between organic and inorganic fertilizers was implemented, and it is expected that during the second planting season, the use of organic fertilizers together with PGPR can support sustainable rice production and improve soil fertility.

Thus, this research is expected to contribute to the development of more environmentally friendly and sustainable agricultural technologies, focusing on improving soil quality and reducing dependence on inorganic fertilizers.

II. METHODS

This study was conducted from March to July 2023 at the Jatimulyo Experimental Farm, Faculty of Agriculture, Brawijaya University, Malang, East Java, Indonesia. The tools used in this study included a leaf area meter (LAM), oven, analytical balance, camera, and SPAD. The materials used in this research consisted of Inpari 32 rice seeds, and fertilizers including urea, NPK fertilizer, organic fertilizer, and PGPR (Plant Growth-Promoting Rhizobacteria).

This study used a split-plot design, consisting of main plots and subplots. The main plots consisted of two PGPR treatments: without PGPR (R0) and with 15 ml per liter of PGPR (R15). The subplots consisted of six organic fertilizer dose treatments: (1) P0 = farmer's usual fertilization practice (500 kg ha^{-1} urea + 500 kg ha^{-1} NPK), (2) P1 = 100% inorganic (250 kg ha^{-1} urea + 275 kg ha^{-1} NPK), (3) P2 = 4.5 tons ha^{-1} organic fertilizer, (4) P3 = 7 tons ha^{-1} organic fertilizer, (5) P4 = 9.5 tons ha^{-1} organic fertilizer, and (6) P5 = 12 tons ha^{-1} organic fertilizer. A total of 12 treatment combinations were applied, repeated three times, resulting in 36 experimental plots. Each experimental plot consisted of 200 rice plant clumps, giving a total of 2,400 rice plant clumps used in this study.

III. FIGURES AND TABLES

Nutrient Residues

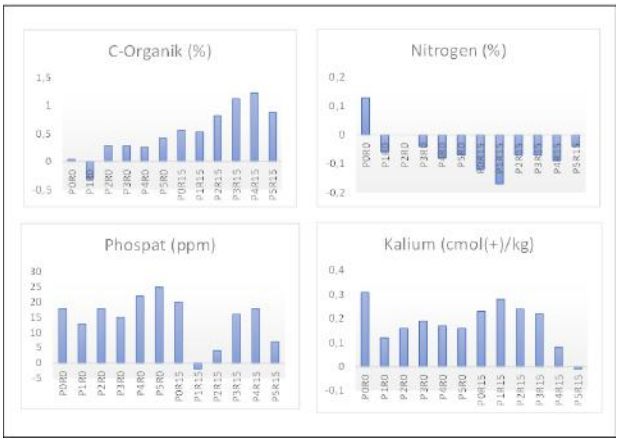

Fig.1. Nutrient Residue

C-Organic is an important parameter in determining soil quality, particularly in relation to fertility and the soil's ability to support crop productivity. The C-Organic graph shows a gradual increase in organic carbon content from treatment P0 to P5 and rotation up to R15.

At the start of the treatments (P0R0), the C-Organic content is very low, even approaching negative values. This indicates that the organic material content in the soil was relatively low initially, which may have been caused by previous soil management practices, such as excessive chemical use or the absence of organic matter inputs (Prakash, 2023).

However, from treatments P2 to P5, particularly at rotation R15, there is a significant increase in C-Organic content. This suggests that certain treatments, likely involving the addition of organic matter or changes in soil management techniques, play a major role in increasing organic carbon levels. The increase in C-Organic indicates enhanced accumulation of organic material in the soil (Zhao et al., 2023). Organic matter not only serves as a nutrient source for soil microorganisms but also improves soil structure, enhances water retention capacity, and increases nutrient availability for plants (Hussain et al., 2023).

The consistent increase in C-Organic demonstrates that these treatments not only improve soil fertility but also have the potential to mitigate climate change through soil carbon sequestration (Wenzel et al., 2023).

Nitrogen: Complex Dynamics and Decrease in Content Nitrogen is an essential nutrient for plants, yet its availability in soil is often highly dynamic due to its mobility in the soil ecosystem. The nitrogen graph shows significant fluctuations, with a declining trend in nitrogen content after several treatments and rotations. At the starting point (P0R0), a slight decrease is observed, followed by a brief increase at P1R0, but the subsequent trend tends to decline until P5R15.

The decrease in nitrogen content is likely caused by several factors. Nitrogen in the soil can be lost through various processes, including:

- Denitrification, the conversion of nitrate (NO_3^-) to nitrogen gas (N_2) by microorganisms under anaerobic conditions, which leads to nitrogen loss from the soil (Ding et al., 2021).
- Volatilization, the loss of nitrogen as ammonia (NH_3) gas, which occurs in soils with high pH or after the application of nitrogen fertilizers containing ammonium (Dominghetti et al., 2016).
- Leaching, the movement of nitrogen in the form of nitrate dissolved in water to deeper soil layers, especially under irrigation or heavy rainfall conditions (Pal et al., 2020).

Additionally, plants tend to absorb large amounts of nitrogen during the vegetative phase, which could explain the decline in nitrogen content in the soil after several rotations. A small increase in nitrogen is observed at the end of the cycle (P5R15), likely due to the return of plant residues or the addition of fertilizers that improve nitrogen content.

Phosphorus: Prominent Fluctuating Pattern Phosphorus is a nutrient required by plants in relatively small amounts compared to nitrogen but is crucial for plant growth and development. The phosphorus graph shows a notable fluctuating pattern, where some treatments lead to significant increases, but a drastic decrease is observed in the later stages.

At the beginning of treatments (P0 to P2), a significant increase in phosphorus content is observed, peaking at P2R15. This may be attributed to the mineralization of organic matter containing phosphorus. This increase suggests that early-stage treatments are highly effective in improving phosphorus availability in the soil (Cheng et al., 2020).

However, the drastic decrease in later stages, particularly after P4R15 to P5R15, suggests that phosphorus undergoes immobilization or is absorbed in large amounts by plants. Phosphorus immobilization in the soil can be caused by chemical reactions with metal ions like calcium (in alkaline soils), iron, or aluminum (in acidic soils), forming insoluble phosphate compounds that are difficult for plant roots to access (Ibrahim et al., 2022). This phenomenon indicates that although phosphorus is added to the soil, not all of it becomes available to plants due to various chemical interactions within the soil.

Potassium: Stability and Plant Absorption Potassium is an essential macronutrient for plant growth, particularly in regulating water balance, protein synthesis, and enzyme activity. The potassium graph shows a relatively stable trend compared to other nutrients. Initially, a decrease in potassium content (P0R0) is observed, but over time, its content tends to increase, reaching a peak at P3R15.

This stability in potassium may be due to its ability to remain in the soil for longer periods. Potassium is not easily lost through leaching, especially in clay soils or soils with a high cation exchange capacity (CEC) ((Thakur & Kumar, 2020). However, at the end of the rotation (P5R15), a decrease in potassium content is noted, possibly due to intensive potassium absorption by plants during the photosynthesis phase. Potassium plays a role in many physiological processes, including photosynthesis, enzyme activation within plants, translocation, and regulation of stomatal opening and closing. Inadequate potassium supply can lead to decreased photosynthetic carbon assimilation, ultimately hindering growth and reducing crop yield (Rawat et al., 2022).

This decrease also underscores the importance of reapplying potassium fertilizers after several growing seasons to ensure adequate potassium availability for plants in subsequent cycles.

Interaction of PGPR and Fertilizer Addition on Plant Nutrient Content

The addition of PGPR enhances the nitrogen content in plants derived from inorganic fertilizers. This suggests that PGPR can contribute to the increased effectiveness of fertilizer use, particularly under optimal conditions. PGPR reduces nitrogen leaching, meaning more nitrogen is available to plants because the loss of nitrogen to the environment is reduced. This indicates that although PGPR does not directly increase growth, it helps to improve the availability of nitrogen from inorganic fertilizers by decreasing nitrogen loss (Gallart et al., 2021). PGPR can assist in enhancing nitrogen absorption in plants (Adesemoye et al., 2010).

Table 1. Nitrogen Content

Treatment	**Nitrogen Content (plant gram^{-1})**					
	P0	**P1**	**P2**	**P3**	**P4**	**P5**
R0	**3,30 b**	**6,77 c**	**1,82 a**	**1,47 a**	**1,49 a**	**1,97 a**
R15	**6,77 c**	**6,34 c**	**1,48 a**	**1,70 a**	**1,78 a**	**1,50 a**
KK a (%)	**10,80**					
KK b (%)	**25,69**					

Table 2. Phosphorus Content

PGPR (ml L^{-1})	**Phosphorus Content (plant gram^{-1})**
R0	**0,79**
R15	**0,81**
KK (%)	**16,37**
Pupuk (ton ha^{-1})	
P0	**1,303 c**
P1	**1,142 b**
P2	**0,575 a**
P3	**0,587 a**
P4	**0,586 a**
P5	**0,590 a**
KK (%)	**16,20**

The use of inorganic fertilizers is highly effective in increasing the phosphorus content in plants. Although phosphorus from inorganic fertilizers is available, only a small percentage is absorbed by the plants, while the majority (67.2%) remains stored in the soil and a small portion (4.4%) is lost from the ecosystem. Therefore, although the addition of inorganic fertilizers can increase phosphorus content in plants, its efficiency is low, with the majority of phosphorus remaining in the soil and not directly taken up by the plants (Luo et al., 2024).

In the treatment with inorganic fertilizers, a significant increase in potassium content in plants is observed in the PGPR addition treatment compared to the control (no PGPR). This indicates that PGPR has the potential to increase potassium content in plants from inorganic fertilizers. PGPR has the ability to dissolve insoluble potassium in the soil into a form that is easily absorbed by plants through processes such as acidolysis, chelation, and exchange reactions. Thus, PGPR helps plants to more efficiently absorb potassium for optimal growth (Zhang et al., 2024).

Table 3. Potassium Content

Treatment	Potassium Content (plant gram^{-1})					
	P0	P1	P2	P3	P4	P5
R0	7,76 b	9,58 c	3,23 a	3,29 a	3,45 a	3,99 a
R15	12,37 d	8,26 b	2,81 a	3,52 a	3,94 a	3,32 a
KK a (%)	14,88					
KK b (%)	15,91					

The treatment with PGPR addition shows the highest values in the inorganic fertilizer treatment, which can be interpreted as evidence that the presence of PGPR supports the process of better nutrient absorption. This highlights the importance of considering biological factors (PGPR) in fertilization practices.

Principal Component Analysis (PCA) Results

Based on the results of Principal Component Analysis (PCA), growth parameters such as Plant Height, Number of Leaves, Number of Tillers, and Chlorophyll Content tend to be more influenced by treatments positioned on the left side of the PCA graph, namely P0R0, P0R15, P1R0, and P1R15. These treatments exhibit a stronger correlation with growth parameters, as indicated by their proximity to the growth-related variables on the left side of the graph. This suggests that the P0 (without fertilizer) and P1 (inorganic fertilizer) treatments have a more significant impact on plant growth based on the measured parameters.

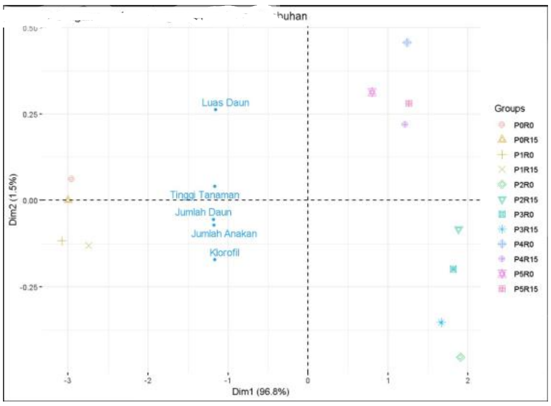

Fig.2. Principal Component Analysis (PCA)

In contrast, treatments located on the right side of the PCA graph, such as P2R0, P2R15, P3R0, P3R15, P4R0, P4R15, P5R0, and P5R15, show a weaker influence on the growth parameters. These treatments demonstrate a weaker correlation with growth variables, as indicated by their greater distance from the growth-related variables on the PCA graph.

The application of fertilizer significantly influences plants during the growth phase. The use of organic fertilizers has not yet been able to yield optimal results for plant growth, thus lagging behind inorganic fertilizers in performance. This is consistent with the findings of Santosa et al., (2017), which showed that the use of organic fertilizer derived from cow manure resulted in lower plant performance compared to treatments using inorganic fertilizers. This difference is attributed to the slower release of nutrients in organic fertilizers, while inorganic fertilizers release nutrients more quickly and precisely, making them easier and faster for plants to absorb.

According to Safitry & Kartika, (2013)), the application of inorganic fertilizers produces higher yields compared to organic fertilizers due to the faster availability of nutrients in inorganic fertilizers.

In terms of plant dry weight, observations across all growth stages show that inorganic fertilizers produce the highest results. This indicates that organic fertilizers still fall short of matching the performance of inorganic fertilizers in terms of plant dry weight at all growth stages. This finding aligns with the study by Bilalis et al., (2018), which demonstrated that inorganic fertilizers resulted in the highest plant dry weight. Furthermore, Sution et al., (2018) explained that applying inorganic fertilizers at doses of 100% to 150% can increase the dry weight of rice plants compared to treatments without fertilizer.

Based on PCA analysis results shown in Figure 2, parameters such as leaf area (*luas daun*), plant height (*tinggi tanaman*), number of tillers (*jumlah anakan*), number of leaves (*jumlah daun*), and chlorophyll content (*kandungan klorofil*) are strongly influenced by inorganic fertilizers. This highlights the significant role of inorganic fertilizers in supporting optimal plant growth.

IV. CONCLUSION

The Principal Component Analysis (PCA) revealed that plant growth parameters, such as height, leaf count, tiller number, and chlorophyll content, were most influenced by treatments on the left side of the PCA graph, namely P0R0, P0R15, P1R0, and P1R15, indicating a significant impact from inorganic fertilizers and the absence of fertilizers. Conversely, treatments on the right side (P2R0, P2R15, P3R0, P3R15, P4R0, P4R15, P5R0, and P5R15) showed weaker effects on growth parameters. Regarding nutrient residues, inorganic fertilizers had low phosphorus efficiency, with much of it remaining in the soil. PGPR application helped improve nitrogen availability by reducing nitrogen leaching, while organic fertilizers and PGPR increased potassium uptake. Overall, organic fertilizers and PGPR affected nutrient residues and plant nutrient uptake, improving soil fertility and plant health, but did not directly promote growth.

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