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Organic and Biofertilizers as Replacements for Synthetic Fertilizers to Increase Rice Yield in Tidal Swamp

Andin Muhammad Abduh [a,*], Masganti [b,c], Nukhak Nufita Sari [d], Abdul Haris [a], Hairil Ifansyah [a], Ronny Mulyawan [d]

[a] Soil Department, Faculty of Agriculture, Lambung Mangkurat University, Banjarbaru, Indonesia,
[b] Food Crop Research Center, Food and Agricultural Research Center, National Research and Innovation Agency (BRIN), Jakarta, Indonesia
[c] Animal Husbandry Department, Faculty of Agriculture, Islamic University of Kalimantan, Banjarmasin, Indonesia
[d] Agroecotechnology Department, Faculty of Agriculture, Lambung Mangkurat University, Banjarbaru, Indonesia

Abstract. *Maintaining soil sustainability to increase and sustain land productivity can be achieved by minimizing synthetic fertilizers and maximizing organic fertilizers and biofertilizers, especially in suboptimal lands. Therefore, this study aimed to determine the effects of organic fertilizers and biofertilizers with reduced NPK (Nitrogen, Phosphate, Potassium) dosage on increasing rice yield in tidal swamp areas in Tebas Sungai Village, West Kalimantan. The procedures were carried out using a complete randomized block design, with several treatments consisting of 175 kg ha^{-1} NPK as a control (P0), 130 kg ha^{-1} NPK + 1.5 tons ha^{-1} cow manure (P1), 130 kg ha^{-1} NPK + 3.0 tons ha^{-1} cow manure (P2), and 130 kg ha^{-1} NPK + 25 kg ha^{-1} biofertilizers (P3). Based on assessment, the study area was then categorized as C overflow type. The results showed that the combination of NPK synthetic fertilizers with cow manure led to a 15.1%, 25%, 5.6%, and 5.4% increase in total tillers, total grains per panicle, weight of 1000 grains, and rice yield, respectively. In addition, the use of NPK fertilizers with biofertilizers increased total tillers, total grains per panicle, weight of 1000 grains, and rice yield by 24.6%, 56%, 7.7%, and 18%, respectively, compared to only NPK fertilizers. Based on these results, improving rice performance in tidal swamp areas could be achieved by integrating organic or biofertilizers with synthetic fertilizers.*
Keywords: *Inorganic fertilizer; Cow manure; Inpari-30; Sub-optimal land.*

Type of the Paper: Regular Article.

1. Introduction

Rice (*Oryza sativa* L.) is a staple food consumed by billions of individuals around the world. Ensuring its constant availability is essential for food security, particularly in countries where a large population consumes rice, such as Indonesia. Consequently, farmers are encouraged to enhance the production of the crop and improve its quality to meet the growing demand from consumers each year [1]. To achieve these objectives, most farmers use synthetic fertilizers to meet the nutrient requirements of rice. However, the practice often leads to an imbalance in soil nutrients, high loss of nitrogen (N) (resulting in groundwater pollution consumed by the

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* First corresponding author
Email: andin.abduh@ulm.ac.id

community), and low N utilization efficiency [2]. Overuse of organic fertilizers can also lead to a decline in soil fertility, ultimately impacting long-term rice production [3].

Due to these impacts, farmers have developed a desire to use organic fertilizers to reduce the use of synthetic variants. However, relying solely on fertilizers is not feasible due to their inability to meet N requirements of rice [4] as the crop primarily depends on soil N [5]. This challenge is more pronounced in tidal swamp areas, which are suboptimal lands with low N content [6], indicating the need to integrate both synthetic and organic fertilizers [7].

In line with previous studies, incorporating organic fertilizers is associated with the use of various substances, such as cow manure, which serves as a significant nutrient source for the growth and development of rice plants, owing to its high N content. Cow manure also enhances soil physical, chemical, and biological properties [8]. N content in cow dung fertilizers is 1.1%, making it highly beneficial to complement synthetic fertilizers in providing N.

In addition to organic fertilizers, the application of biofertilizers can also serve as a viable alternative to minimize reliance on synthetic fertilizers [9]. Several studies showed that biofertilizers are capable of adapting and enhancing plant productivity in swampy areas [10]. The role of these materials is to promote plant growth by providing nutrients through the application of residual microorganisms. These microorganisms assist in mobilizing nutrients from soil and facilitating their conversion into forms that are usable by plants. This transformation occurs through biological processes, such as fixation of N and the generation of compounds that promote growth [11].

One of the effective biofertilizers suitable for tidal swamp areas is soil biota product, which has been successfully developed by the Ministry of Agriculture. Soil biota consists of a blend of decomposer microorganisms (such as *Trichoderma sp*), phosphate (P)-solubilizing bacteria (like *Bacillus sp*), and N-fixing bacteria (such as *Azospirillum sp*) in a carrier medium of powdered plant organic residues. This formulation aids plants in meeting their N and P requirements [10]. Therefore, this study aims to determine the efficacy of organic fertilizers, such as cow manure and biofertilizers when NPK (Nitrogen, Phosphate, Potassium) dosage was reduced from its recommended level, to support rice yield in tidal swamp areas. The results are expected to provide information on whether cow manure or biofertilizers can replace the reduced NPK base fertilizers dosage.

2. Materials and methods

This study was conducted in Tebas Sungai Village (1.1903786 ^{0}N, 109.1808847 ^{0}E), to examine the impacts of the biofertilizers and cow manure. The experimental treatments comprised 175 kg ha^{-1}NPK as a control group (P0), 130 kg ha^{-1} NPK + cow manure at 1.5 tons ha^{-1} (P1), 130 kg ha^{-1}NPK + cow manure at 3.0 tons ha^{-1} (P2), and 130 kg ha^{-1} NPK + biofertilizers at 25 kg ha^{-1} (P3). Treatments were repeated 3 times and arranged in a complete randomized block design. Biofertilizers consisted of *Trichoderma sp*, *Bacillus sp*, and *Azospirillum sp*.

2.1. Land Characteristics

The type of water overflow was one of the determinants of water and land management in tidal swamp areas, which needed to be determined beforehand. The classification of water overflow types in tidal swamp areas was based on the criteria proposed by Hairani and Noor [12]. Another characteristic of the land was the depth of iron sulfide (pyrite), which also determined water and land management techniques, specifically soil cultivation. Therefore, diagonal measurements of pyrite depth were taken at various depths, followed by its tests using hydrogen peroxide.

Soil characteristic level was closely related to land, where soil samples were collected from a depth of 0 to 20 cm to analyze chemical properties, including pH, organic-C, total-N, available-P, exchangeable base, and cation exchange capacity (CEC). Methods for analyzing these parameters were outlined in Table 1.

Table 1. Methods of analysis of soil chemical properties

No.	Type of analysis	Analytical method
1.	pH (H_2O)	pH meter
2.	Organic-C (%)	Walkley & Black
3.	Total-N (%)	Kjeldahl
4.	C/N	Calculated
5.	Available-P (μg g^{-1})	BrayII-Olsen
6.	Exchangeable base (cmol(+) kg^{-1})	NH_4OAc 1,0 N
7.	CEC (cmol(+) kg^{-1})	NH_4OAc 1,0 N

2.2. Study Procedures

Preliminary fertilizers application included lime (700 kg ha^{-1}) applied in all treatments, then NPK 175 kg ha^{-1} for the control and NPK 130 kg ha^{-1} (reduced 25% of recommendation dosage) for the remaining treatments. 15-day-old seedlings of the Inpari-30 rice variety were planted in plots measuring 8 x 10 meters using a planting system called Jarwo 2:1, as shown in Fig. 1. All cow manure, lime, and biofertilizers were applied 15 days before transplanting. NPK fertilizers were applied at a rate of 100 kg ha^{-1} 7 days after transplanting (DAT) in all treatment plots, then 75 and 30 kg ha^{-1} NPK was applied at 30 to 35 DAT in the control and other treatment plots, respectively. Observations were made on plant height and the total of tillers, as well as panicle length, total of filled grains per panicle, 1000-grain weight, and productivity at 30 and 60 DAT. Data analysis was conducted using analysis of variance to distinguish the effects between treatments. Least Significant Difference (LSD) was conducted at a significance level of 95%.

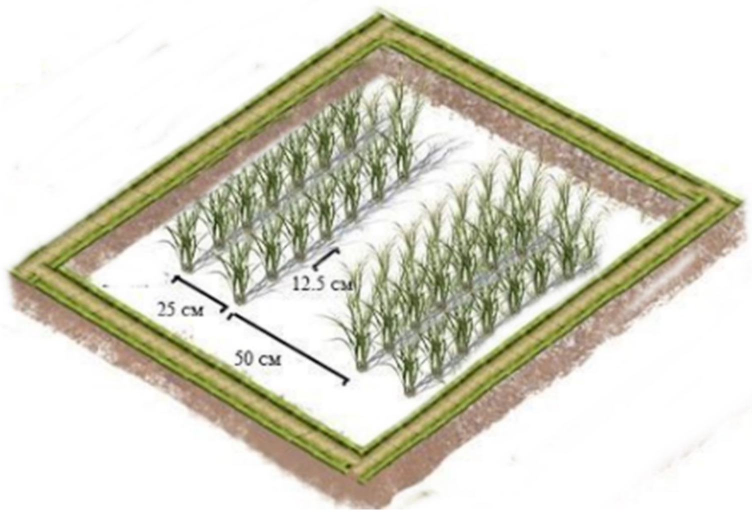


Fig. 1. Jarwo 2:1 Planting System.

3. Results and Discussion

3.1. Land Characteristics

Based on field observations regarding the highest water level and discussions with farmers, it could be concluded that the study area was under the category of tidal swamp land with type C water overflow. During single tides and the rainy season, the highest water level typically reached 10 to 20 cm from soil surface. These results were consistent with the classification proposed by Hairani and Noor [12].

The depth of the pyrite layer was in the range of 60 to 80 cm, with an average of 70 cm, which was suitable for soil cultivation using a 4-wheel tractor. A crucial factor to consider was the water level, ensuring it did not surpass 70 cm from soil surface. When the water level was higher than this, pyrite could oxidize and release a significant amount of H^+ ions, which could drastically degrade the environmental quality of plant growth.

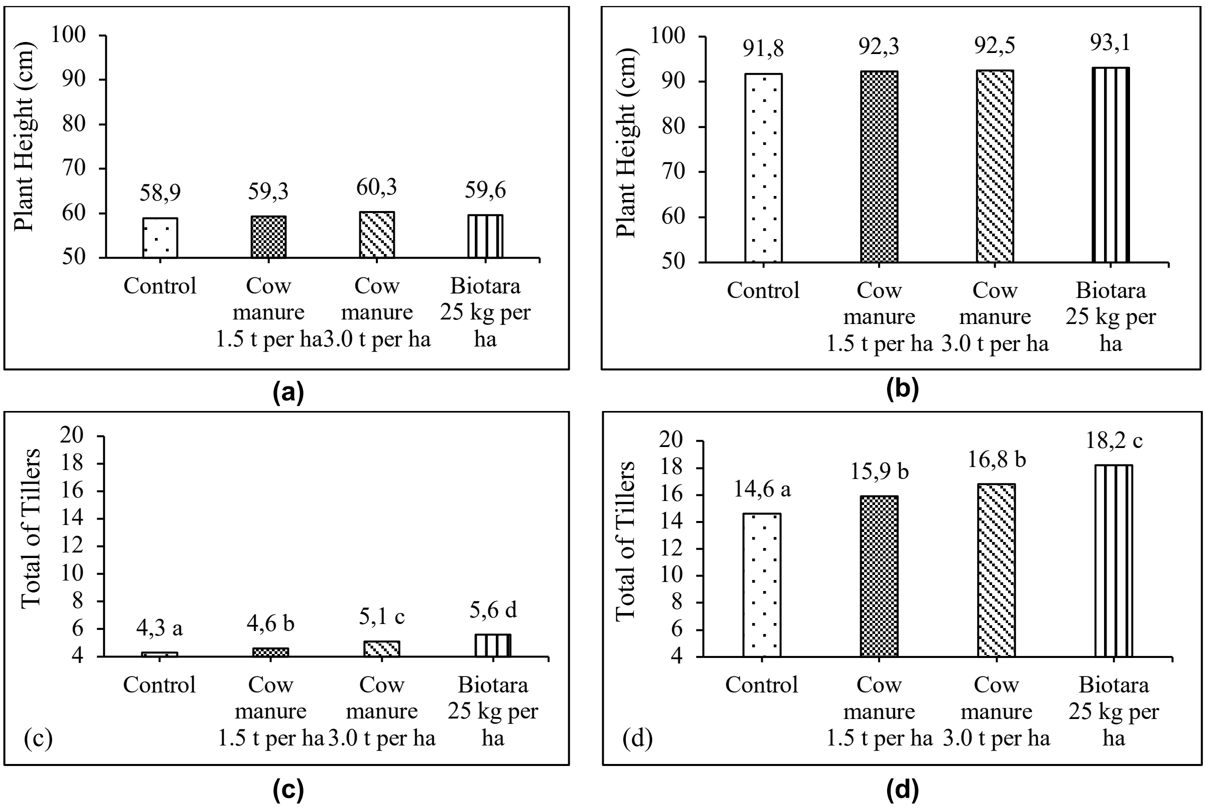
Table 2. Characteristics of soil

No.	Chemical properties and unit	Value	Criteria
1.	pH H_2O	4.59	Acid
2.	Organic-C (%)	1.88	Low
3.	Total-N (%)	0.22	Moderate
4.	C/N	8.5	Low
5.	Available-P ($\mu g\ g^{-1}$)	8.7	Low
6.	Exchangeable-Ca (cmol(+) kg^{-1})	2.3	Low
7.	Exchangeable-Mg (cmol(+) kg^{-1})	2.8	High
8.	Exchangeable-K (cmol(+) kg^{-1})	0.11	Low
9.	Exchangeable-Na (cmol(+) kg^{-1})	0.22	Low
10.	CEC (cmol(+) kg^{-1})	25.73	Moderate

Table 2 presented the results of soil chemical analysis conducted at the study area. The analysis suggested that soil exhibited acidic, had a low content of organic carbon (C-organic), had very low to low availability of phosphorus (Available-P), a moderate level of N-total, low levels of calcium (Ca), K, as well as sodium (Na), a high level of magnesium (Mg), and a moderate to high cation exchange capacity (KTK). To improve soil ability to sustain rice growth and yield in this area, it was imperative to apply lime and fertilize with N, P, and K [13] along with cow manure and biofertilizers application.

3.2. Plant Growth

The analysis of variance in the study on the use of biofertilizers and cow manure revealed that none of the treatments significantly impacted the height of rice plants at 30 and 60 DAT (Fig. 2). This indicated that N requirement for plant height had already been adequately met through the initial application of NPK fertilizers. The reduction of NPK base fertilizers to 130 kg ha^{-1} (less than 25% than recommended dosage) was an initial step in reducing the use of synthetic fertilizers. While this could result in limited soil N availability, it did not impact rice yields [14]. In addition, in most of rice plant's vegetative cycle, it required a consistent supply of N, particularly during stages such as tiller formation and panicle initiation [15].



Different numbers within subfigures show significant disparities as per LSD test at a 95% significance level

Fig. 2. Application of cow manure and biofertilizers on (a) plant height at 30 DAT, (b) plant height at 60 DAT, (c) total of tillers at 30 DAT, and (d) total of tillers at 60 DAT.

The application of biofertilizers resulted in a significantly different total of tillers (5.6 and 18.2 tillers) compared to cow manure both at 30 DAT (4.6 and 15.9 tillers) and 60 DAT (5.1 and 16.8 tillers), as depicted in Fig. 2. The lowest total of tillers was observed in the control treatment (4.3 and 14.6 tillers), indicating a reduced supply of N in soil. Furthermore, cow manure application increased the total of tillers by 18.6% (at 30 DAT) and 15.1% (at 60 DAT) relative to the control group. Rice tillers' growth was highly affected by the presence of N, P, and K, with N having the most significant impact [16]. The total of tillers depended on the percentage of total and available N in specific areas of rice canopy [17]. Other study teams also believed that the total of tillers was predominantly impacted by N uptake of rice plants [18].

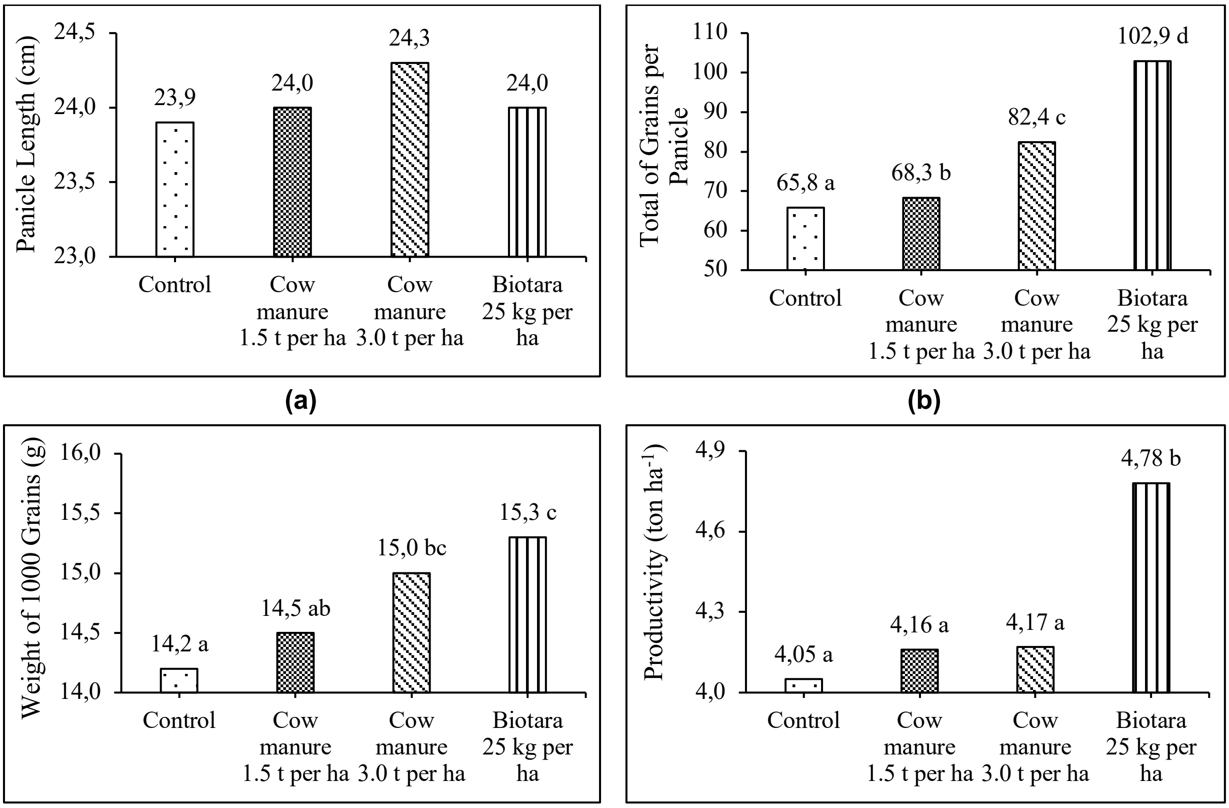
The application of cow manure led to a higher total of tillers in comparison to the control, and increasing doses of cow manure showed a similar trend. This was because cow manure application could enhance soil N content due to its N content of 1.1% [19]. In addition, the use of cow manure as a replacement for NPK was beneficial, but in practical terms, it must be considered for the long term. This was because it significantly enhanced soil capacity to sustain N nutrition for plants. The effects could be less pronounced when implemented in the short term [20].

Unlike cow manure, the application of biofertilizers resulted in the highest total of tillers, showing an increase of 30.2% (at 30 DAT) and 24.6% (at 60 DAT) relative to the control group. In addition, it was attributed to the composition of biofertilizers, which included a consortium of microorganisms (*Trichoderma sp.*) and N-fixing agents (*Azospirillum sp.*). This could enhance N availability for rice more rapidly [10]. *Azospirillum sp.* present in biofertilizers could capture N from the air (atmosphere) through a process called N fixation. Subsequently, the captured N was used by the microorganisms for synthesizing proteins in their cells. After these microorganisms died, the proteins in their cells were broken down (mineralized), releasing N into soil, which in turn contributed to N availability for rice plants [21]. Furthermore, Trichoderma sp. also played a crucial role in increasing the total of tillers in rice plants, as it possessed the ability to function through various mechanisms, including environmental buffering such as drought, pH, waterlogging, and toxicity [22]. Considering that soil in this study had these issues (Table 2) and the problem of high heavy metal content such as iron (Fe), it became more important [6]. In addition, *Trichoderma sp.* could also enhance nutrient uptake by promoting root growth [23]. These mechanisms were believed to be contributing factors to the observed high total of tillers in this study.

3.3. Yield Components and Productivity

Based on the study results, the usage of biofertilizers at a rate of 25 kg ha^{-1} could increase the total of grains per panicle, 1000 grains weight, and productivity in comparison to other treatments. As presented in Fig. 3, the application of biofertilizers resulted in 102.9 grains per panicle (a 56% increase compared to the control), a 1000-grain weight of 15.3 g (a 7.7% increase relative to the control group), and a productivity of 4.78 tons ha^{-1} (an 18% increase compared to the control). However, there was no notable distinction in the panicle length.

The combination of cow manure and NPK fertilizers usage was beneficial as it could sustain optimal rice yields and maintain soil productivity over the long run [24]. This was evident from the fact that applying cow manure could enhance the total of grains per panicle, 1000 grains weight, and rice yield when compared to the control (Fig. 3).



(a) (b) (c) (d)

Different numbers within subfigures show significant disparities as per LSD test at a 95% significance level

Fig. 3. Application of cow dung fertilizers and biofertilizers on (a) panicle length, (b) total of grains per panicle, (c)1000 grains weight, and (d) productivity.

The higher yield components and rice yield observed with the application of biofertilizers were attributed to its microorganisms, such as P-solubilizing bacteria (*Bacillus sp.*), which directly and indirectly affected plant yield components [10]. These bacteria enhanced the availability of phosphorus in soil and increased P absorption by root plants by their ability to dissolve P sources that were not readily available to plants, such as rock P and other inorganic P, through the secretion of organic acids and enzymes [25].

The use of synthetic fertilizers, such as NPK in combination with biofertilizers was a highly effective approach [26] to support rice growth and productivity. The use of NPK fertilizers combined with cow manure reduced synthetic fertilizers by up to 25%, while biofertilizers could reduce more than 25% because the productivity was significantly higher than others. Biofertilizers was an effective way to elevate the uptake of these 3 nutrients by root plants. Furthermore, it not only improved nutrient efficiency but also helped minimize the use of synthetic fertilizers for rice yield, specifically in waterlogged soil conditions [27]. This was evident as the additional use of fertilizers other than biofertilizers showed similar productivity compared to the application of 175 kg ha^{-1} NPK or the control (Fig. 3).

4. Conclusions

In conclusion, using synthetic fertilizers alone was a practice that must gradually be moved away. Integrating both organic and synthetic fertilizers was an excellent choice to maintain soil as a foundation for life. The integration of synthetic NPK fertilizers with cow manure demonstrated better results compared to using NPK fertilizers alone, when reduced by 25% than the recommended dosage. Furthermore, the integration of NPK fertilizers with biofertilizers showed the most optimal rice growth and yields, when reduced by more than 25% of the recommended dosage. This enhanced growth and optimal yields were attributed to the additional microorganisms in biofertilizers that assisted in nutrient availability for rice plants.

Data availability statement

Data will be shared upon request by the readers.

CRediT authorship contribution statement

A.M.A.: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review and editing. M.: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Writing – original draft, Writing – review and editing. N.N.S: Conceptualization, Project administration, Resources, Writing – original draft, Writing – review and editing. A.H.: Conceptualization, Funding acquisition, Investigation, Methodology, Writing – review and editing. H.I.: Investigation, Methodology, Validation, Writing – review and editing. R.M.: Data curation, Formal analysis, Investigation, Resources, Visualization, Writing – review and editing.

Declaration of Competing Interest

The authors of this manuscript declare that there is no conflict of interest or competing interest.

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