

Research Article

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Rice yield grown in different fertilizer combination and planting methods: Case study in Buru Island, Indonesia

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Abstract: Rice productivity in the tropics largely depends on fertilizers as soils are commonly low in nitrogen and phosphorus. Some farmers in this region cultivate rice using the hand-broadcast method, which has resulted in a low yield. Therefore, this on-farm experiment was conducted to compare the performance and yield of broadcasted and transplanted rice production systems under different fertilizer combinations. The experimental was set up in a split plot design with six combination treatments and seven replications. The main plots were planting methods comprised of transplanting and broadcasting. The subplots were a combination of NPK fertilizer, urea, and biofertilizer (BF) with and without compost, while the control treatment was NPK fertilizer and urea. The BF contained nitrogen fixer bacteria and phosphate solubilizer microbes. The results showed that fertilizer combination increased shoot height, root length, shoot and root dry weight (RDW), root-to-shoot ratio (R/S), tiller number, 1,000-grain weight, and yield but did not affect clump number. In addition, the planting method affected the parameters except for R/S and 1,000-grain weight. The yield of transplanted rice grown with NPK fertilizer and urea was 17.5% higher than that of the broadcasting method. Incorporation of chemical fertilizer combined with compost and BF resulted in a comparable yield; transplanted rice yield was only 2.18% more than broadcasted. This showed that diverse fertilizer application is needed to minimize the yield gap between broadcasted and transplanted rice.

Keywords: biofertilizer, broadcasting, compost, plant performance, transplanting

1 Introduction

Lowland and irrigated rice (*Oryza sativa* L.) is a food staple for the majority of inhabitant in Asia. In 2019, Indonesia was the third largest rice producer in Asia. Low-land rice fields in the country covered approximately 10.6 million ha in 2020, but the average yield was 5.1 t ha^{-1} , which is 53–60% lower than its genetic potential. In China, the global leading rice producer, the rice yield was 66–72% of genetic potential.

In rice cultivation, soil characteristics are one of the constraints for enhancing rice productivity, especially in tropical regions. Due to parent material, intensive weathering, severe soil degradation, and improper fertilizer management, tropical soils commonly have low nitrogen (N), phosphorus (P), and organic carbon (organic C) [1,2]. Fertilizer is the predominant factor of rice production in the tropics. The chemical fertilizers are widely used by rice farmers and considered a better way to rapidly increase rice yield [3–5]. The rice productivity in Buru soil with low availability of N and P was increased up to 9.8–29.3% by N, P, and K fertilizer application [6].

Currently, negative impact of intensive chemical fertilization is becoming a global problem. The fertilizer efficiency use is low mainly due to improper fertilizer management. Intensive and high-dose nitrogen fertilizer application can lead to N leaching and volatilization because of the high temperature in the tropics [7–9]. Phosphorus adsorption is a major constraint in tropical soil to supply an adequate amount for plant uptake [10]. Furthermore, chemical fertilizer prices are increasing rapidly due to the Russia–Ukraine war. To minimize the use of chemical fertilizer, biofertilizer (BF) and organic matter amendment are suggested.

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BF is a sustainable way to maintain long-term soil fertility and plant yield. Generally, commercialized BF contains N_2 -fixing bacteria (NFB) and P-solubilizing microbes (PSM) as an alternative substitute for N and P supply from chemical fertilizer [11–13]. The NFB and PSM in general can also synthesize phytohormones that regulate plant growth and development [14]. BF should be inoculated simultaneously with organic matter amendment to optimize microbial activity in the soil since the microbes are mainly heterotrophs and depend on organic-C for metabolism [15]. Organic matters alter the soil's physical, chemical, and biological properties and enhance rice productivity. Paddy soil received organic matter such as rice straw, green manure, and compost combined with NPK fertilizer had higher organic-C, available plant nutrient, and cation exchange capacity, resulting in higher rice yield [16–18].

The transplanted rice production system is more common than the broadcasted one in some area of the tropics. The broadcasting method, known as direct seeding technique, ascribes a rice production system by sowing seeds on the rice field rather than transplanting rice seedling from the nursery. The quality of rice seedlings in the nursery before transplanting into rice fields is commonly good. Transplanting causes uniform spacing and plant growth, limits competition between rice crops for nutrients and space, and reduces weed growth. However, transplanted rice production requires a higher cost but generates lower profit [19,20].

Rice cultivation by using transplanting method resulted in higher productivity than the broadcasting technique. The average rice yield under the broadcasting method was approximately 20–30% lower than the transplanting method [21–23]. Despite the lower production yield, the broadcasting method is easy and cost-effective and requires less labor [23,24]. The disadvantages of this technique are that the crop's density and spacing vary between the plants and need higher nutrients [25]. The weed growth in the broadcasted-base rice production system reduces the yield due to nutrient competition [26]. However, it requires less water and labor and promotes soil's physical properties. This method possibly resulted in similar yields to the transplanting method [27].

Buru Island is a major rice production center in the eastern part of Indonesia. Fertilizer availability and soil quality are the limitations of rice intensification. Rice field is dominated by low organic matter, total N, as well as available P and K [6,28]. Most farmers prefer the broadcasting method because of the labor and planting machine limitations. The problem of rice productivity in Buru was improper nutrient management due to the high

price and limited supply of fertilizer to support broadcasted rice production. Farmers and local governments are unfamiliar with other substitutes to reduce the dose of chemical fertilizer. The local government suggests the farmers change their planting method even though the low yield in broadcasting method had not been proven.

A previous study reports the role of BF and organic matter in increasing transplanted rice yield. This study will be a new approach for increasing growth and hence the yield of broadcasting rice. The objective of on-farm experiment was to compare the performance and yield of broadcasted- and transplanted rice production systems in an irrigated rice field under three different fertilizer combinations. The hypothesis of this field experiment included: (1) the performance and yield of rice cultivated with the mixture of chemical fertilizer, compost, and BF by using the transplanting method was better than the broadcasting method and (2) the combined fertilizer application in the plot using the broadcasting method results in the yield increment. From acquired knowledge, Buru's farmers and decision-makers still do not have accurate data regarding the broadcasted rice productivity under various fertilizer combinations. The results will provide a basis for rice fertilizer management adapted by farmers, agricultural extension officer and local government of Buru district and Indonesia, and researchers of tropical countries where broadcasting method is usually used for rice production system in low fertility soil.

2 Materials and methods

2.1 Study area

Field trial was performed at Savana Jaya, Waeapo District, Buru Regency, Indonesia (Figure 1) from February to May 2018. The geographical position of irrigated field experiment is 03°18'37"S and 127°01'26"E. The annual temperature and relative humidity of the district during the experiment were 23.9–31.1°C and 55.1–79–94%, respectively. Furthermore, the annual rainfall during the trial was 1,774 mm, while the average monthly precipitation was 158.8 mm. The experiment was conducted during the rainy season; hence, the average number of rainy days and sunshine duration were 21.5 days and 52.7%, respectively. Based on Schmidt and Fergusson's classification, the climate of Buru Island was C type.



Figure 1: Field experiment (in red rectangle) located in Savana Jaya of Waeapo District, Buru Regency, Maluku Province.

The topography of the experimental field was flat, and the altitude was 66.6 m above sea level. The trial was conducted in sandy clay Inceptisols with low fertility status. The soil has the acidity of 6.65; low in organic C (0.75%), total N (0.07%), available P (4.62 mg kg⁻¹), total K (19.9 mg 100 g⁻¹), and exchangeable K (0.1 cmol kg⁻¹), but average in total P (16.32 mg 100 g⁻¹); the cation exchange capacity of the soil was low (8.47 cmol kg⁻¹). The chemical soil characteristics were analyzed following the Association of Official Analytical Chemists methods for proximate analysis [29].

Table 1: Fertilizer treatment for lowland rice by using transplanting and broadcasting methods

Treatments	Chemical fertilizer (kg ha ⁻¹)		BF (L ha ⁻¹)	Compost (t ha ⁻¹)
	NPK	Urea		
Control (C)	300	150	—	—
Biofertilizer (BF)	300	150	3	—
Compost–biofertilizer (C–BF)	300	150	3	5

2.2 Field experimental methods and design

A field test was conducted to evaluate the productivity of the inbred rice cv. Cigeulis. Field experiment was set in Split Plot Design. The main plots were planting methods consisted of broadcasting and transplanting method; while the sub plots were the fertilizer treatments consisted of the control with chemical fertilizer (C), and a combination of chemical fertilizer and liquid BF with compost (BF) and without compost (compost and biofertilizer [C–BF]). These treatments were replicated three times. Table 1 presents the doses of the fertilizers. The chemical fertilizer consisted of compound NPK (15-15-15) and urea; the NPK rate was based on the NPK application using transplanting method [30,31].

The liquid BF was developed by the Soil Biology Laboratory, Faculty of Agriculture, Universitas Padjadjaran. It is composed of NFB *Azotobacter chroococcum*, *Azotobacter vinelandii*, *Azospirillum* sp., and *Acinetobacter* sp. and PSM *Pseudomonas* sp. and *Penicillium* sp. The count of bacteria and fungi in BF was at least 10⁷ and 10⁵ CFU mL⁻¹; and the microbes produced phytohormones and organic acids [32]. The compost was made from cow manure mixed with sawdust, fodder grass residue, and decayed cajuput (*Melaleuca cajuputi*) leaves. The chemical composition of the compost was 23.7% organic C, 1.53% total N, 0.1% P, 2.6% K, 1.2 mg kg⁻¹ Fe, 820 mg kg⁻¹ Mn, and 42 mg kg⁻¹ Zn. The carbon-to-nitrogen ratio of compost was 15.41, while the moisture content and acidity were 37.21% and 6.1, respectively.

The orientation, shape, and size of experimental units were adapted to farmer's field. The contiguous and rectangular area were divided into two units for the transplanted- and broadcasted-planting method. Each was split into three fertilizer treatment plots (Figure 2). The plot area was 481–437.5 m² and varied in length and width. The total area for transplanting and broadcasting methods was 1,391 and 1337.5 m², respectively.

2.3 Farming practice in experimental plots

The post-emergence herbicide glyphosate was sprayed 2 days before tillage. The fields were irrigated from the water tunnel nearby to saturate the soil. Afterward, a hand tractor was performed for initial puddling to soften the soil, create a compacted layer, and minimize water percolation losses. After 2 days, the second soil puddling was conducted, and compost was incorporated in the plots with compost treatment.

The rice field for the transplanting method was irrigated to form a puddle of 5 cm in depth. The water was not irrigated into the broadcasted-method field to prevent seed movement. Furthermore, the experimental plots were left for 5 days before pre-emergence herbicide application. The following day, the 18-day-old transplants were mechanically relocated with 25–20 cm spacing and three transplants in each hole. In the broadcast plots, 15 kg ha⁻¹ of seed was manually broadcasted.

The NPK, urea, and BF were applied at 1, 3, and 5 weeks after planting for transplanting units and at 1, 5, and 8 weeks after sowing in broadcasting units. The dose of each application was one-third of the Indonesian Ministry of Agriculture recommendation (Table 1). The BF at 3 L ha⁻¹ was divided into three applications, diluted into 5% with groundwater, and sprayed into the soil and plants.

The systemic insecticide Fipronil at the dose of 50 g L⁻¹ was sprayed at 8 and 56 days after planting. The blast disease attack caused by *Pyricularia grisea* fungus was controlled with a protectant copper fungicide. A contact insecticide from the thiazine group was applied to control the stem borer caused by brown planthopper. Weeds were mechanically removed 5 weeks after planting only in the transplanted-method units.

2.4 Parameters and statistical analysis

The crop cutting experiment was performed to measure plant growth and rice yield in each plot [33]. Seven sample areas were randomly selected for each plot through a square meter bamboo frame. The sample plants were not collected from the plot edge and border. The rice plants inside the frame were measured for shoot height, root length, clump number, tiller number, and effective tiller number at the late vegetative stage. The shoot and root samples were heated at 60°C for 2 days before dry

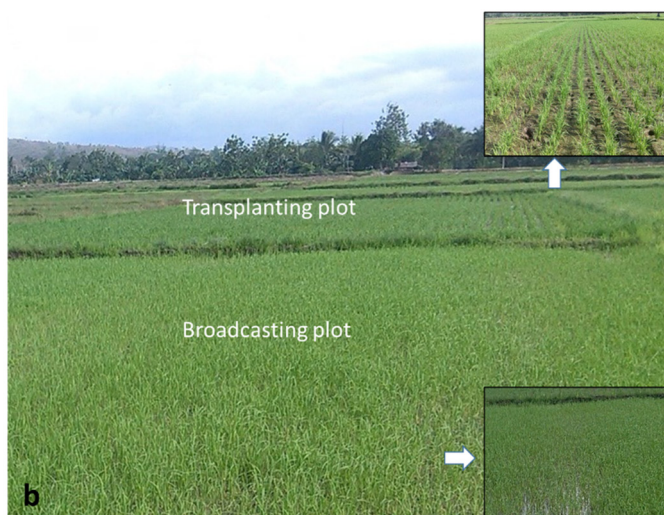
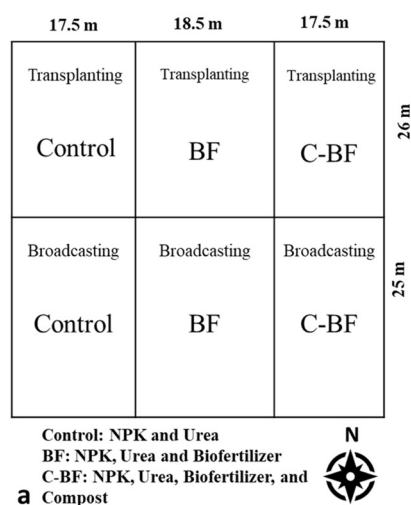


Figure 2: Treatment placement in the field experiment in transplanting and broadcasting plots (a) and 21-day-old rice in transplanting and broadcasting plots (b).

weight analysis, after which the root-to-shoot ratio (R/S) was calculated. The panicles inside the frame were harvested and sun-dried for 3 consecutive days before measuring the total grain dry weight (GDW) and 1,000-grain weight. Rice yield in each experimental plot was calculated based on the average values of GDW in a square meter sampling area.

The data were subjected to analysis of variance (ANOVA) at $p \leq 0.05$, followed by the least significant difference (LSD) test at $p \leq 0.05$ when the sum squares of the parameters were significant. They were analyzed using Minitab Data Analysis and Statistical Tools version 18.

3 Results and discussions

3.1 ANOVA results

Based on ANOVA, the p -values of the main treatments and their interaction on growth and yield parameters are shown in Table 2. Fertilizer treatments had a significant

effect on the parameters except for clump number. The planting methods affected almost all parameters but did not influence R/S and 1,000-grain weight. The interaction effect between fertilizer combination and planting method was significant on shoot dry weight (SDW), tiller number, effective tiller number, grain weight, 1,000-grain weight, and rice yield.

3.2 Plant growth parameters

The positive effect of fertilizer composition on plant growth was reflected in an increase in shoot height, root length, and SDW and RDW but did not influence the clump number (Table 3). Chemical fertilizer in combination with C-BF significantly increased root length, SDW, and RDW compared to NPK + urea (control). Furthermore, rice grown with combined fertilizer (C-BF) resulted in 46.0% more SDW and 83.1% more RDW than the control. The R/S clearly increased by approximately 20% by using BF with or without compost compared to the control.

Table 2: The p -value and significance effect of treatments on parameters based on ANOVA

Sources	Growth parameters							Yield parameters			
	SH (cm)	RL (cm)	SDW (g)	RDW (g)	R/S	CN	TN/clump	ETN/clump	GDW (g) ¹	1,000 GDW (g)	Yield (t ha ⁻¹)
Fertilizer	0.000*	0.000*	0.000*	0.000*	0.000*	0.802	0.000*	0.000*	0.000*	0.001*	0.000*
Planting methods	0.000*	0.003*	0.000*	0.000*	0.110	0.000*	0.000*	0.000*	0.000*	0.445	0.000*
Fertilizer × planting	0.343	0.344	0.013*	0.085	0.479	0.764	0.016*	0.001*	0.000*	0.023*	0.000*

*Significant at $p \leq 0.05$.

¹Data taken from the square meter sampling area.

SH – shoot height; RL – root lengths; SDW – shoot dry weight; RDW – root dry weight; R/S – root-to-shoot ratio; CN – clump number; TN – Tiller number; ETN – effective tillers number; GDW – grain dry weight.

Table 3: The main effect of fertilizer combination and planting method on rice growth parameters measured 60 days after planting

Treatments	Shoot height (cm)	Root length (cm)	Shoot DW (g)	Root DW (g)	R/S ¹	CN ²
Fertilizer combination						
Control (C)	77.26 ± 13.67b	15.30 ± 1.08b	6.13 ± 1.25c	1.60 ± 0.50c	0.26 ± 0.05b	22.27 ± 4.27a
BF	84.31 ± 11.16a	15.77 ± 0.82b	8.27 ± 0.91b	2.58 ± 0.39b	0.31 ± 0.03a	22.69 ± 4.69a
Compost and biofertilizer (C-BF)	85.31 ± 10.49a	16.76 ± 1.08a	8.95 ± 1.08a	2.93 ± 0.48a	0.33 ± 0.04a	22.22 ± 4.23a
Planting method						
Transplanting (T)	92.81 ± 4.31a	16.34 ± 0.81a	8.39 ± 1.07a	2.60 ± 0.53a	0.31 ± 0.05a	18.60 ± 1.56b
Broadcasting (B)	71.78 ± 7.07b	15.55 ± 1.16b	7.18 ± 1.86b	2.13 ± 0.83b	0.29 ± 0.05a	26.18 ± 2.29a

Values indicated by the same letter are not significantly different based on the LSD test ($p \leq 0.05$).

¹R/S – root-to-shoot ratio.

²CN – clump number in a square meter.

Most of the plant growth parameters were higher in the transplanting unit compared to the broadcasting unit. However, the clump number in the transplanted rice was lower than in the broadcasted one, while the R/S was remained unchanged (Table 3). The shoot height of transplanted rice was 29.2% higher than broadcasted rice. In the transplanting method, root length, SDW, and RDW increased up to 5, 15, and 22%, respectively, compared to the broadcasting technique. Meanwhile, the clump number of transplanted rice was 29.8% lesser.

The field trial showed that the interaction between the planting method and fertilizer treatment on SDW was significant (Table 2). The effect of fertilizer composition on SDW depends on the planting method (Figure 3). Broadcasted rice which received NPK and urea had 31%

less SDW than transplanted rice treated with similar fertilizer.

Compared to the control, there is a significant increase in SDW after BF application in both planting methods. The inoculation increased SDW in the transplanting or broadcasting method. However, this parameter was 10.5% higher in the transplanting method. Fertilizer combination (C–BF) resulted in similar SDW in the two planting methods. Incorporating organic matter combined with chemical fertilizer and BF increased SDW up to 25.9 and 75.5% in the transplanting and broadcasting units, respectively. Therefore, chemical application with compost and BF was the best-combined treatment to increase SDW.

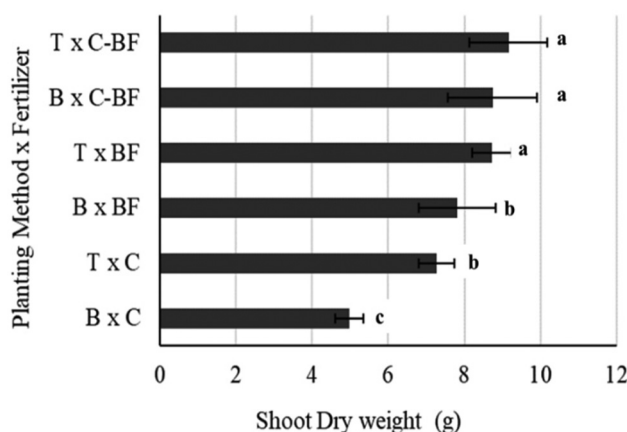


Figure 3: The SDW of rice crops grown with different planting methods and combined fertilizer treatments 60 days after planting. The planting methods were transplanting (T) and broadcasting (B). Fertilizer combination consisted of NPK and urea (control, C); NPK, Urea, biofertilizer (BF); NPK, Urea, compost and biofertilizer (C-BF). Error bars represent the standard error of the mean. Different letters were indicated significantly different based on the LSD test ($p \leq 0.05$).

3.3 Rice yield component parameter

All yield parameters were affected by either fertilizer composition or planting method (Table 4). BF inoculation significantly increased tiller number, effective tiller, grain weight, and rice yield but did not affect the 1,000-grain weight. The combination of NPK fertilizer, urea, C–BF significantly resulted in higher yield parameters than other treatments. Those fertilizer treatments resulted in 58, 48, and 48% more effective tiller, grain weight per m^2 , and rice yield, respectively.

According to Table 4, rice grown using the transplanting method produced 25.1 and 80.0% higher tiller number and effective tiller number consecutively. This planting method then has 18.6 and 18.8% more GDW and rice yield compared to the broadcasting method. In contrast, the two planting methods did not affect 1,000-grain weight.

The effect of the planting method on TN and ETN depends on the fertilizer combination. Regardless of the

Table 4: Main effect of fertilizer combination and planting method on yield parameters

Treatments	TN ¹ per plant	ETN ² per plant	GDW ($g\ m^{-2}$)	1,000-grain weight (g)	Rice yield ($t\ ha^{-1}$)
Fertilizer composition					
Control (C)	$30.86 \pm 8.01b$	$11.92 \pm 5.59c$	$497.0 \pm 53.96c$	$25.86 \pm 0.94b$	$4.97 \pm 0.54c$
BF	$38.93 \pm 3.65a$	$13.73 \pm 4.40b$	$581.1 \pm 121.15b$	$26.40 \pm 0.86b$	$5.81 \pm 1.21b$
Compost and biofertilizer (C-BF)	$37.43 \pm 5.36a$	$18.90 \pm 7.61a$	$739.0 \pm 49.17a$	$27.69 \pm 1.78a$	$7.38 \pm 0.49a$
Planting method					
Transplanting (T)	$39.71 \pm 4.47a$	$19.11 \pm 4.29a$	$657.4 \pm 106.70a$	$26.51 \pm 1.33a$	$6.57 \pm 1.07a$
Broadcasting (B)	$31.76 \pm 6.45b$	$10.61 \pm 2.46b$	$553.9 \pm 130.84b$	$26.79 \pm 1.59a$	$5.53 \pm 1.31b$

Values indicated by the same letters are not significantly different based on LSD ($p \leq 0.05$).

¹TN – tiller number.

²ETN – effective tillers number.

fertilizer combination, the transplanting rice showed higher TN and ETN (Figure 4a and b). Transplanting rice grown with control fertilizer showed a significant increase in TN to approximately 54% compared to broadcasting rice. However, the TN of transplanting rice after compost and BF application did not differ significantly from the TN of the BF treatment (Figure 4a). The ETN of rice was higher in the transplanting plots with any fertilizer combination (Figure 4b). Application of NPK, urea, compost, and BF in a transplanting rice was the best treatment to enhance the ETN up to 43 and 42% compared to chemical and BF application (BF) and control (C), respectively. The result showed that the highest ETN was observed in transplanted rice with a C-BF fertilizer combination.

The application of any combined fertilizer enhanced GDW in both planting methods compared to the control (Figure 5a). Nonetheless, the GDW of both transplanting

and broadcasting rice treated with chemical fertilizer and C-BF mixture was comparable with those grown with chemical and BF. The highest GDW was observed in transplanted rice treated with combined fertilizer (C-BF), which is 39% higher than those under only chemical fertilizer.

The 1,000-grain weight of control fertilizer (C) and the mixture of chemical and BF in both planting method did not differ based on ANOVA (Figure 5b). Nonetheless, compared to control fertilizer, a 1,000-grain weight increment was found in combined fertilizer (C-BF). Broadcasted rice treated with combined fertilizer had the highest 1,000-grain weight over another combination treatment.

Control fertilizer generally caused lower rice yield in both planting methods (Table 5). The yield of transplanting rice grown with NPK fertilizer and urea (control) was 17.5% higher than in the broadcasting method. Meanwhile, the yield of transplanting rice under

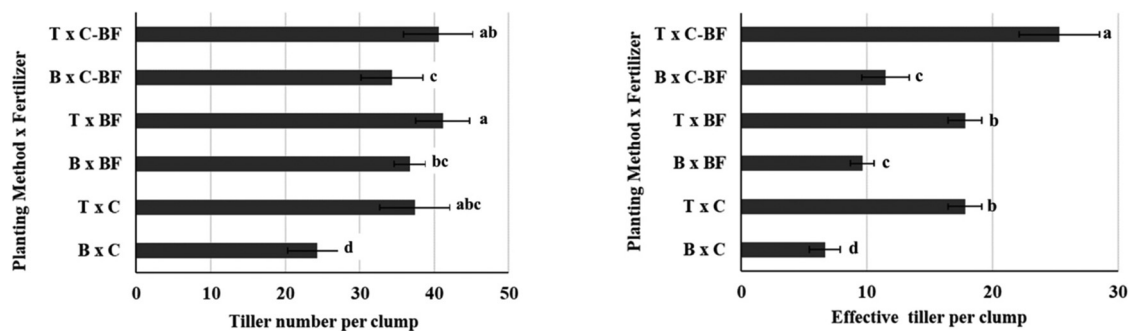


Figure 4: The tiller and effective tiller number of a rice clump with different planting methods and fertilizer combination treatments 60 days after planting. The planting methods were transplanting (T) and broadcasting (B). Fertilizer combination composed of NPK and urea (control, C); NPK, urea, biofertilizer (BF); NPK, urea, compost and biofertilizer (C-BF). Error bars represent the standard error of the mean. Different letters indicate significantly different based on the LSD test ($p \leq 0.05$).

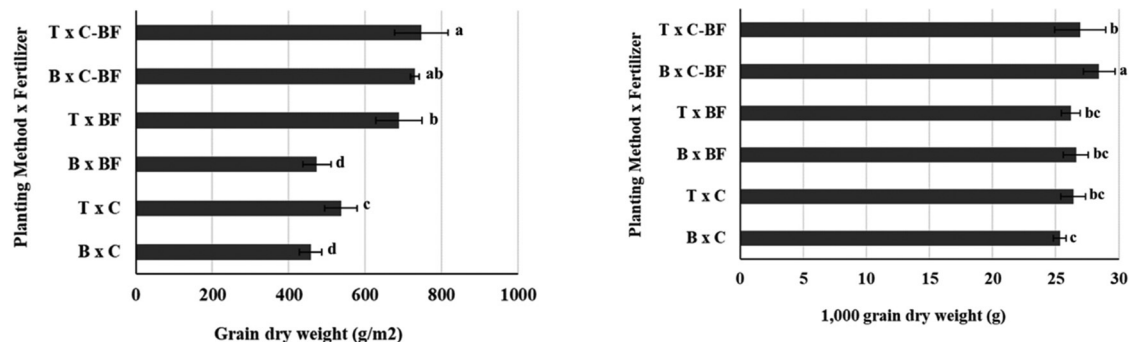


Figure 5: The GDW and 1,000-grain weight with different planting methods and fertilizer combination treatments 60 days after planting. The planting methods were transplanting (T) and broadcasting (B). Fertilizer combination were NPK and urea (control, C); NPK, urea, biofertilizer (BF); NPK, urea, compost and biofertilizer (C-BF). Error bars represent the standard error of the mean. Different letters indicated the significantly different based on the LSD test ($p \leq 0.05$).

Table 5: Rice yield grown under transplanting and broadcasting methods in different fertilizer compositions

Combination of planting method and fertilizer	Rice productivity (t ha ⁻¹)
Transplanting rice (T)	
Control: NPK and urea (C)	5.37 ± 0.42c
NPK, urea, BF	6.88 ± 0.60b
NPK, urea, compost–biofertilizer (C–BF)	7.47 ± 0.70a
Broadcasting rice (B)	
Control: NPK and urea (C)	4.57 ± 0.29d
NPK, urea, BF	4.74 ± 0.36d
NPK, urea, compost–biofertilizer (C–BF)	7.31 ± 0.11ab

Values indicated by the same letters are not significantly different based on LSD ($p \leq 0.05$).

chemical fertilizer and BF was 45.1% higher than the broadcasting technique. Chemical fertilizer combined with compost and BF resulted in a comparable yield in both planting method. The yield of transplanted rice was only 2.18% higher than that of the broadcasted method when using NPK, urea, compost, and BF.

4 Discussion

The experimental plots were fertilized with NPK and urea because the soil was deficient in N, P, and K. The main effect of fertilizer combination and planting method treatments on growth parameters was significant. This supports the result that the balanced fertilizer combination affects nutrient provision and enhances rice growth and yield [12,34]. In the current experiment, the role of BF inoculation also providing the bio-stimulant since the BF used in this trial contained phytohormone-producing microbes for promoting rice root growth [35,36]. The R/S of rice after BF and compost application was increased, showing an induction effect toward root growth. Therefore, the N, P, and K uptake of rice treated with BF could be increased. The results of this study were similar to the inoculation of BF containing NFB and PSB that improve plant height and rice tillering [12,37].

The application of compost significantly increased plant growth based on ANOVA. Organic matter amendment is essential for food crop production by improving the supply of soil organic carbon and nutrients [38,39], total porosity, and water status of rice soil [40]. Soil carbon is essential in controlling and enhancing N₂ fixation activity since the NFB requires high energy for N₂

fixation, and the bacteria are heterotrophic [41]. The result was in line with the increased rice growth in the tropical and subtropical environment after various organic matter amendments [16–18].

The results showed that planting methods affected plant growth parameters. The broadcasting method caused scattered rice growth in the field, and the distance between clumps was narrow (Figure 2). The narrow spacing led to nutrient competition; insufficient nutrient for plant uptake can reduce plant development and tillering [42]. The R/S increment in transplanting rice may induce nutrient uptake because competition between individual clumps is less than in broadcasting rice [25,27]. This supports other results that direct seeding reduces clumps number per square meter, plant height, and total and productive tiller number [21,22,43].

The present study states that combined fertilizer application counterbalanced the negative effect of the broadcasting method by supplying more nutrients for rice growth and yield. An increase in the effective tiller number was observed due to the application of compost, which accelerates the microbial activity in the rhizosphere to provide nutrients for plants [39]. Also, the nutrient provision through NFB and PSM is another reason for the increased plant growth in vegetative stadia [11–13]. Rice productivity of broadcasting and transplanting methods was comparable under combined fertilizer consisted of chemical fertilizer, compost, and BF. The experimental data confirmed that under proper fertilization, the productivity of broadcasted rice production system could be increased to gain a similar yield to transplanted rice method.

BF inoculation and soil organic matter amendment improve the nutrient provision to overcome the competition in the broadcasted rice cultivation system. In the current study, BF inoculation can overcome nutrient deficiency mainly N and P and led to increase the plant growth and tillering. In general, the non-symbiotic NFB are reported to provide 15–60 kg ha⁻¹ year⁻¹ of N [44,45]. The PSM increase available P in soil by organic acid and phosphatase production mechanisms to release the phosphate from unavailable P [46]. Furthermore, compost amendment in rice field is reported to increase the availability of N, P, and K [47,48].

According to the cultivar description, rice cv. Cigeulis has an average 1,000-grain weight of 28 g, a yield of 5 t ha⁻¹, and genetic yield potency up to 8 t ha⁻¹. The present study verified that BF and compost could increase rice yield grown using broadcasted-cultivation system in Buru Island. Despite a limited report on the effect of fertilizer combination in broadcasted rice in Indonesia, this

result follows the application of mixed inorganic–organic fertilizer and BF to enhance the yield of broadcasted rice significantly elsewhere [49,50].

At certain times, fertilizer is unavailable or available in less quantity in Buru Island. This situation led to the improper use of chemical fertilizer. The NPK fertilizer and urea were recommended by the Indonesia Ministry of Agriculture based on average soil fertility and a transplanted-based rice production system. In fact, most farmers cultivated rice in low fertility soil using the broadcasting method. The results provided new information about the yield increment of broadcasting rice after more proper fertilizer combination. Furthermore, this experiment showed that organic matter and BF could be recommended to enhance yield of broadcasted rice and reach their genetic potency.

5 Conclusion

The combination of chemical fertilizer, compost, and BF treatment was more outstanding in increasing root length, SDW, and RDW compared to chemical fertilizer. In addition, the growth and productivity of both planting methods was influenced by fertilizer composition. Rice grown by the transplanting method showed better performance. Furthermore, the shoot height, root length, SDW, and RDW were significantly increased up to 29.2, 5, 15, and 22%, respectively, compared to broadcasting rice. In contrast, the clump number of transplanted rice was 29.8% less than the broadcasted rice. The application of chemical fertilizer (NPK + urea) in combination with BF and compost produced 31 and 29.4% more yield in transplanting and broadcasting methods, respectively, compared to chemical fertilizer. Incorporating NPK, urea, compost, and BF with the both methods are the best treatment to enhance rice yield. The yield of both methods was not significantly different. The yield of broadcasting method was only 2.18% less than the transplanting technique.

The present study provides evidence that chemical fertilizer combined with BF and compost is prominent to increase rice productivity grown with broadcasting method in low soil fertility on Buru Island. In the future, combined fertilizer is expected to be used in Buru supported by organic waste availability and the initial rise of compost and liquid bio-organic fertilizer production.

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Data availability statement: The dataset generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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