

Optimizing Rice Seed (*Oryza sativa* L.) Production and Quality through Organic Fertilizer Application

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Abstract

Rice (*Oryza sativa* L.) is a vital cereal crop and primary food source for over half of the global population, especially in Asia, Africa, and Latin America. This study evaluated the effect of organic fertilizers on optimizing rice seed production and quality. Organic fertilizers improve soil physical, chemical, and biological properties, thereby enhancing nutrient availability. A study was conducted standard and premium organic fertilizers (petroganik), in a completely randomized design with six treatments: no fertilizer (control), (12.5% organic C) at 500 kg/ha, and the premium organic fertilizer (15% organic C) at 250, 500, 750, and 1000 kg/ha. With four replications, 24 experimental plots were established. Results showed that while application of premium organic fertilizer did not affect vegetative growth, it significantly increased the number of productive tillers and overall yield. Applying 500 kg/ha of premium organic fertilizer increased rice yield by up to 13% compared to the control, with a relative agronomic effectiveness of >95%. Seed quality improved, indicated by higher germination rates, vigor index, and maximum growth potential. The after-ripening period was shortened by two weeks compared to control seeds, i.e., from 5 to 3 weeks, but did not affect seed storability.

Keywords: after-ripening, control deterioration, relative agronomic effectiveness, soil nutrient, vigor

Introduction

Rice (*Oryza sativa* L.) is a staple food crop in many countries, including Indonesia. According to data from the Central Bureau of Statistics (Statistics Indonesia, 2023), national rice production from January to April 2023 reached 12.91 million tons, lower than last year's recorded 13.71 million tons. It is also estimated that rice consumption in May will increase from 2.51 million tons (2022) to 2.54 million tons (2023), and in June it will rise from 2.52 million tons to 2.55 million tons. A solution to meet rice consumption needs is the need for government encouragement to improve rice productivity. Rice productivity is significantly influenced by various factors, starting from the use of high quality seeds, targeted fertilization, proper irrigation, pest and disease control, and others (Anida et al., 2021). Seed quality plays a crucial role in determining crop production, from germination capacity to overall plant growth. Therefore, efforts to improve the quality of rice seeds directly impact agricultural productivity.

The production of quality seeds must follow the principles of genetics and agronomy. The availability of nutrients in the plant's growing environment is essential to producing seeds with high physiological quality. One factor supporting rice productivity is the availability of fertilizers containing various nutrients for plant growth and yield. The crucial nutrients are nitrogen (N), phosphorus (P), and potassium (K). These three macronutrients interact with each other to support plant growth. Nitrogen (N) is one of the essential nutrients for plants (Hawkesford et al., 2023).

The plants' absorption of nitrogen influences the development and growth of plants. The higher the plant absorbs nutrients, the faster its growth. Nitrogen (N) benefits for rice plants include promoting vegetative growth starting from root, stem, and leaf development (Wulandari & Winarsih, 2022). Another role of N in seed quality is to enhance protein synthesis in seeds, which is vital in forming enzymes and tissues needed during seed germination (Buchanan et al., 2015). Phosphorus (P) plays a role in improving root development and serves as an energy source by forming ATP (Margenda, 2020). Another function of P on seed quality includes enhancing the formation and development of embryo roots and improving energy availability during germination (Sun et al., 2023). Potassium (K) helps maintain plant resistance against lodging and boosts rice productivity (Andayani et al., 2021). Its role in seed quality can improve physiological processes such as nutrient transportation, crucial for seed vigor and early growth (Cardarelli et al., 2022). (Ningsih & Rahmawati, 2017) stated that the availability of nutrients such as NPK is essential for plants in large quantities to form carbohydrates, proteins, lipids, and nucleic acids constituting the newly formed seed cells.

Adding organic materials through organic fertilizers is one solution to improving soil conditions in Indonesia. Organic fertilizer is derived from dead plants, animal manure or parts, and other organic waste that has undergone processing, is available in solid or liquid form, and can be enriched with minerals and microbes beneficial for increasing nutrient content and soil organic matter, as well as improving the physical, chemical, and biological properties of the soil (Ndau et al., 2023). Research by Rifka et al. (2019) demonstrated that treatments with organic fertilizers and bio-fertilizers improved the seed quality of soybeans. Seeds that received high-dose fertilization treatments had sufficient food reserves to carry out physiological activities during germination. This is thought to be due to the higher protein content in the seeds, which can break down food reserves, allowing absorbed energy to be more readily transformed, resulting in larger seedlings.

Petroganik is a manufactured organic fertilizer that contains 12.5% organic carbon. Its granular form facilitates easy application and helps loosen and fertilize the soil, making it suitable for all soil types (Pinasti et al., 2020). The premium version of petroganik has an organic carbon content of at least 15% and a carbon-to-nitrogen (C/N) ratio of 25. The higher organic carbon content can potentially improve soil structure and aeration more effectively, promoting better nutrient absorption by plant roots. The purpose of this study is to investigate the effects of organic fertilizers with varying carbon contents on rice growth and yield.

Materials and Methods

The research was conducted from October 2023 to March 2024 at the Sawah Baru Experimental Station and the Seed Quality Storage and Testing Laboratory, Department of Agronomy and Horticulture, IPB University. Petroganik is a manufactured organic fertilizer that contains 12.5% organic carbon. Its granular form facilitates easy application and helps loosen and fertilize the soil, making it suitable for all soil types (Pinasti et al., 2020). The premium version of petroganik, herein after referred to as premium organic fertilizer, has an organic carbon content of 15% and a carbon-to-nitrogen ratio (C/N) of 25. The purpose of this study is to investigate the effects of organic fertilizers with varying carbon contents on rice growth and yield. The higher organic carbon content in the organic fertilizer can potentially improve soil structure and aeration.

The materials used in this research include 'Inpari 32' rice seeds, petroganik organic fertilizer, herein after referred to as the standard organic fertilizer, with a C-organic content of 12.5%, Premium petroganik organic fertilizer, herein after referred to as the premium organic fertilizer with a C-organic content of 15%, NPK 15-10-12, urea, and distilled water. Rice seeds were germinated in the IPB 72-1 germinator. Other equipment includes EYELA SB 24 water bath, scales, opaque paper, packaging plastic, and tweezers.

The experimental design used in this study is a completely randomized design with one factor and six treatment levels (Table 1), with four replications, resulting in 24 experimental plots. The plots measure 4 m × 5 m with a planting distance of 25 cm × 25 cm. Table 1 provides details of the treatment levels.

The fertilization schedule was divided into several stages based on crop growth phases. During the land preparation stage (0 days after planting, DAP), standard organic fertilizers, and premium were applied. Basal fertilization consists of NPK (15-10-12) and urea to supply essential macronutrients for early plant development. The first top-dressing fertilization was applied at 15 DAP; the second top-dressing was applied at 30 DAP using urea to meet nitrogen requirements during the reproductive phase.

Observations and measurements in this study encompassed several key variables categorized into soil analysis, vegetative and generative growth parameters, fertilizer effectiveness, and seed quality assessment. Soil chemical properties were analysed before and after the experimental period to assess nutrient dynamics and potential treatment effects. Vegetative growth parameters included plant height and the number of vegetative tillers. Plant height was measured weekly from 2 to 9 weeks after planting (WAP) on ten randomly selected clumps per experimental plot, recorded from the base of the stem to the tip of the tallest leaf. Concurrently, vegetative tillers were enumerated

by counting all tillers emerging from 10 sample plants.

Generative growth parameters comprised the number of productive tillers per clump (defined as tillers bearing panicles), panicle length (measured from the panicle base to the apex), total grain count per panicle, grain filling percentage (calculated as the ratio of filled grains to total grains, multiplied by 100), dry harvested grain yield (DHG, based on a harvest area of 15.75 m² at 25% moisture content), and dry milled grain yield (DMG, calculated from DHG dried to 14% moisture content). The weight of 1,000 grains was also determined using the counting method: 100 seeds were manually counted and weighed, with a moisture content of 14%; the DMG yield percentage was calculated as the proportion of DMG relative to DHG. Productivity per unit area was further estimated using the panicle component productivity model by Yoshida (1981):

$$\text{Productivity (ton/ha)} = \frac{\text{PT/m}^2 \times \text{TGC} \times \text{GFP} \times \text{Weight of 1000 grains (g)}}{10^5}$$

Where:

- PT : Productive tillers
- TGC : Total grain count
- GFP : Grain filling percentage

Ten sample panicles, taken randomly from the total panicles bulked from each experimental plot, were measured for panicle components, including panicle length and the number of grains

Table 1

Treatment Levels for Testing the Effectiveness of Organic Fertilizers on Rice

Treatments
Ministry of Agriculture Planting Calendar for rice fields, Dramaga District/local farmer habits (control) 250 kg/ha NPK 15-10-12 + 275 kg/ha urea
500 kg/ha standard organic fertilizer ¹) + 300 kg/ha NPK 15-10-12 + 200 kg/ha urea
250 kg/ha premium organic fertilizer ²) + 300 kg/ha NPK 15-10-12 + 200 kg/ha urea
500 kg/ha premium organic fertilizer ²) + 300 kg/ha NPK 15-10-12 + 200 kg/ha urea
750 kg/ha premium organic fertilizer ²) + 300 kg/ha NPK 15-10-12 + 200 kg/ha urea
1000 kg/ha premium organic fertilizer ²) + 300 kg/ha NPK 15-10-12 + 200 kg/ha urea

Notes. ¹) Standard petroganik (carbon content: 12.5%); ²) premium petroganik, (carbon content of 15%); applied at planting. The non-organic fertilizers are applied at 15 DAP and 30 DAP.

(total, filled, and unfilled) per panicle.

Evaluation of fertilizer effectiveness is determined through technical tests, in which fertilizers are deemed adequate if the treatment statistically shows results equal to or higher than the standard fertilizer treatment (control) or performs better than the control at the 5% significance level. A fertilizer is declared effective if it has an RAE value of $\geq 95\%$. This value indicates that the fertilizer can increase yield more than the control (International Fertilizer Industry Association, 1992). The agronomic effectiveness of inorganic fertilizers is determined using the Relative Agronomic Effectiveness (RAE) method (Mackay et al., 1984; Mansyur et al., 2021) using the following formula:

$$\text{RAE} = \frac{\text{Production of rice from the tested - controlled fertilizer}}{\text{Production of rice from the comparative - controlled fertilizer}} \times 100\%$$

Seed quality parameters are evaluated during the after-ripening period, including germination and vigor tests conducted weekly from the 2nd to the 8th week after harvest (WAH), with germination percentage (GP) recorded until a threshold of 80% is reached. GP was calculated based on the number of normal seedlings observed on the 5th and 14th day after planting (DAP), following the International Seed Testing Association (2021) protocols. Seedling vigour index (SVI) was calculated from the number and length of normal seedlings recorded during the initial observation. Maximum growth potential was determined as the cumulative percentage of normal and abnormal seedlings at the final evaluation. Storability and vigor under stress conditions were evaluated using a controlled deterioration test (CDT), in which seeds were equilibrated to 20% moisture content, sealed in aluminum foil, and incubated in a water bath at 45 °C for 48 ± 0.25 hr. Following incubation, seeds were cooled under running water for 5 min, rested for 30 min, and subsequently subjected to standard germination testing.

The data were analyzed using the analysis of variance (ANOVA). Significant differences among treatments were determined using Duncan's Multiple Range Test (DMRT) at the 95% confidence level. Statistical analyses were

performed using Microsoft Excel and SPSS.

Results and Discussion

Soil Analysis

The soil pH in this study is 5.86, which classifies it as slightly acidic and still suitable for plant growth, as soil pH can be an initial indicator of soil fertility. Acidic soils tend to reduce nutrient availability. Low pH increases micronutrients' solubility while decreasing macronutrients' solubility (Mansyur et al., 2021). Soils with low pH (classified as acidic) can be caused by high rainfall, which triggers the decline of base cations and increases soil acidity.

The organic carbon content in this study is 1.86%, which is classified as low due to continuous soil use for planting. Unsustainable agricultural management can decrease organic matter content, reducing soil quality (Wihardjaka, 2021). The decline in organic carbon content in rice fields treated with organic fertilizers and experiencing waterlogging slows decomposition, leading to an increase in soil organic matter. Rice fields treated with organic fertilizers have higher organic carbon content than those without organic fertilizers (Mahbub et al., 2023). Other factors influencing carbon loss from agricultural soil include climate, soil type, tillage intensity and depth, crop rotation, amount of organic fertilizer input, amount of crop residue on the soil surface, quality of crop residues returned to the soil, soil biological activity, duration of fallow land, and soil erosion (Matson et al., 1997).

Soil analysis was conducted on all experimental plots for parameters such as pH (H₂O), organic carbon, total nitrogen, cation exchange capacity (CEC), and exchangeable potassium (Ex-K), revealing no significant changes between before and after the treatment (Table 2). The soil analysis results after the study for the potential-K parameter showed a significant decrease in all treatments compared to before the study. Conversely, the phosphorus potential potential-P parameter increased (Table 2).

Decreases in potential-K in rice fields treated with organic fertilizers may be due to plant utilization/absorption during early growth (Reta, 2023). The increase in potential-P in rice soils after organic fertilizer application occurs because of a series of chemical, biological, and physical processes in the soil. Fitriatin et al. (2019) state that the decomposition of organic material found in fertilizers also gradually releases phosphorus, providing a stable and continuous supply of phosphorus for rice plants.

Applying organic fertilizers generally aims to improve the soil's physical, biological, and chemical conditions. Organic fertilizers can improve soils that have become compacted due to continuous application of inorganic fertilizers. Sudartini et al. (2024) showed that the application of inorganic fertilizers with the addition of organic fertilizers can significantly reduce soil density and increase pH, organic carbon, total nitrogen, available nitrogen, available phosphorus, and available potassium compared to treatments without fertilizers or only inorganic fertilizers. Adding organic fertilizers increases microbial populations, likely because it increases soil carbon availability (Mbay et al., 2023).

Growth of Rice in Paddy Fields with Organic Fertilizer Treatments

Based on the experimental results, the plant height and the number of vegetative tillers showed no significant differences across all treatments (Table 3). The parameters of pH H₂O, organic carbon, total nitrogen, cation exchange capacity (CEC), and exchangeable potassium did not change during the experiment (Table 2), resulting in no differences in plant height and the number of vegetative tillers. Organic fertilizers have a longer decomposition time, leading to the release of nutrients, such as nitrogen (N), that do not supply the plant's needs quickly enough during the early vegetative phase (Barlóg et al., 2022). The application of organic fertilizer generally increases soil pH, organic C content, total N, and cation exchange capacity, thereby improving nutrient availability and stimulating vegetative growth, such as plant height and the number of tillers (Marzouk et al., 2024). However, another study by Diop et al. (2024) reported that when the dose, quality, or duration of organic fertilizer application is insufficient to significantly modify soil chemical properties, the resulting growth effects tend to be minimal or indistinguishable between treatments. The results of this study

Table 2

Soil Analysis Before and After the Study

Treatments	pH	Organic C (%)	Total N (%)	CEC (cmol/kg)	Ex-K (cmol/kg)	Potential P (mg P ₂ O ₅ /100g)	Potential K (mg K ₂ O/100g)
Initial values	5.86	1.865	0.235	20.23	0.262	212.94 b	36.22 a
After treatments							
Control (without organic fertilizer)	5.48	1.752	0.215	18.18	0.215	262.82 a	12.81 b
Organic fertilizer ¹⁾ at 500 kg/ha	5.52	1.840	0.225	18.12	0.228	277.30 a	11.88 b
Premium organic fertilizer ²⁾ 250 kg/ha	5.68	1.922	0.238	18.88	0.295	259.79 a	14.24 b
Premium organic fertilizer ²⁾ 500 kg/ha	5.52	2.012	0.228	18.08	0.252	254.86 a	14.85 b
Premium organic fertilizer ²⁾ 750 kg/ha	5.53	1.958	0.232	18.40	0.268	250.74 a	14.96 b
Premium organic fertilizer ²⁾ 1000 kg/ha	5.58	2.030	0.238	18.82	0.295	292.08 a	15.18 b
CV (%)	5.05	24.220	20.260	8.01	36.440	19.61	48.77

Notes. ¹⁾ Standard petroganik (carbon content 12.5%); ²⁾ Premium petroganik (carbon content 15%). CEC = cation exchange capacity, Ex-K = exchangeable potassium. Values with different letters in the same column indicate significant differences based on the DMRT at $\alpha = 5\%$.

confirm that the effectiveness of organic fertilizer in supporting vegetative growth is determined not only by its presence but also by its capacity to alter soil chemical properties, thereby increasing nutrient availability.

Rice Crop Yields with Various Organic Fertilizer Treatments

Adding organic fertilizer did not affect the parameters of the panicle components (panicle length, total grain number, filled grain percentage, and 1000-grain weight). The application of premium organic fertilizer increased the number of productive tillers in plants compared to the control, except at the 750 kg/ha dose. The highest number of productive tillers was observed in plants fertilized with organic fertilizer premium at 500 kg/ha, which did not differ significantly from 1000 kg/ha (Table 4). According to Sujinah et al. (2020), the characteristics of the panicle are more influenced by genotype than by fertilization.

Soil analysis results (Table 2) show that a combination of organic and inorganic fertilizers

increases the availability of nutrients, such as organic carbon, which in turn increases cation exchange capacity, enabling plants to absorb nutrients for generative development. Based on the research by Pandey et al. (2024), adding organic fertilizer combined with inorganic fertilizer contributes to the development of rice tillers into productive tillers, which will subsequently affect rice yield. This is also supported by Brady and Weil (2010), that organic carbon increases cation exchange capacity (CEC), allowing the soil to retain nutrients supports the growth of productive tillers. According to Beadle (1985), phosphorus strengthens the root system, enabling plants to absorb more nutrients to support the growth of productive tillers. Combining organic and inorganic fertilizers ensures that these nutrients are available sufficiently.

Potassium increases the number of grains per panicle, the percentage of filled grains, and the weight of 1000 grains (Dobermann & Fairhurst, 2000). Potassium primary role is to activate various. Available potassium in the soil can improve grain quality and reduce the impact

Table 3

Rice Height and Tiller Number at Various Treatments Organic Fertilizer

Treatments	Weeks after planting					
	2	3	4	5	7	9
	Plant height (cm)					
Control (without organic fertilizer)	27.78	33.85	41.30	51.45	77.40	87.15
Organic fertilizer ¹⁾ at 500 kg/ha at 500 kg/ha	29.90	37.18	42.98	56.38	79.72	90.78
Premium organic fertilizer ²⁾ 250 kg/ha	30.78	37.72	42.68	53.48	79.28	90.12
Premium organic fertilizer ²⁾ 500 kg/ha	31.02	39.58	46.05	58.28	82.42	91.65
Premium organic fertilizer ²⁾ 750 kg/ha	29.75	37.88	44.18	55.38	81.25	90.98
Premium organic fertilizer ²⁾ 1000 kg/ha	29.88	37.18	42.62	53.05	77.85	89.20
	Number of tillers					
Control (without organic fertilizer)	9.52	18.28	29.58	41.42	42.08	24.48
Organic fertilizer ¹⁾ at 500 kg/ha at 500 kg/ha	10.30	20.60	30.90	44.90	41.62	23.45
Premium organic fertilizer ²⁾ 250 kg/ha	11.90	21.15	32.05	44.12	42.10	24.72
Premium organic fertilizer ²⁾ 500 kg/ha	10.92	21.88	34.80	46.30	44.02	25.20
Premium organic fertilizer ²⁾ 750 kg/ha	10.80	20.85	33.22	45.15	42.95	24.58
Premium organic fertilizer ²⁾ 1000 kg/ha	10.50	20.18	31.10	44.50	42.62	25.25

Notes. ¹⁾ Standard petroganik (carbon content 12.5%); ²⁾ Premium petroganik (carbon content 15%). Values with different letters in the same column indicate significant differences based on the DMRT at $\alpha = 5\%$.

of maturation accelerated by phosphorus.

Based on Table 5, adding organic fertilizer did not affect DHG per plot, DMG per plot, and DMG yield. Plant productivity based on panicle components increased significantly with the addition of premium organic fertilizer at 500 and 1000 kg/ha, compared to the control or lower fertilizer doses. Premium organic fertilizer doses of 500, 750, and 1000 kg/ha show no significant differences and can increase plant productivity, as indicated by panicle components.

In this study, applying premium organic fertilizer at 500 kg/ha increased rice yields by up to 13% compared to the control (no organic fertilizer). The application of organic alongside chemical fertilizers can increase rice yield by

15-20% compared to using chemical fertilizers alone (Bachtiar et al., 2020). According to Marschner (2011) combination of organic and inorganic fertilizers increases the availability and absorption efficiency of nitrogen, phosphorus, and microelements through the mobilization of bound nutrients, improved soil structure, and support of microbial activity, thus encouraging high productivity in rice.

Relative Agronomic Effectiveness (RAE)

The results of the RAE (Table 6) calculation based on the panicle component's productivity show that applying premium organic fertilizer at doses greater than 500 kg/ha is effective in

Table 4

Number of Productive Tillers and Panicle Components at Various Treatments Organic Fertilizer

Treatments	Number of productive tillers	Panicle components			
		Panicle length (cm)	Total number of grains	Percentage of filled grains (%)	1000 grain weight (g)
Control (without organic fertilizer)	19.98 d	20.50	126.05	80.43	29.86
Organic fertilizer ¹⁾ 500 kg/ha	20.80 cd	20.82	127.72	79.89	29.07
Premium organic fertilizer ²⁾ 250 kg/ha	21.32 bc	20.82	125.78	76.08	29.60
Premium organic fertilizer ²⁾ 500 kg/ha	22.50 a	20.87	130.12	78.90	29.56
Premium organic fertilizer ²⁾ 750 kg/ha	20.48 cd	21.14	135.65	79.44	29.25
Premium organic fertilizer ²⁾ 1000 kg/ha	22.18 ab	21.11	129.05	81.73	29.21

Notes. ¹⁾ Standard petroganik (carbon content 12.5%); ²⁾ Premium petroganik (carbon content 15%). Values with different letters in the same column indicate significant differences based on the DMRT at $\alpha = 5\%$.

Table 5

Rice Production and Productivity at Various Treatments Organic Fertilizer

Treatment	Dry harvested grain per plot (kg)	Dry milled grain per plot (kg)	Milling yield (%)	Productivity (ton/ha)
Control (without organic fertilizer)	11.09	9.78	82.06	6.79 b
Organic fertilizer ¹⁾ 500 kg/ha	12.35	10.08	77.25	6.91 b
Premium organic fertilizer ²⁾ 250 kg/ha	11.18	9.51	79.53	6.77 b
Premium organic fertilizer ²⁾ 500 kg/ha	11.98	10.06	76.37	7.66 a
Premium organic fertilizer ²⁾ 750 kg/ha	12.53	10.52	78.97	7.24 ab
Premium organic fertilizer ²⁾ 1000 kg/ha	11.66	10.41	81.44	7.62 a

Notes. ¹⁾ Standard petroganik (carbon content 12.5%); ²⁾ Premium petroganik (carbon content 15%). Values with different letters in the same column indicate significant differences based on the DMRT at $\alpha = 5\%$.

increasing yields. The revenue-to-fertilizer cost ratio (RCf) decreased across all treatments using petroganik premium organic fertilizer, reflecting significant differences in fertilizer costs. Petroganik organic fertilizer treatment is subsidized at IDR 800.00/kg. In contrast, premium organic premium fertilizer is an unsubsidized fertilizer priced at IDR 3,375,000/kg on the official Petrokimia Gresik online store.

Based on the farm analysis results (Table 7), across all treatments, the application of organic fertilizer in rice farming significantly enhanced both rice yield and net profit. A comparison between applying 500 kg/ha of premium organic

fertilizer and the control treatment (no organic fertilizer) showed a profit difference. The total benefit was recorded at IDR 45,592,480 for the organic fertilizer treatment and IDR 40,349,792 for the control, resulting in a profit margin of IDR 5,242,688 in favour of the organic fertilizer application.

Effect of Organic Fertilizer on Seed Quality Components

Based on Table 8, applying organic fertilizer affects rice seeds after the ripening

Table 6

Calculation of the Ratio of Income to Fertilizer Cost, Cost Requirement to Produce 1 Kg of DHG, and RAE at Various Treatments Organic Fertilizer

Treatments	RCf Pc	CfP Pc (IDR)	RAE Pc (%)
Control (without organic fertilizer)	7.59	902.51	-
Organic fertilizer ¹⁾ 500 kg/ha	8.16	839.08	-
Premium organic fertilizer ²⁾ 250 kg/ha	7.43	921.75	-10.20
Premium organic fertilizer ²⁾ 500 kg/ha	7.41	924.61	698.99
Premium organic fertilizer ²⁾ 750 kg/ha	6.25	1095.87	358.56
Premium organic fertilizer ²⁾ 1000 kg/ha	5.95	1150.74	667.30

Notes. ¹⁾ Standard petroganik (carbon content 12.5%); ²⁾ Premium petroganik (carbon content 15%). Values with different letters in the same column indicate significant differences based on the DMRT at $\alpha = 5\%$. RCf Pc = ratio of revenue to fertilizer cost, RAE Pc = relative agronomy effectiveness based on the productivity of based on the productivity of panicle components. CfP Pc = fertilizer cost to produce 1 kg of dry harvestable grains (DHG) based on the productivity of panicle components. based on productivity of panicles. RAE Pc = based on the productivity of panicles.

Table 7

Cost and Benefit Analysis of Rice Production with Various Treatments Organic Fertilizers

Treatments	Productivity (ton/ha)	Income (IDR)	Cost (IDR)	Benefit (IDR)	CfP Pc (IDR)
Control (without organic fertilizer)	6.79	46,474,792	6,125,000	40,349,792	902,51
Organic fertilizer ¹⁾ at 500 kg/ha	6.91	47,335,692	5,800,000	41,535,692	839,08
Premium organic fertilizer ²⁾ at 250 kg/ha	6.77	46,387,025	6,150,000	40,237,025	921,75
Premium organic fertilizer ²⁾ at 500 kg/ha	7.67	52,492,481	6,900,000	45,592,480	924,61
Premium organic fertilizer ²⁾ at 750 kg/ha	7.24	49,561,620	7,650,000	41,911,620	1095,87
Premium organic fertilizer ²⁾ at 1000 kg/ha	7.63	52,219,537	8,400,000	43,819,536	1150,74

Notes. ¹⁾ Standard petroganik (carbon content 12.5%); ²⁾ Premium petroganik (carbon content 15%). Values with different letters in the same column indicate significant differences based on the DMRT at $\alpha = 5\%$. CfP Pc = fertilizer cost to produce 1 kg of dry harvestable grains (DHG) based on the productivity of panicle components.

period. Plants not given organic fertilizer have a longer after-ripening period of 5 weeks, whereas applying Petroganik Premium organic fertilizer can shorten it to 3 weeks at a dose of 500 kg/ha. According to Nugraha and Soejadi (2001), the after-ripening period can be grouped into three categories: short (<4 weeks after harvest), medium (4-8 weeks after harvest), and long (>8 weeks after harvest). Onyenali et al. (2020) reported that using organic fertilizers can increase the nutrient content of seeds, such as nitrogen and phosphorus, thereby improving seed quality. According to Zhen et al. (2020) the nutrients provided by organic fertilizers act as key components in biochemical pathways

that support seed filling. Nitrogen increases the synthesis of storage proteins such as gliadin and glutenin, which determine seed weight and quality. Phosphorus supports the biosynthesis of nucleic acids and the movement of sugars through the phloem, aiding the formation of energy reserves in the seed.

The vigor index indicates the speed and uniformity of seed germination. Based on these results, it can be concluded that a shorter after-ripening period for rice seeds allows the seed certification process to be completed more quickly. Germination increases rapidly due to the availability of reserve energy from carbohydrates that are quickly mobilized for

Table 8

Seed Germination Percentage of the After-Ripening Period With Various Treatments Organic Fertilizer

Treatments	Week after harvest (WAH)						
	2	3	4	5	6	7	8
	Germination percentage (%)						
Control (without organic fertilizer)	57.5 b	59.5 c	76.0 b	83.0	87.0	86.0	92.5
Organic fertilizer ¹⁾ 500 kg/ha	70.0 a	71.5 ab	82.0 a	84.0	85.0	89.0	92.5
Premium organic fertilizer ²⁾ 250 kg/ha	70.5 a	69.0 bc	84.0 a	89.5	88.5	90.0	94.0
Premium organic fertilizer ²⁾ 500 kg/ha	75.0 a	81.5 a	84.0 a	89.5	93.0	92.5	94.0
Premium organic fertilizer ²⁾ 750 kg/ha	74.0 a	79.5 a	85.0 a	86.5	90.0	94.5	94.5
Premium organic fertilizer ²⁾ 1000 kg/ha	71.5 a	77.0 ab	80.5 ab	80.5	90.5	93.5	91.5
	Vigor index (%)						
Control (without organic fertilizer)	35.5 c	32.5 d	62.0 bc	56.0 c	79.0 bc	84.0	89.5
Organic fertilizer ¹⁾ 500 kg/ha	46.0 b	45.5 c	71.0 ab	66.0 abc	76.5 c	82.5	91.5
Premium organic fertilizer ²⁾ 250 kg/ha	47.0 b	47.5 bc	73.5 a	74.0 ab	85.5 ab	87.5	89.5
Premium organic fertilizer ²⁾ 500 kg/ha	61.5 a	62.0 a	67.5 abc	76.0 a	85.5 ab	90.5	91.0
Premium organic fertilizer ²⁾ 750 kg/ha	55.0 ab	57.5 ab	74.5 a	69.5 ab	86.0 a	92.0	92.0
Premium organic fertilizer ²⁾ 1000 kg/ha	51.0 b	58.0 ab	58.0 c	64.0 bc	82.5 abc	88.5	89.0
	Maximum growth potential (%)						
Control (without organic fertilizer)	62.5 b	63.0 b	77.5 b	83.5	87.0	86.5	93.5
Organic fertilizer ¹⁾ 500 kg/ha	71.0 a	72.0 ab	82.5 ab	84.5	85.0	90.5	92.5
Premium organic fertilizer ²⁾ 250 kg/ha	71.5 a	73.0 ab	85.5 a	91.0	91.0	91.0	95.0
Premium organic fertilizer ²⁾ 500 kg/ha	76.0 a	82.5 a	84.0 a	89.5	93.0	93.5	95.0
Premium organic fertilizer ²⁾ 750 kg/ha	76.5 a	81.0 a	86.0 a	87.5	91.5	94.5	95.0
Premium organic fertilizer ²⁾ 1000 kg/ha	71.5 a	78.0 a	81.5 ab	81.5	92.0	94.5	92.0

Notes. ¹⁾ Standard petroganik (carbon content 12.5%); ²⁾ Premium petroganik (carbon content 15%). Values with different letters in the same column indicate significant differences based on the DMRT at $\alpha = 5\%$.

the germination process (Muñoz-Llandes et al., 2023). During imbibition, turgor pressure in seed cells increases (Umar, 2012). This process breaks dormancy and initiates cellular activation; various necessary enzymes are activated to hydrolyze endosperm food reserves into nutrients for embryo development. Adding organic fertilizer increases the MGP of seeds; show a lower increase in MGP. The magnitude of the MGP of seeds indicates high seed viability conditions (Tikafebrianti et al., 2019).

Evaluation of Vigor in Relation to Storability

Organic fertilizer treatment did not significantly affect rice seed vigor in terms

of storability (Table 9, $t = 0.866$, $p > 0.05$). Seed cell membrane stability plays a key role in determining storability. When seeds are subjected to oxidative stress, as in the control deterioration (CD) test, lipids in the seed cell membrane undergo peroxidation, leading to ion leakage, loss of membrane integrity, and ultimately seed death. Adding organic fertilizers does not directly affect seeds' antioxidant levels or lipid membrane integrity (McDonald, 1999). The phosphorus and potassium present in the soil from organic fertilizers may help form energy reserves in the seed (such as ATP for metabolism). However, this effect is only during the early phase of germination, not on long-term storability (Wimalasekera, 2015).

Table 9

Rice Seed Germination Before and After Control Deterioration

Treatment	Rice germination percentage (%)	
	Before controlled deterioration (4 WAH)	After controlled deterioration
Control (without organic fertilizer)	76.0	76.5
Organic fertilizer ¹⁾ 500 kg/ha	82.0	83.0
Premium organic fertilizer ²⁾ 250 kg/ha	84.0	84.0
Premium organic fertilizer ²⁾ 500 kg/ha	84.0	83.0
Premium organic fertilizer ²⁾ 750 kg/ha	85.0	82.0
Premium organic fertilizer ²⁾ 1000 kg/ha	80.5	80.0
<i>T</i> -test	<i>P</i> -value = 0.86	

Notes. ¹⁾ Standard petroganik (carbon content 12.5%); ²⁾ Premium petroganik (carbon content 15%). WAH = week after harvest.

Conclusions

The use of premium organic fertilizer with a carbon content of 15% does not enhance vegetative growth but increases the number of productive tillers and yield; at 500 kg/ha, it increased rice yields by up to 13% compared to the control, with relative agronomic effectiveness $\geq 95\%$. The application of premium organic fertilizer improved seed quality, as indicated by germination rate, vigour index, and maximum growth potential, compared with the control, and shortened the after-ripening period of rice seeds by 2 weeks, but did not affect the storability of rice seeds.

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