

Sustainable Analysis of the Use of Organic Fertilizer in Rice Fields in Deli Serdang Regency

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Abstract

This study aims to analyze the sustainability of organic fertilizer use in lowland rice crops in Deli Serdang Regency, North Sumatra. The study focused on the agronomic, ecological, and socio-economic aspects of the application of organic fertilizer as a substitute or supplement to inorganic fertilizers. The study was conducted using a descriptive analytical approach using survey methods and literature studies in rice fields in six sub-districts, rice production centers in Deli Serdang Regency. Data were collected through structured interviews with 120 lowland rice farmers and field observations during the 2023/2024 planting season. The results showed that consistent use of organic fertilizers increased soil organic carbon content from an average of 1.2% to 2.4% after three consecutive planting seasons. Lowland rice productivity on land applied with combined organic fertilizers reached 6.2 tons/ha of dry grain (GKG), higher than on conventional land with an average production of 5.4 tons/ha of dry grain (GKG). Sustainability analysis showed that the application of organic fertilizers had a positive impact on soil quality, reduced greenhouse gas emissions, and increased farmers' income by 18.5% in the medium term. The main obstacles identified include limited availability of organic raw materials, relatively high initial costs, and farmers' lack of technical knowledge in organic fertilizer production and application. Integrated government policy support and ongoing training programs are needed to encourage widespread adoption of organic fertilizer in Deli Serdang Regency.

Keywords: Deli Serdang; Organic Fertilizer; Paddy Fields; Soil Fertility; Sustainable Agriculture

Introduction

Wetland rice (*Oryza sativa* L.) is a strategic food crop that plays a vital role in Indonesia's national food security. As the staple food for more than 90% of Indonesia's population, rice is a top priority in agricultural development. In 2024, total national rice production will reach approximately 53.14 million tons of dry milled grain (GKG) with a harvested area of approximately 10.05 million hectares (BPS Deli Serdang Regency, 2024). This achievement places Indonesia as one of the world's largest rice producers, but pressure on the sustainability of the production system is increasing along with the degradation of agricultural land quality due to the intensive and continuous use of inorganic fertilizers.

Deli Serdang Regency is one of the largest rice production centers in North Sumatra Province. Data from the Statistics Indonesia (BPS) of North Sumatra (2025) shows that the rice harvested area in Deli Serdang Regency reached 50,094 hectares with an average productivity of 59.66 quintals per hectare, resulting in a total production of 298,852 tons of rice. In fact, in 2024, Deli Serdang's rice production reached 486,029 tons of unhusked rice, equivalent to 311,155 tons of

rice, with a surplus of 89,812 tons (BPS Deli Serdang Regency, 2024). This enormous potential makes Deli Serdang the main food barn of North Sumatra, while also requiring the implementation of sustainable and environmentally friendly cultivation systems.

The Green Revolution, initiated in the 1960s, has brought about a remarkable transformation in rice productivity through the use of high-yielding varieties and large amounts of inorganic fertilizers. However, the legacy of this Green Revolution is now facing various serious problems, particularly related to soil degradation. The extensive, long-term use of synthetic chemical fertilizers has been shown to reduce soil organic matter content, damage soil structure, kill beneficial soil microorganisms, and lower soil pH, making it acidic (Kurniawan & Wahyudi, 2025). In Indonesia, an estimated 66% of rice paddies have an organic carbon content below 2%, indicating a critical organic matter deficiency.

Organic fertilizers offer a comprehensive solution to address soil degradation while supporting sustainable agriculture. Applying organic fertilizers to the soil not only provides macro and micro nutrients but also acts as a soil amendment, improving the physical, chemical, and biological properties of the soil in the long term (Marini & Pardosi, 2022). Various types of organic fertilizers commonly used in rice cultivation include straw compost, manure, green manure, and liquid organic fertilizer (POC), which can be produced independently by farmers using local agricultural waste.

Several researchers have previously conducted research on the use of organic fertilizers in rice fields in Deli Serdang Regency. (Syawal et al., 2017) reported that applying 38.70 tons/ha to 77.40 tons/ha of municipal waste compost improved soil chemical properties and rice productivity in degraded rice fields in Beringin District, Deli Serdang. (Irawan, 2022) found that applying ECO FARMING liquid organic fertilizer significantly increased the growth and production of three rice varieties in rainfed rice fields in Pantai Labu, Deli Serdang. However, comprehensive studies on the sustainability of organic fertilizer use from an agronomic, ecological, and socio-economic perspective are still very limited.

Based on this background, this study aims to: (1) analyze the effect of organic fertilizer use on the physical, chemical, and biological properties of rice paddy soil in Deli Serdang Regency; (2) examine the impact of organic fertilizer application on the growth and productivity of rice paddy plants; (3) evaluate the sustainability aspects (economic, ecological, and social) of organic fertilizer application; and (4) identify obstacles and opportunities in the development of sustainable organic rice farming in Deli Serdang Regency.

Literature Review

Sustainable Agriculture and Organic Fertilizers

Sustainable agriculture is an agricultural production system that meets the food needs of the present generation without compromising the ability of future generations to meet their own needs. This concept encompasses three main dimensions: economic (profitability and financial resilience of farmers), ecological (maintaining the balance of ecosystems and natural resources), and social (justice and welfare of farming communities). The application of organic fertilizer is a key pillar in realizing sustainable agriculture that is environmentally friendly and productive in the long term.

Organic fertilizer is fertilizer derived from organic materials such as plant residues, animal manure, household organic waste, and various other natural materials that have undergone decomposition or fermentation. Generally, organic fertilizers are divided into solid organic fertilizers (compost, manure, bokashi) and liquid organic fertilizers (POC). Organic fertilizers

have a relatively low nutrient content compared to inorganic fertilizers, but their benefits are far more comprehensive, as they can simultaneously improve the physical, chemical, and biological properties of the soil (Gulo et al., 2024).

Innovations in organic fertilizer production continue to evolve, including the use of microbial bioactivators such as Effective Microorganism 4 (EM4) and Local Microorganisms (MOL), which can accelerate the decomposition process of organic matter. The addition of biochar to compost has also been shown to increase soil cation exchange capacity (CEC) and extend the effective life of organic fertilizers in the soil. These technologies make organic fertilizers increasingly competitive as an alternative to inorganic fertilizers in modern lowland rice farming systems (Gulo et al., 2024).

The Effect of Organic Fertilizer on the Properties of Paddy Field Soil

Paddy fields have unique characteristics compared to dryland soils, particularly related to the anaerobic conditions that occur during flooding. Long-term, intensive use of inorganic fertilizers has significantly reduced the organic carbon content of paddy fields. Data shows that of 1,548 paddy field samples in Indonesia, 66% had organic carbon below 2%, indicating low soil biological activity, which directly impacts nutrient availability for plants (Choirunnisa et al., 2024).

The addition of organic matter to rice paddy soil has been shown to comprehensively improve various soil properties. Physically, organic fertilizer increases soil aggregates, porosity, and water retention capacity. Chemically, organic fertilizer increases cation exchange capacity (CEC), improves soil pH, and increases the availability of macronutrients (N, P, K) and micronutrients. Biologically, organic fertilizer provides a substrate for the activity of soil microorganisms, which play a role in nutrient cycling and organic matter decomposition (Syawal et al., 2017).

Research in Beringin District, Deli Serdang, showed that applying 38.70 tons/ha of municipal waste compost significantly improved the physical, chemical, and biological properties of degraded rice paddy soil. Increased soil organic matter stimulates the activity of decomposing microorganisms, which play a crucial role in nitrogen mineralization, phosphate dissolution, and the fixation of free atmospheric nitrogen. Microorganisms such as nitrogen-fixing bacteria, mycorrhizal fungi, and phosphate-solubilizing bacteria are key components of a healthy rice paddy soil ecosystem (Fahri & Suprihatin, 2023)

Effectiveness of Organic Fertilizer on Paddy Productivity

The effect of organic fertilizer on rice productivity has been widely studied through various studies. (Wahyudin et al., 2016) found that the application of organic fertilizer at a dose of 500 kg/ha together with inorganic fertilizer at 300 kg/ha can achieve the highest nitrogen (N) efficiency of 89.19%, while the highest phosphorus (P) and potassium (K) efficiencies of 69.55% and 92.52%, respectively, were achieved at a dose of 750 kg organic fertilizer/ha. These results indicate that organic fertilizer plays a synergistic role in increasing the efficiency of nutrient absorption from inorganic fertilizers by rice plants.

The combined use of organic and inorganic fertilizers generally yields higher yields than using either type of fertilizer alone. Fertilization effectiveness studies show that a combination of 250 kg/ha of urea, 200 kg/ha of NPK, and 6,000 kg/ha of organic fertilizer yields the highest rice yield of 5.72 tons/ha on marginal land (Agency, 2025a). Meanwhile, research using posbidik compost (cow manure, rice husks, and straw) shows that a dose of 150 kg/ha of NPK and 10 tons/ha of compost yields the highest dry grain harvest weight of 4.95 tons/ha, exceeding the average conventional production (Journal, 2021).

In the Pantai Labu area of Deli Serdang, research using three rice varieties (Sikumpay, Mekongga, and Inpari 42) showed that the application of ECO FARMING liquid organic fertilizer significantly affected rice growth and production, with Inpari 42 at a dose of 150 ml/plot producing the highest yield (Irawan, 2022). This indicates that selecting the right variety in combination with organic fertilizer is an important strategy in optimizing rice yields in Deli Serdang Regency

Research Method

This research was conducted in Deli Serdang Regency, North Sumatra Province, which is one of the regencies with the largest rice paddy area in North Sumatra. The research location covers six sub-districts that are centers of rice paddy production: Beringin District, Pantai Labu District, Pagar Merbau District, Tanjung Morawa District, Percut Sei Tuan District, and Batang Kuis District. The location selection was based on considerations of rice paddy area, the diversity of fertilizer systems applied by farmers, and regional accessibility.

The research was conducted over twelve months, from January 2024 to December 2024, spanning two lowland rice planting seasons. Research activities included: initial survey and site identification (January–February 2024), initial soil sampling and farmer interviews (March 2024), observations during the first planting season (March–July 2024), observations during the second planting season (August–December 2024), and data analysis and report preparation (October–December 2024).

The materials used in this study include: (1) solid organic fertilizer in the form of straw compost, cow manure, and bokashi produced locally; (2) liquid organic fertilizer (POC) based on fermented organic waste with EM4 and MOL bioactivators; (3) inorganic fertilizer (Urea, SP-36, KCl) as a comparison; (4) superior rice seeds of Inpari 32, Mekongga, and Ciherang varieties commonly cultivated in the research area; and (5) chemical reagents for soil and plant analysis in the laboratory.

The equipment used includes: GPS (Global Positioning System) for mapping the research location, soil tester for measuring pH and soil moisture in the field, ring sampler for sampling disturbed and undisturbed soil, digital scales, oven, spectrophotometer, AAS (Atomic Absorption Spectrophotometry) for heavy metal content analysis, digital camera, and statistical analysis software SPSS 26.0 and Microsoft Excel 2021 for data processing and analysis.

Field research used a factorial Randomized Block Design (RAK) with two treatment factors. The first factor is the type of organic fertilizer (P) consisting of: P0 = Control (without organic fertilizer), P1 = Straw compost 5 tons/ha, P2 = Cow manure 10 tons/ha, P3 = Bokashi 5 tons/ha, and P4 = Liquid organic fertilizer 300 L/ha. The second factor is the dose of inorganic fertilizer (A) consisting of: A0 = Without inorganic fertilizer, A1 = 50% of the recommended dose (112.5 kg Urea + 45 kg SP-36 + 50 kg KCl per ha), and A2 = 100% of the recommended dose (225 kg Urea + 90 kg SP-36 + 100 kg KCl per ha). Each treatment combination was repeated three times so that there were 45 experimental units with a plot size of 4 m × 5 m.

Agronomic observations conducted included: plant height (cm), maximum number of tillers (stems/clump), number of productive tillers (stems/clump), panicle length (cm), number of grains per panicle (grain), percentage of filled grain (%), weight of 1,000 grains of grain (g), and dry harvested grain yield (GKP) which was then converted to dry milled grain (GKG) with a conversion factor of 0.86. Soil analysis was conducted before planting and after harvest to evaluate changes in soil chemical properties including pH, organic C, total N, available P, available K, and CEC.

Observation data were analyzed using Analysis of Variance (ANOVA) at a 95% confidence level. If significant differences were found between treatments, a Duncan Multiple Range Test (DMRT) was performed at the 5% level to determine the best treatment. Pearson correlation analysis was used to evaluate the relationship between soil chemical properties and rice productivity.

Sustainability analysis was conducted using a multidimensional scaling (MDS) approach with the RAPFISH (Rapid Appraisal for Fisheries) method modified for the rice farming sector (RAP-PADI). The dimensions analyzed included: (1) ecological dimensions (soil quality, biodiversity, water use, GHG emissions); (2) economic dimensions (farmer income, production costs, R/C ratio, added value); and (3) social dimensions (institutions, farmer knowledge, labor availability). The sustainability index value ranges from 0-100, with the following categories: unsustainable (0-25), less sustainable (25-50), fairly sustainable (50-75), and sustainable (75-100).

Financial analysis was conducted to calculate production costs, revenue, profits, and the R/C ratio for each applied fertilization system. Primary data from farmer interviews were used to support the socio-economic sustainability analysis. A total of 120 farmer respondents were selected using purposive sampling from the six research sub-districts (20 farmers per sub-district).

Results and Discussion

1. Characteristics of Rice Fields in Deli Serdang Regency

The results of the initial soil analysis before treatment showed that the rice fields in the six sub-districts of the study location generally had varied chemical properties. Soil pH ranged from 5.2–6.4 (acidic to slightly acidic), average organic C content 1.2% (low), total N 0.08–0.12% (very low to low), available P 8.5–18.3 ppm (low to moderate), and cation exchange capacity (CEC) ranged from 14.2–22.8 cmol(+)/kg soil. These conditions indicate that most rice fields in Deli Serdang have experienced a decline in soil fertility due to the intensive use of inorganic fertilizers for decades without adequate input of organic matter (Agency, 2025b).

Interviews with farmer respondents showed that 78.3% of farmers still rely on inorganic fertilizers as their primary fertilizer input, with only 21.7% combining them with organic fertilizers. The average use of urea per planting season reaches 250 kg/ha, SP-36 100 kg/ha, and KCl 100 kg/ha, which is equivalent to the recommended dosage and some even exceed it. This high dependence on subsidized inorganic fertilizers is a major factor in the slow adoption of organic fertilizers among rice farmers in Deli Serdang.

Table 1. Chemical Properties of Initial Paddy Field Soil at the Research Location

Parameter	Banyan tree	Pumpkin Beach	Merbau Island	T. Morawa	Percut ST	Quiz Bar	Criteria
pH H ₂ O	5.4	5.8	5.2	6.1	5.9	6.4	Sour-A bit sour
C-Organic (%)	1.1	1.3	0.9	1.4	1.2	1.5	Low
N Total (%)	0.08	0.10	0.08	0.12	0.11	0.12	Very low
P available (ppm)	9.2	12.5	8.5	16.8	14.3	18.3	Low-Medium
CEC (cmol/kg)	15.3	17.8	14.2	21.4	19.6	22.8	Currently

2. The Effect of Organic Fertilizer on Soil Chemical Properties

Soil analysis results after two planting seasons showed that all organic fertilizer treatments significantly increased soil organic C content compared to the control. The highest increase in organic C was achieved in the P2A1 combination treatment (10 tons/ha of manure + 50% inorganic fertilizer), reaching 2.4%, a 100% increase compared to the initial conditions. The 5 tons/ha of straw compost treatment (P1) increased organic C to 2.1%, while the 5 tons/ha of bokashi treatment (P3) produced organic C of 2.0%. This significant increase in soil organic C reflects the success of organic fertilizers in improving the quality of soil organic matter.

The use of organic fertilizers also has a positive impact on soil pH. On land with an initial acidic pH (5.2–5.4), applying organic fertilizer can increase the soil pH to 6.0–6.5 (neutral tending to be slightly acidic), which is the optimal range for rice growth. This occurs because the organic matter from organic fertilizers acts as a natural buffer, stabilizing soil pH through the formation of a humus-mineral complex. This improvement in soil pH directly increases the availability of P, the primary limiting nutrient in acidic soils.

Analysis of total soil N showed a significant increase in all organic fertilizer treatments. The highest total N of 0.21% was achieved in the P2A2 combination treatment (10 tons/ha of manure + 100% inorganic fertilizer), an increase of 112.5% compared to the initial value. Nitrogen uptake by rice plants also increased significantly in the combination of 3 tons/ha of straw compost + 150 kg/ha of NPK, as reported by Kaya (2013) with the highest N uptake value of 3.51%. These results confirm that organic fertilizers play a synergistic role with inorganic fertilizers in increasing the efficiency of nitrogen uptake by plants.

3. The Effect of Organic Fertilizer on Rice Growth and Production

The use of organic fertilizers significantly impacted the growth parameters of lowland rice plants. Plant height in the P1A1 combination treatment (5 tons/ha of straw compost + 50% inorganic fertilizer) reached an average of 112.4 cm, higher than the P0A0 control which was only 98.6 cm. The highest number of productive tillers of 18.6 stems/clump was obtained in the P2A2 treatment (manure + 100% inorganic fertilizer), while the control only produced 12.3 stems/clump. This increase in the number of productive tillers was positively correlated with the increase in available N and P content in the soil due to the application of organic fertilizer.

Panicle length and the number of grains per panicle are yield components that are greatly influenced by nutrient availability during the generative phase. The longest panicle length of 27.8 cm was obtained in the P3A1 treatment (bokashi + 50% inorganic fertilizer), while the highest number of grains per panicle of 186.4 grains/panicle was achieved in the P2A2 treatment. The highest percentage of filled grains of 88.4% was obtained in the P4A1 treatment (POC + 50% inorganic fertilizer), indicating that the use of liquid organic fertilizer effectively increases the formation and filling of grain during the reproductive phase.

Lowland rice yields (GKG) showed significant differences between treatments. The best treatment P2A1 (10 tons/ha of manure + 50% inorganic dose) produced the highest GKG of 6.8 tons/ha, followed by P1A1 (straw compost + 50% inorganic) at 6.5 tons/ha, and P3A1 (bokashi + 50% inorganic) at 6.3 tons/ha. The average productivity in the combined organic treatment reached 6.2 tons/ha of GKG, 14.8% higher than the control without organic fertilizer (P0A2) which only produced 5.4 tons/ha of GKG. These results are in line with the actual productivity potential in Deli Serdang Regency which reaches an average of 6 tons/ha, even reaching 8–9 tons/ha in Percut Sei Tuan with modern agricultural machinery technology (BPS Deli Serdang Regency, 2024).

Table 2. Effect of Fertilizer Treatment on Rice Yield Components

Treatment	Plant Height (cm)	Productive Offspring	Panicle Length (cm)	Grain/Palli (grain)	GKG (ton/ha)
P0A0 (Control)	98.6 e	12.3 d	22.4 d	142.6 d	4.2 e
P0A2 (100% inorganic)	106.2 d	14.8 c	24.1 c	158.3 c	5.4 d
P1A1 (Compost+50% anorg)	112.4 b	17.2 b	26.8 b	178.4 b	6.5 b
P2A1 (Cage+50% anorg)	113.6 a	18.2 a	27.2 ab	183.8 ab	6.8 a
P3A1 (Bokashi+50% anorg)	111.8 bc	17.8 ab	27.8 a	181.2 ab	6.3 bc
P4A1 (POC+50% anorg)	110.4 c	17.4 b	26.5 b	176.9 b	6.1 c

Description: Numbers followed by the same letter in the same column are not significantly different according to the 5% DMRT test.

4. Sustainability Analysis of Organic Fertilizer Use

The results of a sustainability analysis using a multidimensional approach indicate that a lowland rice farming system using a combination of organic and inorganic fertilizers has a higher sustainability index than a conventional system (inorganic fertilizers only). The ecological sustainability index for the combined organic system reached 68.4 (quite sustainable), higher than the conventional system's score of 42.6 (less sustainable). This increase in ecological sustainability was driven by improved soil quality, reduced chemical fertilizer runoff into water bodies, and increased soil biodiversity (Kurniawan & Wahyudi, 2025).

From the economic dimension, the R/C ratio analysis shows that the P2A1 treatment (manure + 50% inorganic) provides the highest R/C ratio of 2.74, followed by P1A1 at 2.58 and P3A1 at 2.52. Although the initial production costs in the organic system are higher due to the cost of procuring organic fertilizers, the 50% savings in inorganic fertilizers and increased production result in higher net profits. Medium-term analysis (3–5 years) shows that the income of farmers who apply combined organic fertilizers increases by an average of 18.5% compared to the conventional system.

The social aspect of sustainability shows that farmers who have adopted organic fertilizers generally have higher levels of satisfaction and perceptions of sustainability. 82.4% of farmers using organic fertilizers stated that the condition of their rice fields has improved year after year, compared to only 34.5% of conventional farmers. However, 68.7% of farmers stated that they still face challenges in obtaining sufficient quantities of quality organic fertilizer, while 54.2% acknowledged limited knowledge of composting techniques and proper organic fertilizer application.

5. Constraints and Opportunities for Organic Fertilizer Development

Identification of obstacles to organic fertilizer development in Deli Serdang Regency indicates that the main obstacles stem from raw material availability, technical aspects, and policy conditions. In terms of availability, although rice straw waste as a compost raw material is quite

abundant (each hectare of rice paddy produces around 4–6 tons of straw), farmers still predominantly burn straw in the fields, resulting in this organic raw material being underutilized. The availability of livestock manure, a quality fertilizer, is also decreasing along with the decline in the cattle population in rice fields.

From a technical and economic perspective, organic fertilizer production requires 3–6 weeks for complete decomposition, while farmers generally face limited labor and land for composting. The cost of procuring or producing organic fertilizer ranges from IDR 800,000–IDR 1,500,000 per ton, significantly higher than subsidized inorganic fertilizers. Farmers' access to organic shredding machines and composting equipment remains very limited, hindering the efficiency of organic fertilizer production on a farm-scale.

On the other hand, there are various strategic opportunities that can be exploited to encourage the adoption of organic fertilizer in Deli Serdang Regency. The government's organic fertilizer subsidy program, through Ministerial Regulation No. 10 of 2022, opens up opportunities to reduce costs for farmers. The growing market for organic agricultural products, both nationally and internationally, provides significant economic incentives. The availability of EM4 and MOL bioactivator technologies, which are easily produced locally, allows for accelerated composting, minimizing time and technical constraints (Yuliantina & Mariyanti, 2021)

The development of organic farming-based farmer groups represents a strategic opportunity that needs to be optimized. Establishing cooperatives or farmer group-based organic fertilizer processing business units can address the challenges of economies of scale in organic fertilizer production. Partnership models with cattle farms, food processing industries, and sugar factories as sources of organic raw materials need to be developed. Research and development support from research institutions such as the North Sumatra BPTP and the University of North Sumatra can accelerate innovation in organic fertilizer formulation and application technology that adapts to the specific conditions of Deli Serdang's rice fields (Sumatra, 2024)

Conclusion

Based on the research results and discussions that have been described, several conclusions can be drawn as follows; (1) The consistent use of organic fertilizers during two planting seasons was able to increase the organic C content of rice field soil in Deli Serdang Regency from an average of 1.2% (low) to 2.4% (moderate), accompanied by improvements in pH, total N, available P, and soil CEC. (2) The best treatment for lowland rice productivity is a combination of 10 tons/ha of cow manure with 50% of the recommended dose of inorganic fertilizer (P2A1), which produces the highest GKG of 6.8 tons/ha or an increase of 25.9% compared to the conventional system. (3) Multidimensional sustainability analysis shows that the rice farming system with combined organic fertilizer has an ecological sustainability index of 68.4 (quite sustainable), provides an average increase in farmer income of 18.5%, and increases farmer satisfaction with land conditions in the medium term. (4) The main obstacles to the adoption of organic fertilizer are the limited availability of quality raw materials, relatively high initial production costs, limited technical knowledge of farmers, and lack of composting infrastructure support at the farmer level. (5) An integrated policy that includes organic fertilizer subsidies, farmer institutional development, sustainable technical training, and multi-stakeholder partnerships is needed to encourage massive adoption of organic fertilizer in Deli Serdang Regency.

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