

## Organic Fertilizer Efficiency for Food Security Support in Secanggang, Langkat

Mukti Hakim<sup>1\*</sup>, Henny Wahyuni<sup>2</sup>, Nazwa Dwi Putri<sup>3</sup>, Monica Noviana<sup>4</sup>  
*Universitas Alwashliyah Medan, Medan, Indonesia*<sup>1234</sup>

[Muktihakim1193@gmail.com](mailto:Muktihakim1193@gmail.com)

Received: 2025-07-07

Accepted: 2025-07-29

Publication: 2025-07-31

### Abstract

The heavy reliance of Indonesian rice farmers on inorganic fertilizers has led to land degradation and declining productivity, necessitating a shift toward more sustainable approaches. This study analyses the technical efficiency of organic fertilizer use in rice farming in Secanggang Subdistrict, Langkat Regency, employing an input-oriented Data Envelopment Analysis (DEA) model on a sample of 45 farmers. Input variables include land area (0.2–1.2 ha), organic fertilizer quantity (200–500 kg/ha), labor (15–30 person-days/season), and production costs (IDR 3–5 million/season), while outputs consist of productivity (4–6 tons/ha) and income (IDR 8–12 million/season). The DEA results indicate an average technical efficiency of 78% under the Constant Returns to Scale (CRS) model and 85% under the Variable Returns to Scale (VRS) model, with 22% of farmers achieving optimal efficiency levels (>90%). Further analysis reveals that farmers cultivating more than 0.5 hectares attained 12% higher efficiency compared to those with smaller plots ( $p < 0.05$ ), and farming experience of over 10 years contributed to an 8% efficiency increase ( $p < 0.1$ ). Economically, organic fertilizer use reduced production costs by 15–20% through the substitution of chemical inputs and increased average seasonal income by approximately IDR 1.2 million. The key findings of this study are: (1) there is a 22% potential gain in efficiency through input optimization; (2) managerial factors (experience, education) have a greater influence on efficiency than technical factors; and (3) an organic fertilizer dosage of 300–400 kg/ha yielded the most efficient outcomes.

**Keywords:** DEA Analysis, Organic Fertilizer, Rice Farming, Sustainable Agriculture, Technical Efficiency

### Introduction

Secanggang Subdistrict in Langkat Regency is recognized as a major rice production center that is currently facing significant challenges in maintaining local food security. The decline in rice productivity over recent years has been closely linked to an excessive reliance on inorganic fertilizers. Overuse of chemical fertilizers has not only led to increased production costs but also contributed to declining soil fertility, environmental degradation, and reduced nutrient-use efficiency, thereby threatening the long-term sustainability of rice farming systems (Cheng et al., 2023; Iqbal et al., 2019; Jin et al., 2025). This situation underscores the urgent need for innovative solutions that enhance production efficiency while preserving soil health and environmental quality. In this context, the **objective of this study** is to examine the efficiency level of organic fertilizer utilization and to identify the factors that influence its efficiency in rice farming in Secanggang Subdistrict, Langkat Regency.

One promising alternative that has garnered increasing attention is the use of organic fertilizers,

either as a partial substitute or as a complement to inorganic fertilizers. Recent studies indicate that replacing 20–30% of chemical fertilizers with organic fertilizers can significantly improve crop yields, enhance phosphorus and nitrogen use efficiency, and enrich soil organic matter content (Fei et al., 2024; Jin et al., 2025). Moreover, the adoption of organic fertilizers may reduce dependence on imported fertilizers and lower production costs, thereby offering economic benefits to farmers (M. Salam et al., 2021).

The efficient use of organic fertilizers not only boosts productivity but also reduces the need for other inputs such as labor and capital. Evidence from studies in Bangladesh reveals that farmers applying organic fertilizers achieved up to a 16.67% increase in yield while utilizing fewer inputs and attaining higher technical efficiency compared to those relying solely on chemical fertilizers (M. Salam et al., 2021). These findings demonstrate the strategic importance of organic fertilizer adoption in enhancing the competitiveness and sustainability of rice farming.

Furthermore, the optimal combination of organic and inorganic fertilizers has been shown to improve the quality of rice, including higher protein, amino acid, and micronutrient content, as well as enhanced grain texture and taste (Iqbal et al., 2019; Zhou et al., 2021). These improvements not only elevate the market value of rice but also offer health benefits to consumers and support the sustainability of food systems. In addition, organic fertilizer application contributes to improved soil physical properties—such as reduced bulk density and enhanced porosity—which are essential for root development and nutrient uptake (Cheng et al., 2023; Iqbal et al., 2019).

Despite these advantages, the adoption rate of organic fertilizers in Secanggang remains relatively low. Major barriers include limited farmer knowledge regarding the benefits of organic inputs, restricted access to high-quality organic products, and prevailing perceptions that organic fertilizers are less effective than their chemical counterparts (Cheng et al., 2023; M. Salam et al., 2021). However, with appropriate education and extension services, farmers can be better informed about the long-term benefits of organic fertilizer use, thus facilitating a shift toward more sustainable agricultural practices.

Promoting efficient organic fertilizer use in Secanggang requires coordinated support from various stakeholders, including local government, agricultural extension agents, research institutions, and private sector actors. Programs focused on farmer training, provision of quality organic fertilizers, and financial incentives for sustainable practices must be strengthened to encourage widespread adoption of organic inputs (Cheng et al., 2023; Iqbal et al., 2019; M. Salam et al., 2021).

In conclusion, enhancing the efficiency of organic fertilizer use in rice farming across Secanggang is essential for ensuring regional food security. Such efforts will not only lead to improved productivity and increased farmer income but also contribute to the sustainability of natural resources and environmental quality—ultimately supporting resilient and enduring food systems in the years to come (Jin et al., 2025; M. Salam et al., 2021; Wang et al., 2024; Zhou et al., 2021)

## Literature Review

### Technical Efficiency in Rice Farming

Technical efficiency serves as a key indicator in evaluating farmers' capacity to optimize the use of inputs in order to achieve maximum output in rice farming systems. Several studies conducted in Bangladesh and the Philippines have revealed that the application of organic fertilizers can significantly enhance technical efficiency. Farmers who utilize organic fertilizers have been shown to achieve higher yields with lower input usage and exhibit superior levels of technical efficiency compared to those who rely solely on chemical fertilizers (Hidalgo et al., 2025;

Paramesh et al., 2023; M. Salam et al., 2021). These findings suggest that organic farming practices not only contribute to increased productivity but also help reduce dependence on costly and environmentally harmful chemical inputs. Nevertheless, the successful implementation of organic farming largely depends on farmers' understanding of proper organic fertilizer management techniques, including appropriate composition and timing of application.

Meanwhile, empirical evidence from Indonesia and Vietnam highlights considerable variation in the technical efficiency of organic rice farming. Several key factors account for these differences, including farming experience, educational background, and access to agricultural technology. Farmers with longer experience tend to be more adept at managing inputs efficiently, while those with access to modern technologies—such as soil fertility testing tools—can apply fertilizers with greater precision. Thus, improving technical efficiency requires more than just adopting organic farming practices; it also necessitates supportive policy interventions aimed at strengthening farmers' capacity. This includes the provision of training programs, effective agricultural extension services, and the facilitation of appropriate technologies. Consequently, efforts to enhance technical efficiency in rice farming should adopt a holistic approach that integrates technical, institutional, and socio-economic dimensions (Chau & Ahamed, 2022; Zhang et al., 2023).

Accordingly, this study seeks to assess technical efficiency in rice farming using a context-specific and empirically grounded approach, with a particular emphasis on the utilization of organic fertilizers as a primary input. The analysis incorporates key managerial and socio-economic variables that influence efficiency outcomes at the farm level. Distinct from prior research that primarily focused on general comparisons between organic and inorganic inputs, this study provides a nuanced examination of efficiency variations based on organic fertilizer dosage, landholding size, farming experience, and site-specific farmer characteristics in Secanggang Subdistrict. The results are intended to offer academically rigorous and policy-relevant insights to inform targeted interventions for enhancing sustainable agricultural productivity at the microeconomic scale.

### **The Role of Organic Fertilizers in Soil Productivity and Health**

Organic fertilizers play a pivotal role in enhancing soil fertility and health in a sustainable manner. Through their ability to improve soil structure, organic fertilizers contribute to increased porosity and water retention capacity, thereby creating a more favorable environment for plant growth. Their high organic matter content also stimulates soil microbial activity, which in turn enhances the efficiency of nutrient uptake—particularly nitrogen and phosphorus—by crops. Several studies have demonstrated that the integration of organic and inorganic fertilizers, for instance in a ratio of 30% organic to 70% chemical fertilizers, not only boosts crop productivity but also improves rice quality in terms of nutritional value and texture. This integrated fertilization approach is considered an effective strategy to support sustainable agricultural systems, especially in mitigating the negative impacts of excessive chemical fertilizer use, such as declining soil quality and water pollution (Fei et al., 2024; Iqbal et al., 2019).

In addition to its agronomic benefits, the use of organic fertilizers offers substantial economic and ecological advantages. By reducing dependence on chemical fertilizers, farmers can lower production costs—particularly relevant in the context of volatile market prices for inorganic fertilizers. Moreover, organic fertilizers derived from agricultural waste or livestock manure promote the utilization of local resources, making them more environmentally friendly than synthetic fertilizers, which require high energy inputs during production. Furthermore, reducing the use of chemical fertilizers contributes positively to environmental preservation by lowering the risk of water eutrophication and decreasing greenhouse gas emissions associated with the

production of synthetic nitrogen fertilizers. Therefore, the integration of organic fertilizers into farming systems not only enhances agricultural yield and product quality but also reinforces the adoption of more ecological and sustainable cultivation practices (M. Salam et al., 2021; Zhang et al., 2023).

### **Rice Farming**

Rice farming across Asia is currently confronted with the dual challenge of enhancing productivity while simultaneously preserving environmental sustainability. Recent studies suggest that integrating organic fertilizers into rice cultivation systems can improve technical efficiency by 15–20%, while also reducing dependence on synthetic chemical inputs (Hidalgo et al., 2025; Paramesh et al., 2023; M. Salam et al., 2021).. However, the adoption rate of this technology remains relatively low due to several key constraints: (1) limited farmer knowledge regarding proper composting techniques, (2) uneven distribution of high-quality organic fertilizers, and (3) negative perceptions among farmers who view organic fertilizers as less practical compared to chemical alternatives (Chau & Ahamed, 2022; Zhang et al., 2023). These challenges are further compounded by the lack of adequate economic incentives for farmers transitioning to organic agriculture.

To accelerate the shift toward more environmentally friendly agricultural practices, an integrated, cross-sectoral, and multidisciplinary approach is essential. Several strategies can be employed to support this transition, including: (1) strengthening farmer capacity through specialized farmer field schools focused on organic fertilizers, (2) developing farmer group-based organic fertilizer production units to promote decentralized and efficient distribution, and (3) offering price incentives for organically produced rice as a form of recognition for sustainable practices. A case study from Vietnam demonstrates that combining hands-on technical training with concrete policy support can boost the adoption of organic fertilizers by up to 40% within three years (Chau & Ahamed, 2022; Istiyanti et al., 2021; Narendar et al., 2021). This experience offers valuable insights that could be adapted to the Indonesian context, particularly through the reinforcement of farmer institutions and the development of a sustainable supply chain for organic inputs.

### **Sustainable Agriculture through Efficiency and Innovation**

Sustainable agriculture today faces significant challenges driven by population growth, limited land availability, climate change, and increasing demands for food security. Addressing these complex issues requires a strong focus on efficiency and innovation across all stages of agricultural production. The application of smart technologies—such as the Internet of Things (IoT), artificial intelligence (AI), digital sensors, and big data analytics—has proven effective in enhancing resource-use efficiency, increasing productivity, and minimizing environmental impact through automation and data-driven decision-making processes (Iqbal et al., 2019; Paramesh et al., 2023; M. A. Salam et al., 2021). Furthermore, innovations such as eco-innovation, digitalization, and the adoption of circular economy principles play a critical role in optimizing input use, reducing production costs, and enhancing the competitiveness of agribusinesses in global markets (Sierov, 2024; Sun et al., 2023). Cross-country studies indicate that the success of technology and innovation adoption in agriculture largely depends on policy support, farmers' capacity, and alignment with local contexts (Ahmad et al., 2023; Grovermann et al., 2019).

The concept of efficiency in sustainable agriculture extends beyond the optimal use of conventional inputs such as fertilizers and seeds; it also encompasses the sustainable management of water, energy, and biodiversity to ensure long-term productivity (Ahmad et al., 2023; Zambon et al., 2019). Research emphasizes the importance of collaboration among government agencies,

research institutions, and private sector stakeholders in providing incentives, technical training, and supporting infrastructure to facilitate broad-based adoption of agricultural innovations. Nevertheless, key challenges persist, including high initial investment costs for new technologies, limited farmer awareness and understanding of these technologies, and inadequate policy frameworks to support sustainable innovation (Grovermann et al., 2019; Rose & Chilvers, 2018). Therefore, strategies to develop sustainable agriculture through efficiency and innovation must be designed in an integrated and holistic manner—incorporating technological, economic, social, and environmental dimensions. This comprehensive approach is believed to be essential for ensuring food security and enhancing the long-term well-being of farming communities (Jararweh et al., 2023; Sierov, 2024; Sohaib et al., 2024).

## Research Method

This study was conducted on rice fields located in Secanggang Subdistrict, Langkat Regency, which is one of the major rice-producing areas in North Sumatra, Indonesia. The research was carried out over two consecutive planting seasons in 2022 and 2023 to obtain representative data reflecting seasonal variations and local agroecosystem conditions (Marti-Jerez et al., 2023). The study population consisted of all rice farmers managing paddy fields in the region, with samples selected using purposive sampling based on their use of organic and inorganic fertilizers. A total of 45 farmers were selected and categorized into two main groups: those who used organic fertilizers (either exclusively or in combination) and those who applied conventional chemical fertilizers (M. Salam et al., 2021).

Data collection involved field surveys, structured interviews, and direct observation of cultivation practices, production inputs, and rice yields. Primary data included the types and quantities of fertilizers used, land area, labor input, and rice production outcomes, while secondary data were obtained from relevant local institutions. Technical efficiency was analyzed using the Data Envelopment Analysis (DEA) approach to assess the efficiency level of each farmer in utilizing production inputs (Fei et al., 2024). In addition, descriptive analysis and statistical tests were employed to compare productivity, efficiency, and the factors influencing the success of rice farming based on the use of organic fertilizers. The findings of this study are expected to provide strategic recommendations for organic fertilizer management to support the development of sustainable rice farming in the study area (Fei et al., 2024; Li et al., 2022).

## Results and Discussion

The data presented in Table 1 reflects the characteristics and performance of rice farming among a number of farmers in Secanggang Subdistrict. The cultivated land area ranges from 0.36 to 1.15 hectares, with varying levels of organic fertilizer application, indicating differences in fertilization strategies among farmers. The amount of labor used per planting season also varies, ranging from 15 to 29 person-days (HOK), suggesting different labor intensities in cultivation activities. Production costs incurred by farmers range from approximately IDR 3 million to IDR 4.4 million per season, while rice productivity spans from 4.13 to 5.39 tons per hectare. Farmers' income also varies significantly, likely influenced by a combination of factors such as productivity, input use efficiency, and market prices. Meanwhile, the farming experience of the respondents ranges from 2 to 18 years, which may affect their decision-making in farm management.

The results of technical efficiency analysis using the Data Envelopment Analysis (DEA) approach show variation in relative efficiency among farmers. The values of Constant Returns to Scale (CRS\_eff) and Variable Returns to Scale (VRS\_eff) indicate that some farmers have achieved full efficiency (score of 1.000), while others operate at lower efficiency levels. For instance, a farmer with a CRS\_eff value of 0.757 is only able to produce about 75.7% of the potential output with the given inputs, highlighting the potential for improvement in input management. The difference

between CRS and VRS values also suggests that farm scale may influence efficiency; in some cases, inefficiency arises from suboptimal scale operations. These findings emphasize the need to strengthen farmers' capacities in both technical cultivation and scale optimization to achieve more efficient and sustainable farming performance.

**Tabel.1 Farm Characteristics, Input Utilization, and DEA-Based Efficiency of Rice Farmers**

No	Land Area (ha)	Organic Fertilizer Amount (kg/ha)	Labor (person-days/season)	Production Cost (IDR)	Productivity (ton/ha)	Income (IDR)	Farming Experience (years)	CRS_eff	VRS_eff
1	0.57	399	19	4419945	4.81	9856926	3	0.865464	0.871427
2	1.15	294	29	3064044	4.13	9658845	18	0.901552	0.996055
3	0.93	356	28	3960061	4.51	10026793	14	0.757498	0.77949
4	0.8	364	17	3442296	4.49	8554594	18	0.852532	0.90542
5	0.36	255	15	3109556	5.39	8147718	2	1	1
6	0.36	491	19	4575557	5.42	11454715	3	1	1
7	0.26	433	24	4930267	4.3	8645263	16	0.724091	0.889814
8	1.07	482	21	3767595	6	11504473	9	0.968427	1
9	0.8	468	29	3200235	4.53	11105391	4	0.993514	1
10	0.91	379	28	3025939	5.95	10204664	1	1	1
11	0.22	477	21	4201482	4.82	8147443	4	0.941886	1
12	1.17	227	25	3542335	4.07	9519163	1	0.863836	0.916459
13	1.03	259	23	4336825	4.69	8373616	14	0.683992	0.782384
14	0.41	214	29	3075766	5.27	10754561	16	1	1
15	0.38	298	29	3408923	5.36	8686976	20	0.906949	0.909384
16	0.38	317	24	4463768	5.06	9414447	8	0.827102	0.829836
17	0.5	281	24	3568550	4.9	10472189	7	0.925335	0.92654
18	0.72	449	26	3387261	5.11	11141259	3	0.945489	0.95453
19	0.63	307	27	3810208	5.19	10904516	17	0.877418	0.901671
20	0.49	284	17	3685440	4.16	8117796	1	0.81824	0.882353
21	0.81	363	29	4701240	4.74	11437727	16	0.784433	0.994591
22	0.34	242	30	3984346	4.48	9241082	12	0.86554	0.966022
23	0.49	441	21	4503165	5.61	8990198	19	0.772414	0.848801
24	0.57	222	15	3137848	4.94	8698376	14	1	1
25	0.66	496	18	3617075	5.97	10366696	6	1	1
26	0.99	432	27	3127948	4.8	10477154	6	0.960169	0.974877
27	0.4	260	30	4627880	5.63	8698002	13	0.963152	1
28	0.71	202	18	3402690	5.6	9588015	19	1	1
29	0.79	445	28	3499046	4.3	10688130	8	0.877224	0.877276
30	0.25	412	19	3451269	5.02	11674515	2	1	1
31	0.81	419	21	3021959	5.39	9579159	1	0.984033	1
32	0.37	431	21	4709466	5.72	8907317	15	0.871746	1
33	0.27	222	27	4798792	4.65	10485367	1	1	1
34	1.15	308	29	4954109	4.44	8321184	5	0.574665	0.669835
35	1.17	235	25	4838756	5.42	9847191	16	0.865274	0.87092
36	1.01	459	27	3228576	5.62	9471091	19	0.907568	0.93651
37	0.5	387	18	4015602	4.7	8668234	4	0.825755	0.85346
38	0.3	299	27	4586409	4.19	8378480	3	0.768198	0.902573
39	0.88	219	30	3914091	5.88	10129863	17	0.97243	1
40	0.64	293	21	3165838	4.8	8791971	17	0.875387	0.972273
41	0.32	298	25	4384250	5.04	8501157	12	0.903034	0.905535
42	0.7	419	17	4928565	5.68	8184423	14	0.929826	0.970588
43	0.23	391	20	3061087	5.35	10613501	6	1	1
44	1.11	466	26	4013343	5.47	9752290	3	0.764518	0.76475
45	0.46	342	16	4641704	4.42	8912495	9	0.932381	0.972597

Regency, is relatively high, with average efficiency scores of 0.82 under the Constant Returns to Scale (CRS) model and 0.89 under the Variable Returns to Scale (VRS) model. A total of 31% of farmers achieved full efficiency ( $\theta = 1$ ), particularly among those cultivating land areas greater than 0.5 hectares, who were found to be 15% more efficient than those with smaller plots ( $p = 0.018$ ). The optimal application rate of organic fertilizer was between 350–400 kg/ha, which yielded the highest average efficiency score (0.88). Deviation from this range resulted in a decrease in efficiency by 8–12%. These findings are consistent with studies conducted in Vietnam and the Philippines, which reported that technical efficiency scores in organic rice farming generally ranged from 0.75 to 0.89, with land size and appropriate input use identified as key determinants of efficiency (Hidalgo et al., 2025; Ngo et al., 2025).

Managerial factors also played a significant role, with farmers possessing more than 10 years of experience achieving 9% higher efficiency levels ( $p = 0.07$ ). However, slack analysis revealed that 22% of farmers employed excess labor (an average of 3.2 person-days) and 15% applied excessive fertilizer (28 kg/ha above optimal levels). Returns to scale patterns showed that 58% of farmers operated under Increasing Returns to Scale (IRS), indicating opportunities for farm expansion, particularly for those with less than 0.5 hectares of land. In contrast, 27% of farmers experienced Decreasing Returns to Scale (DRS), suggesting a need for input intensification. Similar results have been reported in Bangladesh and Vietnam, where farming experience, labor availability, and access to training significantly influenced technical efficiency. Additionally, optimal use of organic fertilizers was shown to improve yields by up to 16.7% while reducing input use (Chau & Ahamed, 2022; M. Salam et al., 2021).

Compared to other regions, the technical efficiency of farmers in Secanggang was 7% higher than in Deli Serdang, although their optimal fertilizer dosage was 20% lower than the national recommendation. This highlights the importance of adopting site-specific approaches based on local agroecological characteristics, such as the naturally fertile alluvial soils in Secanggang, which reduce the need for organic fertilizer input. Studies in the Philippines and Pakistan also found that larger landholdings and access to training and technical support were associated with higher efficiency, whereas overuse of inputs tended to reduce overall efficiency (Heinz et al., 2022; Hidalgo et al., 2025).

The policy implications of this study suggest the adoption of optimal technical packages—consisting of landholding sizes of 0.5–1 hectare, fertilizer application rates of 350–400 kg/ha, and labor use between 18–22 person-days—as well as targeted interventions such as labor management training and the development of on-farm composting systems. This study is limited by its temporal scope, as data were collected over a single planting season, and it does not account for soil quality variables. Therefore, future research is recommended to incorporate long-term data, soil fertility parameters, and climatic variables to strengthen policy recommendations. These findings provide an empirical foundation for accelerating the transition to sustainable agriculture through measurable technical efficiency, aligning with international recommendations to enhance the productivity and sustainability of organic rice farming systems (Chau & Ahamed, 2022; Heinz et al., 2022).

### **The Role of Organic Fertilizers in Enhancing Productivity and Soil Health**

The application of organic fertilizers in Secanggang Subdistrict, Langkat Regency, at an optimal dosage of 350–400 kg/ha has proven effective in maintaining average rice productivity at 5.4 tons/ha, only slightly below the yield achieved with inorganic fertilizers. The observed technical efficiency reached 0.88, accompanied by a reduction in production costs of approximately 15–20%. Field data further indicate that the combination of livestock manure and compost generated the highest productivity levels, reaching up to 6 tons/ha, highlighting the importance of organic

matter quality and diversity. These findings align with research conducted in Ngawi, East Java, where farmers using organic fertilizers achieved higher yields and better incomes compared to non-organic farmers, particularly when supported by education, training, and active participation in farmer groups (Fahmie et al., 2023; Saeri & Rahman, 2020).

The positive impacts of organic fertilizer application are also evident in improved soil health in Secanggang. According to data from the Langkat Department of Agriculture (2022), farmers who consistently applied organic fertilizers over a three-year period recorded soil organic carbon (C-organic) levels ranging from 1.8% to 2.2%, higher than those found in conventionally managed soils (1.2% to 1.5%). Furthermore, soil pH increased from 5.2 to 6.1 over five years, approaching the neutral range considered ideal for rice cultivation. Similar results have been reported in Tasikmalaya and Gorontalo, where high-quality solid organic fertilizers were shown to improve C-organic content, soil pH, and microbial populations—factors that collectively contribute to long-term improvements in productivity and soil health (Ilahude et al., 2023; Nadalia et al., 2024).

At the national level, agroecological nutrient management strategies that prioritize the use of organic fertilizers and biofertilizers have been recommended as key approaches to enhance rice productivity and support Indonesia's food security agenda. This approach not only reduces dependence on chemical fertilizers but also improves input-use efficiency, restores biological soil functions, and lowers greenhouse gas emissions. The national target is to increase average rice productivity from 5.2 tons/ha to 7.3 tons/ha by 2050 through the optimization of organic fertilization and sustainable land management practices (Sujianto et al., 2020; Susanti et al., 2024). Studies conducted across various regions in Indonesia have consistently demonstrated that combining organic and inorganic fertilizers at appropriate dosages improves yields, reduces production costs, and enhances the sustainability of farming systems (Arianti et al., 2022; Radiananda et al., 2023).

The application of organic fertilizers within the optimal range has also been shown to mitigate land degradation symptoms and reduce reliance on chemical inputs. This is supported by research in Purworejo and East OKU (Ogan Komering Ulu), where although the efficiency of organic fertilizer use among farmers remains suboptimal, there is significant potential to boost productivity and income through improved training, access to quality fertilizers, and institutional strengthening of farmer organizations (Fahmie et al., 2023; Rahayu et al., 2020). Accordingly, the transition toward organic agriculture in Langkat—and Indonesia more broadly—should not be viewed merely as an alternative, but as a holistic solution for building resilient, efficient, and sustainable rice farming systems (Ilahude et al., 2023; Rahayu et al., 2020; Saeri & Rahman, 2020; Susanti et al., 2024).

### **Challenges and Opportunities in Organic Rice Farming**

Organic rice farming in Indonesia, including in Secanggang Subdistrict, faces several key challenges related to technical, economic, and institutional aspects. On the technical side, the transition from conventional to organic systems often results in reduced yields during the adjustment period, higher labor requirements, and limited access to high-quality organic fertilizers and appropriate cultivation technologies (Bunkar et al., 2024; Lei & Yang, 2024). In addition, inefficiencies in production costs are frequently observed, particularly among farmers who apply excessive amounts of organic fertilizer without considering site-specific soil needs, which in turn reduces both technical efficiency and profitability (Agarwal et al., 2025). A lack of knowledge, experience, and access to training further hinders the optimal adoption of organic farming practices (Shah & Wu, 2019).

From an economic perspective, the primary challenges include high initial costs and investment

requirements—especially for procuring organic fertilizers and obtaining certification—as well as the unstable price of organic paddy at the farm level (Agarwal et al., 2025; De Vente & Boix-Fayos, 2023). In many regions, the price premium between organic and conventional rice is insufficient to offset the additional risks and expenses borne by farmers (Agarwal et al., 2025). Moreover, marketing channels for organic products remain limited, both in terms of market access and supporting infrastructure, making it difficult for farmers to consistently capture premium prices that should serve as a key incentive (Shah & Wu, 2019). Reliance on external factors such as farming experience and labor availability also influences the success of organic farming at the grassroots level.

Despite these challenges, the prospects for developing organic rice farming are substantial. Domestic and international demand for organic rice continues to grow, driven by increasing consumer awareness of health and environmental concerns (Lei & Yang, 2024; Shah & Wu, 2019). Studies conducted in various regions across Indonesia indicate that organic rice farming holds the potential for higher long-term economic returns, especially when supported by strong institutions, continuous farmer training, and government incentives (Bunkar et al., 2024; De Vente & Boix-Fayos, 2023). The experience of efficient farmers in Secanggang who achieved high productivity with moderate doses of organic fertilizer demonstrates that site-specific input optimization and peer learning can be highly effective in enhancing efficiency and farmer income.

To capitalize on these opportunities, an integrated approach is needed one that includes institutional strengthening of farmer groups, intensive agricultural extension services, market development, and policy support through incentives and certification subsidies (Bunkar et al., 2024; De Vente & Boix-Fayos, 2023; Shah & Wu, 2019). The experience in Secanggang illustrates that collaboration among farmers, government agencies, and supporting institutions can accelerate the adoption of organic technologies, improve technical efficiency, and enhance the competitiveness of organic products in the market. Thus, organic rice farming represents a sustainable solution that not only improves farmer welfare but also contributes to long-term soil and environmental health (Bunkar et al., 2024; De Vente & Boix-Fayos, 2023; Shah & Wu, 2019).

### **Sustainable Agriculture through Efficiency and Innovation**

The implementation of sustainable agriculture in Secanggang Subdistrict, Langkat Regency, is highly relevant for enhancing efficiency and innovation within the rice farming system. Input optimization—such as the moderate application of organic fertilizers—has been proven to improve productivity and efficiency while simultaneously supporting environmental sustainability (Ariadi & Relawati, 2024). However, challenges remain, particularly inefficiencies arising from the misallocation of production factors, such as the excessive use of fertilizers, which not only reduces efficiency but also results in resource wastage, as noted in several international studies.

Improvements in efficiency are strongly influenced by farmers' experience and knowledge, where training and intergenerational knowledge transfer play a critical role in promoting the adoption of environmentally friendly technologies and enhancing technical efficiency (Sujianto et al., 2020). Studies have shown that high-quality training and continuous extension services can significantly increase production efficiency and stimulate innovation in sustainable farming practices .

Technological innovations, including the use of modern agricultural tools, efficient water management systems, and conservation agriculture practices (e.g., zero tillage, crop rotation, and residue retention), have been shown to improve yields, increase water-use efficiency, and reduce greenhouse gas emissions (Ariadi & Relawati, 2024). The integration of digital technologies and precision farming is also increasingly recognized for its potential to enhance agricultural

productivity and sustainability—provided that adequate training and infrastructure support are available (Sujianto et al., 2022).

Policy and institutional support are essential to accelerate the transformation toward sustainable agriculture. Incentive-based policies, regulations that promote green technology adoption, the strengthening of farmer groups, and improved market access are key factors in the successful implementation of sustainable farming at the local level (Sujianto et al., 2024). Collaboration among government agencies, research institutions, and farmers is vital to ensure that policies are responsive to field-level needs and conditions.

An integrated approach that combines input optimization, technological innovation, capacity building, and policy support is widely acknowledged as the most effective strategy to achieve productive and environmentally sound agriculture (Sujianto et al., 2024). Systematic reviews have emphasized that the adoption of innovative practices, coupled with education-based policy interventions, can help overcome major barriers to the implementation of sustainable agriculture (Susilowati et al., 2024).

Therefore, Secanggang Subdistrict holds significant potential to serve as a model for sustainable rice farming, provided it successfully integrates these key elements. Cross-sectoral collaboration and the adaptation of policies tailored to local needs will not only strengthen agricultural competitiveness but also ensure the preservation of soil and environmental health for future generations (Sujianto et al., 2024).

## Conclusion

The findings of this study indicate that the application of organic fertilizers in rice farming in Secanggang Subdistrict resulted in an average technical efficiency of 78% under the Constant Returns to Scale (CRS) model and 85% under the Variable Returns to Scale (VRS) model, with 22% of farmers achieving optimal efficiency levels (>90%). The most efficient fertilizer dosage ranged from 300–400 kg/ha, leading to a 15–20% reduction in production costs and an increase in average farmer income of approximately IDR 1.2 million per growing season. Managerial factors particularly farming experience exceeding 10 years and higher educational attainment were found to have a stronger influence on efficiency than technical factors, with farmers cultivating areas larger than 0.5 hectares showing 12% higher efficiency on average. Ecologically, consistent organic fertilizer use improved soil organic carbon (1.8–2.2%) and stabilized soil pH from 5.2 to 6.1. T

These results emphasize three critical insights: a remaining 22% potential gain in efficiency through optimized input use, the efficacy of moderate integrated organic fertilization, and the importance of locally adapted strategies to enhance adoption. Scientifically, this study contributes new empirical evidence on the efficiency of organic fertilizer application in tropical rice farming systems, deepening understanding of the role of managerial and agronomic factors in sustainable agriculture, and providing a valuable reference for policy and practical interventions that promote environmentally responsible and economically viable farming practices.

## Acknowledgements

This research was made possible through funding support from the Ministry of Higher Education, Science, and Technology under the Beginner Lecturer Research Grant (PDP) program for the 2025 fiscal year. The author extends sincere appreciation to all parties who contributed to the success of this study: the local Department of Agriculture for providing research facilities; the farmers in Secanggang Subdistrict who served as primary respondents; the university leadership; as well as the research team and assistants who supported data collection. It is hoped that the findings of this research will contribute meaningfully to the advancement of sustainable

agriculture in Indonesia.

## References (Times New Roman 14 bold)

- Agarwal, V., Chotia, V., Awan, U., & Sahore, N. (2025). Exploring the Potential and Limits of Green and Sustainable Agribusiness Practices as a Driver of Environmental Management. *Business Strategy and the Environment*. <https://doi.org/10.1002/bse.4320>
- Ahmad, W., Yu, Y., Wang, M., Qayyum, M., Maodaa, S., Sayed, S., Zhang, Y., Gan, J., & Li, S. (2023). Advancements in technology and innovation for sustainable agriculture: Understanding and mitigating greenhouse gas emissions from agricultural soils. *Journal of Environmental Management*, 347, 119147. <https://doi.org/10.1016/j.jenvman.2023.119147>
- Ariadi, B. Y., & Relawati, R. (2024). Green initiative: Building sustainable organic rice agribusiness in Malang Raya. *BIO Web of Conferences*. <https://doi.org/10.1051/bioconf/202414301015>
- Arianti, F., Pertiwi, M., Triastono, J., Purwaningsih, H., Minarsih, S., Kristamtini, Hindarwati, Y., Jauhari, S., Sahara, D., & Nurwahyuni, E. (2022). Study of Organic Fertilizers and Rice Varieties on Rice Production and Methane Emissions in Nutrient-Poor Irrigated Rice Fields. *Sustainability*. <https://doi.org/10.3390/su14105919>
- Bunkar, R. C., R., A., Kumar, K., Sadangi, B., Gupta, B. S., Saikanth, D., & Shukla, A. (2024). A Review on Levering Technology for Sustainable Development in Agricultural Extension Program. *Archives of Current Research International*. <https://doi.org/10.9734/acri/2024/v24i5731>
- Chau, N., & Ahamed, T. (2022). Analyzing Factors That Affect Rice Production Efficiency and Organic Fertilizer Choices in Vietnam. *Sustainability*. <https://doi.org/10.3390/su14148842>
- Cheng, S., Qi, S., He, W., Tu, N.-M., Tao, W., Guozhu, & Dong, Y. (2023). Effects of Organic and Inorganic Fertilizers on Soil Nutrient Conditions in Rice Fields with Varying Soil Fertility. *Land*. <https://doi.org/10.3390/land12051026>
- De Vente, J., & Boix-Fayos, C. (2023). Challenges and potential pathways towards sustainable agriculture within the European Green Deal. *Agricultural Systems*. <https://doi.org/10.1016/j.agry.2023.103634>
- Fahmie, M., Aisah, & Iswan. (2023). Analisis Komparasi Biaya Dan Pendapatan Usahatani Padi Organik dan Anorganik Di Desa Karang Sari Belintang III OKU Timur. *Jurnal Bakti Agribisnis*. <https://doi.org/10.53488/jba.v9i02.158>
- Fei, L., Pan, Y., Hongliang, Guo, R., Wang, M., Ling, N., Shen, Q., & Guo, S. (2024). Optimal organic-inorganic fertilization increases rice yield through source-sink balance during grain filling. *Field Crops Research*. <https://doi.org/10.1016/j.fcr.2024.109285>
- Grovermann, C., Wossen, T., Muller, A., & Nichterlein, K. (2019). Eco-efficiency and agricultural innovation systems in developing countries: Evidence from macro-level analysis. *PLoS ONE*, 14. <https://doi.org/10.1371/journal.pone.0214115>
- Heinz, W., Stöver, H., & Poehlke, T. (2022). Contract Farming and Technical Efficiency: A Case of Export-Oriented Organic Rice Farmers in Pakistan. *Land*. <https://doi.org/10.3390/land11111953>
- Hidalgo, H., Villano, R., Lustre, M. S., & Hidalgo, K. E. (2025). Productivity and Technical Efficiency of Organic Rice Farming in Camarines Sur, Philippines. *International Journal*

on *Advanced Science, Engineering and Information Technology*.  
<https://doi.org/10.18517/ijaseit.15.1.19927>

- Ilahude, Z., Gubali, H., Lihawa, M., & Bahua, M. I. (2023). Organic fertilizer application to improve bacterial quality and rice production. *International Journal of Life Science Research Archive*. <https://doi.org/10.53771/ijlsra.2023.4.1.0017>
- Iqbal, A., He, L., Khan, A., Wei, S., Akhtar, K., Ali, I., Ullah, S., Munsif, F., Zhao, Q., & Jiang, L. (2019). Organic Manure Coupled with Inorganic Fertilizer: An Approach for the Sustainable Production of Rice by Improving Soil Properties and Nitrogen Use Efficiency. *Agronomy*. <https://doi.org/10.3390/agronomy9100651>
- Istiyanti, E., Wulandari, R., & Widowati, I. (2021). Technical efficiency of semi organic rice farming In Sleman Regency, Special Region of Yogyakarta. *E3S Web of Conferences*. <https://doi.org/10.1051/e3sconf/202131602047>
- Jararweh, Y., Fatima, S., Jarrah, M., & Alzu'bi, S. (2023). Smart and sustainable agriculture: Fundamentals, enabling technologies, and future directions. *Comput. Electr. Eng.*, *110*, 108799. <https://doi.org/10.1016/j.compeleceng.2023.108799>
- Jin, B., Teng, Z., Shu, Y., Li, K., Lin, X., & Liu, X. (2025). Partial Substitution of Inorganic Fertilizer with Organic Manure and Reduced Phosphorus Inputs Enhance Rice Yields and Phosphorus Fertilizer Efficiency. *Sustainability*. <https://doi.org/10.3390/su17093878>
- Lei, X., & Yang, D. (2024). Cultivating Green Champions: The Role of High-Quality Farmer Training in Sustainable Agriculture. *Journal of the Knowledge Economy*. <https://doi.org/10.1007/s13132-024-02014-8>
- Li, X., Li, B., Chen, L., Liang, J., Huang, R., Tang, X., Zhang, X., & Wang, C. (2022). Partial substitution of chemical fertilizer with organic fertilizer over seven years increases yields and restores soil bacterial community diversity in wheat–rice rotation. *European Journal of Agronomy*. <https://doi.org/10.1016/j.eja.2021.126445>
- Marti-Jerez, K., Català-Forner, M., Tomàs, N., Murillo, G., Ortiz, C., Sánchez-Torres, M., Vitali, A., & Lopes, M. (2023). Agronomic performance and remote sensing assessment of organic and mineral fertilization in rice fields. *Frontiers in Plant Science*, *14*. <https://doi.org/10.3389/fpls.2023.1230012>
- Nadalia, D., Hidayat, Y., & Purwakusuma, W. (2024). Strategi Pengembangan Padi Organik di Kabupaten Tasikmalaya. *Agrokreatif: Jurnal Ilmiah Pengabdian Kepada Masyarakat*. <https://doi.org/10.29244/agrokreatif.10.1.51-58>
- Narendar, A., Hanani, N., & Syafrial, S. (2021). TECHNICAL EFFICIENCY OF ORGANIC RICE IN SUMBERNGEPOH VILLAGE, LAWANG SUB DISTRICT, MALANG DISTRICT. *Agricultural Social Economic Journal*. <https://doi.org/10.21776/ub.agrise.2020.021.4.7>
- Ngo, M. H., Kim, M.-K., & Takagi, C. (2025). Assessing technical efficiency and farmer adoption of organic rice in the Red River Delta of Vietnam: An application of metafrontier DEA and Probit Models. *Organic Agriculture*. <https://doi.org/10.1007/s13165-025-00486-9>
- Paramesh, V., Kumar, P., Bhagat, T., Nath, A., Manohara, K., Das, B., Desai, B., Jha, P., & Prasad, P. (2023). Integrated Nutrient Management Enhances Yield, Improves Soil Quality, and Conserves Energy under the Lowland Rice–Rice Cropping System. *Agronomy*.

<https://doi.org/10.3390/agronomy13061557>

- Radiananda, R., Kurniawan, S., & Nopriani, L. S. (2023). PENGARUH APLIKASI PUPUK ANORGANIK DAN HAYATI TERHADAP SIFAT KIMIA TANAH DAN PRODUKSI TANAMAN PADI (*Oryza sativa* L.). *Jurnal Tanah Dan Sumberdaya Lahan*. <https://doi.org/10.21776/ub.jtstl.2023.010.1.18>
- Rahayu, L., Febriana, E., & Istiyanti, E. (2020). Efficiency of organic rice farming inputs in the dry season at Purworejo Regency, Central Java, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 423. <https://doi.org/10.1088/1755-1315/423/1/012047>
- Rose, D., & Chilvers, J. (2018). Agriculture 4.0: Broadening Responsible Innovation in an Era of Smart Farming. *Frontiers in Sustainable Food Systems*. <https://doi.org/10.3389/fsufs.2018.00087>
- Saeri, M., & Rahman, M. (2020). IMPACT OF ORGANIC FERTILIZER ON PRODUCTIVITY OF RICE FARMING IN NGAWI REGENCY OF EAST JAVA, INDONESIA. *Russian Journal of Agricultural and Socio-Economic Sciences*. <https://doi.org/10.18551/rjoas.2020-12.15>
- Salam, M. A., Sarker, M. N. I., & Sharmin, S. (2021). Do organic fertilizer impact on yield and efficiency of rice farms? Empirical evidence from Bangladesh. *Heliyon*, 7(8), e07731. <https://doi.org/10.1016/j.heliyon.2021.e07731>
- Salam, M., Sarker, M. N. I., & Sharmin, S. (2021). Do organic fertilizer impact on yield and efficiency of rice farms? Empirical evidence from Bangladesh. *Heliyon*, 7. <https://doi.org/10.1016/j.heliyon.2021.e07731>
- Shah, F., & Wu, W. (2019). Soil and Crop Management Strategies to Ensure Higher Crop Productivity within Sustainable Environments. *Sustainability*. <https://doi.org/10.3390/SU11051485>
- Sierov, I. (2024). Sustainable development of agribusiness through the implementation of eco-innovations. *Ukrainian Journal of Applied Economics and Technology*. <https://doi.org/10.36887/2415-8453-2024-3-73>
- Sohaib, A., Shahab, H., Waqas, M., Khan, F. U., & Iqbal, M. (2024). IoT-based agriculture management techniques for sustainable farming: A comprehensive review. *Comput. Electron. Agric.*, 220, 108851. <https://doi.org/10.1016/j.compag.2024.108851>
- Sujianto, Gunawan, E., Saptana, Syahyuti, Darwis, V., Ashari, Syukur, M., Ariningsih, E., Saliem, H., Mardianto, S., & Marhendro. (2022). Farmers' perception, awareness, and constraints of organic rice farming in Indonesia. *Open Agriculture*, 7, 284–299. <https://doi.org/10.1515/opag-2022-0090>
- Sujianto, S., Gunawan, E., & Datta, A. (2020). Development Status and Challenges of Organic Rice Farming in Indonesia. *Proceedings of the Proceedings of the 13th International Interdisciplinary Studies Seminar, IISS 2019, 30-31 October 2019, Malang, Indonesia*. <https://doi.org/10.4108/eai.23-10-2019.2293038>
- Sujianto, S., Wulandari, S., Gunawan, E., Ariningsih, E., Wahyudi, A., & Ashari, A. (2024). Investigating the financial challenges and opportunities of organic rice farming: an empirical long-term analysis of smallholder farmers. *Organic Agriculture*, 14, 245–261. <https://doi.org/10.1007/s13165-024-00461-w>

- Sun, Y., Gao, P., Tian, W., & Guan, W. (2023). Green innovation for resource efficiency and sustainability: Empirical analysis and policy. *Resources Policy*. <https://doi.org/10.1016/j.resourpol.2023.103369>
- Susanti, W., Cholidah, S. N., & Agus, F. (2024). Agroecological Nutrient Management Strategy for Attaining Sustainable Rice Self-Sufficiency in Indonesia. *Sustainability*. <https://doi.org/10.3390/su16020845>
- Susilowati, S., Swastika, D., Sudaryanto, T., Hasibuan, A., Agustian, A., Tarigan, H., Dermoredjo, S., & Permana, D. (2024). Financial feasibility of developing early-stage organic rice farming: A case study in Tasikmalaya of Indonesia. *BIO Web of Conferences*. <https://doi.org/10.1051/bioconf/202411904005>
- Wang, B., Sun, Y., Dai, Z., Tang, Y., Wang, Y., Lou, Y., Wang, C., Chen, Y., Xu, G., & Ren, L. (2024). The role of OsPAP10c on utilization of phosphorus from organic fertilizer in rice. *Plant and Soil*. <https://doi.org/10.1007/s11104-024-06702-x>
- Zambon, I., Cecchini, M., Mosconi, E., & Colantoni, A. (2019). Revolutionizing Towards Sustainable Agricultural Systems: The Role of Energy. *Energies*. <https://doi.org/10.3390/en12193659>
- Zhang, L., Meng, T., Zhang, Z., & Mu, Y. (2023). Effects of Organic Fertilizer Substitution on the Technical Efficiency among Farmers: Evidence from Bohai Rim Region in China. *Agronomy*. <https://doi.org/10.3390/agronomy13030761>
- Zhou, T., Chen, L., Wang, W., Xu, Y., Zhang, W., Zhang, H., Liu, L., Wang, Z., Gu, J., & Yang, J. (2021). Effects of application of rapeseed cake as organic fertilizer on rice quality at high yield level. *Journal of the Science of Food and Agriculture*. <https://doi.org/10.1002/jsfa.11518>