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ANALYSIS OF TECHNICAL EFFICIENCY AND FACTORS AFFECTING INEFFICIENCY IN RICE FARMING: A COMPARATIVE STUDY OF INTEGRATED PEST MANAGEMENT (IPM) AND NON-IPM FARMERS IN KAMPAR SUBDISTRICT, KAMPAR REGENCY, RIAU PROVINCE

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Abstract

Pesticides are considered valuable production inputs in agriculture. However, pesticides do not directly contribute to increasing production. Instead, pesticides can reduce crop damage by controlling plant pests. One common misunderstanding among farmers is the misuse of pesticides, including the use of higher doses or concentrations than the recommended ones. To ensure the long-term sustainability of agriculture, an alternative pest control method is integrated pest management (IPM), which aims to use pesticides rationally. Farmers exhibit variations in their employment of production factors such as seeds, fertilizers, pesticides, and labor, resulting in corresponding differences in production outputs, productivity, and factor utilization efficiency. Therefore, this study aims to estimate the influence of input usage on rice production between farmers implementing IPM and non-IPM, to estimate the technical efficiency level of rice farmers implementing IPM and non-IPM and identify factors affecting inefficiency in rice farming, and formulate alternative policies to improve efficiency. The analytical method used is the stochastic frontier production function. The results show that the average technical efficiency levels achieved by IPM and non-IPM farmers are 0.80 and 0.69. Land area and synthetic fertilizers have a positive effect on IPM production, while seeds and synthetic fertilizers have a favorable impact on non-IPM production. However, the interaction between synthetic pesticides and frequency has a negative effect on production. Social and economic factors that contribute to technical inefficiency include education in both IPM and non-IPM farming systems. Additionally, the percentage of healthy crop cultivation has a significant impact on inefficiency in non-IPM farming systems.

Keywords: Technical Efficiency, Inefficiency, Stochastic frontier, Integrated Pest Management (IPM), and Non-IPM.

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INTRODUCTION

Efficiency analysis remains a compelling area of study, encompassing both developing and developed nations. Its significance lies in providing valuable insights into the potential for enhancing agricultural productivity within the constraints of available resources, particularly in developing countries. The measurement of efficiency serves as a vital indicator of agricultural performance (Haryani, 2009). Additionally, these analyses play a pivotal role in evaluating the sustainability of agricultural practices (Madau, 2007). By investigating and understanding efficiency levels, policymakers, and stakeholders can make informed decisions to promote sustainable and productive agricultural systems. Kampar Regency is one of the rice-producing regions in Riau. The harvested rice field area reached 6,535.8 hectares in 2021, with a production of 31,717.0 tons and a productivity of 4.85 tons/ha (DTPHPR, 2022). The estimated population of the Regency in 2022 is 761,567 people, with an average current growth rate of 3.3%. The average rice consumption per capita is 108.74 kg per year, resulting in an annual requirement of 82,812.8 tons. However, there is still a shortage of 51,096 tons, or 60% of rice every year (PPID, 2021).

The degree of pest infestation has a significant impact on rice farming productivity, with the outbreaks causing extensive negative effects on crops in numerous Asian countries. Therefore, pesticide usage in the region is comparably high when contrasted with other developing nations (Hossain *et al*., 2000). Pesticides are widely recognized as valuable inputs in modern agriculture but their direct contribution to increasing production is limited. They play a crucial role in crop protection by minimizing the damage caused by pests. In contrast, other inputs such as fertilizers and seeds have a more direct impact on production yields (Cooper and Dobson, 2007; Shende and Bagde, 2013). One common misconception among farmers is that higher doses of pesticides than recommended can result in increased production yields. This notion is inaccurate and can lead to negative consequences for human health and non-target organisms. Therefore, it is critical to adopt a more judicious and responsible approach to pesticide use in agriculture (Shende and Bagde, 2013). To ensure the long-term sustainability of agriculture, IPM emerges as a viable alternative for pest control. IPM seeks to achieve rational pesticide application while harmoniously integrating various strategies (Zalucki *et al*., 2009). It represents a cross-sectoral program that aims to systematically and cohesively establish IPM principles and technologies among farmers, thereby promoting sustainable and environmentally conscious agricultural development. Furthermore, the National IPM Program encompasses pest management and broader targets such as improving productivity, enhancing the quality of agricultural products, increasing agricultural efficiency, improving farmers' capacity and welfare, and preserving the environment. The utilization of production factors, including seeds, fertilizers, pesticides, and labor, varies among farmers, leading to variations in their respective outputs, productivity, and the efficiency of factor usage. This study seeks to estimate the level of technical efficiency among rice farmers implementing IPM and non-IPM practices, identifying the factors that contribute to inefficiency, and formulating alternative policies to improve efficiency.

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METHOD

The study was conducted in Kampar Subdistrict, Kampar Regency, Riau Province using primary and secondary data. A purposive sampling method was used and the samples consisted of farmers using IPM and non-IPM methods, selected intentionally. Respondent farmers, implementing IPM and non-IPM methods, were selected from several villages in Kampar Subdistrict. Farmers with IPM were identified based on their participation in training and adherence to principles in rice cultivation.

There were 127 IPM farmers in the Kampar Subdistrict (BPP, 2020). During the observation period, 38 were using IPM, hence the sampling was performed through a census. For comparison, 62 non-IPM farmers were purposively selected as respondents, resulting in a total sample size of 100 farmers. This study was conducted from October 2021 to March 2022.

The stochastic frontier production function estimation equation model for rice farming can be written as follows:

1. Equation model for IPM farming in Kampar Subdistrict

$$\text{Ln } Y_i = \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 \ln X_{4i} + \beta_5 \ln X_{5i} + \beta_6 \ln X_{6i} + \beta_7 \ln X_{7i} + v_i - u_i \quad \ldots \ldots \ldots \quad (1)$$

Y_i = total IPM rice production (kg of Harvested Dry Grain)

X_1 = land area (hectares)

X_2 = seeds (kg)

X_3 = organic fertilizer (kg)

X_4 = synthetic fertilizer (sum of NPK, TSP, KCL, ZA, SP36 fertilizer usage in kg)

X_5 = natural pesticide * frequency (liter)

X_6 = synthetic pesticide * frequency (liter)

X_7 = labor (HOK)

β_0 = intercept

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7$ = estimated parameters

$v_i - u_i$ = error term (inefficiency effect within the model)

The expected signs of the parameters are $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7 > 0$, indicating positive estimates.

2. Equation model for non-IPM farming in Kampar Subdistrict

$$\text{Ln } Y_i = \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 \ln X_{4i} + \beta_5 \ln X_{5i} + \beta_6 \ln X_{6i} + v_i - u_i \quad \ldots \ldots \ldots \quad (2)$$

Y_i = total IPM rice production (kg of Harvested Dry Grain)

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X_1 = land area (hectares)

X_2 = seeds (kg)

X_3 = organic fertilizer (kg)

X_4 = synthetic fertilizer (sum of NPK, TSP, KCL, ZA, SP36 fertilizer usage in kg)

X_5 = synthetic pesticide * frequency (liter)

X_6 = labor (HOK)

β_0 = intercept

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ = estimated parameters

$v_i - u_i$ = error term (inefficiency effect within the model)

The expected signs of the parameters are $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6 > 0$, indicating positive parameter estimates.

Efficiency analysis The stochastic frontier estimation model using Maximum Likelihood Estimation (MLE) can be measured using the following formula (Coelli, 1998):

$$TE = \frac{y_i}{y^*} = \frac{y_i}{\exp(x_i\beta)} = \frac{\exp(x_i\beta + V_i - U_i)}{\exp(x_i\beta + V_i)}$$

$$= \exp(-u_i) \qquad I = 1,2,3,\ldots N \quad \ldots\ldots \quad (3)$$

Where y_i is the actual production from observations and y* is the estimated frontier production obtained from the stochastic frontier production. The technical efficiency for a farmer ranges between zero and one, or TEi: $0 \leq TEi \leq 1$.

The equation model for estimating the factors or effects of technical inefficiency on IPM and non-IPM farmers in Kampar Subdistrict is expressed as follows:

$$u_i = \delta_0 + \delta_1 Z_{1i} + \delta_2 Z_{2i} + \delta_3 Z_{3i} + \delta_4 Z_{4i} + \delta_5 Z_{5i} + \delta_6 Z_{6i} + \delta_7 Z_{7i} + \varepsilon_i \quad \ldots \quad (4)$$

where:

u_i = technical inefficiency effect

δ_0 = constant

Z_1 = farmer's age (years)

Z_2 = formal education level of the farmer (years)

Z_3 = experience in rice cultivation (years)

Z_4 = membership dummy in a farmer group (with a value of 1 if a member of a farmer group, and 0 otherwise)

Z_5 = frequency of meetings with extension workers during farming (in times)

Z_6 = application rate percentage of healthy crop cultivation techniques (%)

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Z_7 = distance from home to the rice field (km)

δ = estimated coefficient values, where δ_1, δ_2, δ_3, δ_4, δ_5, δ_6 and δ_7 are expected to be <0

εi = random error term

RESULTS AND DISCUSSION

Production Function Analysis

The estimation results of the stochastic frontier in Table 1 depict the performance of both IPM and non-IPM at the existing technological level.

Table 1: Estimation results of Stochastic Frontier Production Function with Maximum Likelihood Estimation (MLE)

Input Type	IPM Farming		Non-IPM Farming	
	Coefficient	P > | z |	Coefficient	P > | z |
Stochastic frontier				
Constant	7,399	0,000	6,009	0,000
Land (X_1)	0,638	0,000***	0,058	0,244
Seed (X_2)	-0,029	0,717	0,264	0,023**
Organic Fertilizer (X_3)	0,058	0,529	0,022	0,293
Synthetic Fertilizer (X_4)	0,116	0,022*	0,157	0,000***
Natural Pesticide * Frequency (PSA*F)	0,092	0,160	-	-
Synthetic Pesticide * Frequency (PSS * F)	-0,089	0,480	-0,300	0,004***
Labor (TK)	-0,046	0,762	-0,148	0,170
Model Inefficiency				
Constant	0,001	0,000	1,014	0,000
Age	2,080	0,253	-0,002	0,466
Education	-1,410	0,013**	-0,026	0,015**
Farming_Experience	7,720	0,995	-0,009	0,580
Farmer_Group_Membership	0,001	0,148	0,135	0,158
Meeting_Frequency	4,290	0,696	-0,022	0,211
Healthy_Crop_Technique_Application	-6,620	0,993	-0,007	0,000***
Distance	-3,780	0,813	1,014	0,867

Description: Significance at the α = 10% level, α** = 5% level, α*** = 1% level.

The coefficients present in the production function, which represent the exponents of the Cobb-Douglas function, indicate the production elasticity of each input. The sum of these coefficients provides insight into the condition of return to scale. For IPM and non-IPM, the sum of coefficients for each input in the production function is 0.740 and 0.053. It is important to note that each sum of coefficients is less than 1, indicating that IPM and non-IPM practices in the study area operate under the condition of decreasing returns to scale. This suggests that increasing the proportion of input will result in a relatively smaller proportion of production. According to field observations, this condition of decreasing returns to scale is due to limited natural resources in the area. The irrigation system is inadequate, relying heavily on rainfall. In some locations, heavy rainfall can lead to flooding in rice fields, rendering the use of fertilizer inputs ineffective. These findings are consistent with Liu *et al*., (2018) study, where

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rice farming in the Yunnan Province of China experienced decreasing returns to scale due to environmental changes and resource limitations.

The land area as a production factor significantly affects rice production in IPM in the Kampar Subdistrict. This is indicated by the positive coefficient of the parameter, which is statistically significant at the $\alpha = 1\%$ level in a two-way test. The land area has an elasticity value of 0.638, meaning that a 1% rise results in a 0.638% increase in production. Generally, farmers in the Kampar Subdistrict have small land holdings, less than 0.5 hectares. The expansion of the cultivated land area can also affect rice production. This is consistent with Rahmat (2017), where the land area significantly affects rice production, and increasing the cultivated area has a positive effect on production.

The variable of synthetic fertilizer significantly affects both IPM and non-IPM in terms of rice production, with coefficient values of 0.116 and significance at the $\alpha = 10\%$ level in a two-way test. The positive coefficient implies that a 1% rise in the use of synthetic fertilizer can lead to a 0.116% increase in rice production, provided other factors are constant. For IPM, the use of synthetic fertilizer has a significant positive effect at the $\alpha = 1\%$ level in a two-way test. This finding is consistent with Rivanda *et al*. (2015), where NPK fertilizer positively affects rice production in the Telagasari Subdistrict of Karawang Regency, West Java. In addition, Arnanda *et al*. (2016) reported that KCL fertilizer positively affects production in the Kuala Kampar Subdistrict of Pelalawan Regency.

The variable of seed significantly affects rice production in non-IPM, with a significance value of $0.023 < 0.05$ at the $\alpha = 5\%$ level in a two-way test. The positive coefficient implies that a 1% rise in the use of seeds can lead to a 0.264% increase in rice production, provided other factors remain constant. The number of seeds used is directly proportional to the population of plants and rice production, assuming other production factors are sufficient.

Field observations show that the average use of seed inputs in non-IPM is 113.40 kg per hectare. The recommended seed requirement for planting 1 and 3-4 seedlings per planting hole is 15 kg and 25 kg. The high seed usage in the Kampar Subdistrict is due to the condition of the land and environment, and the use of certified seeds or local seeds repeatedly. The rice fields are rain-fed, thereby tend to be flooded during the rainy season, leading to problems with golden apple snail pests, while during the dry season, mole crickets pests become an issue. To tackle these field issues, farmers in the Kampar Subdistrict often sow more rice seeds than recommended. This practice allows for replanting in case of pest attacks from golden apple snails or mole crickets, specifically during the first 30 days of rice growth. Additionally, non-IPM farmers in the area typically rely on certified and locally adapted seeds that have been used repeatedly over time.

The seeds used by farmers include local superior varieties such as Suntiang, Anak Daro, Cantik Manis, Bujang Merantau, and Batang Piyaman. Furthermore, the certified seeds commonly used include Ciherang, Inpari 42, Inpari 48, and IR 42. The local seeds used are Kuriok, Jangguik, Lubuk Coku, Gudang, Padi Kuning, Suntiang Lola, and others. Certified seeds and superior local seeds usually have better germination rates. The certified seeds are labeled with

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blue color and are also known as **Extension Seeds (ES/BR)** or **"Benih Sebar."** These seeds are the result of four generations of seed selection and are directly marketed to consumers or farmers. They are suitable for planting once in a cropping season. According to Ruskandar (2015), the use of non-labeled seeds is high in Kampar Subdistrict, and limited shops in certain areas pose a challenge in the timely distribution of new superior varieties. In Kampar Subdistrict, farmers mostly use local superior and blue-labeled seeds that have been planted repeatedly. Blue-labeled rice seeds are designed for single use, meaning that their effectiveness is limited to one planting season. Consequently, the use of such seeds can lead to low production yields. In the Kampar Subdistrict, the use has a significant impact on rice production since the germination rate is typically low. Therefore, the number is seeds used is directly proportional to the likelihood of obtaining ready-to-plant seeds, which can ultimately lead to increased production.

In the Kampar Subdistrict, the interaction between synthetic pesticides and frequency has a significant impact on non-IPM production. This significance is evident with a p-value of 0.004, which is less than the predetermined level of significance α = 5% in the two-way test. The elasticity value of the interaction variable of synthetic pesticides with frequency is -0.300, indicating that a 1% increase in synthetic pesticide usage results in a 0.3% reduction in production. On average, non-IPM farmers in the area apply synthetic pesticides 4.2 times during the cultivation period, with an average usage of 1.78 liters per hectare. Farmers follow a scheduled application routine based on the different stages of plant growth. This practice is aimed at managing the emergence and proliferation of pests that can negatively impact production. It is worth noting that pesticides serve as protective inputs rather than directly contributing to productivity (Lichtenberg and Zilberman, 1986). The elasticity of production concerning pesticides depends on pest and rice variety resistance to pesticides and pests, respectively. In cases of heavy pest attacks, pesticides exhibit a positive elasticity, meaning that their application can have a beneficial impact on production. This differs from the explanation provided by Sumaryanto *et al*. (2003), where a decrease in output elasticity concerning pesticides signifies a severe attack. This explanation holds when pests develop resistance to pesticides, rendering their usage ineffective in controlling the infestation. Therefore, the effectiveness in combating pests may vary depending on the severity of the attack and the presence of pesticide resistance.

Technical Efficiency Analysis

The analysis results using the frontier production function model showed that the average level of technical efficiency achieved by IPM farmers is 0.80 (80%). Therefore, the IPM system in Kampar Subdistrict has been technically efficient and the average level achieved in non-IPM farmers is 0.69 (69%). Furthermore, the non-IPM system has been technically efficient. According to the opinion of Coelli *et al*. (1998), a farm is said to have been efficient when the efficiency is greater than or equal to 0.7.

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Table 2: Distribution of technical efficiency in IPM and Non-IPM farmers

Technical Efficiency Level	IPM farming		Non-IPM farming	
	Number of Farmers (People)	Percentage (%)	Number of Farmers (People)	Percentage (%)
<0.30	0	0	0	0
0.31-0.40	0	0	5	8
0.41-0.50	0	0	5	8
0.51-0.60	0	0	5	8
0.61-0.70	0	0	13	7
0.71-0.80	5	13.15	12	20.9
0.81-0.90	28	73.68	19	30.6
0.91-1.00	5	13.15	3	4.84
Total	38	100	62	100
Maximum	1		0.89	
Minimum	0.71		0.34	
Average	0.80		0.69	

After analyzing the distribution of achievement levels, the highest level of technical efficiency falls within the interval of 0.91-1.00, with 13.15% of IPM farmers achieving this level. This percentage is comparatively higher by 4.84% when compared to non-IPM farmers. In contrast, the proportion of technically efficient farmers among IPM and non-IPM practitioners is 100% and 56.34%, respectively. Therefore, it is evident that IPM practices exhibit greater technical efficiency than non-IPM. These findings align with previous study conducted by Nurani (2014), Gultom (2014), and Hutapea (2012), where the technical efficiency of rice cultivation is under IPM methods.

IPM farmers in the study area have allocated the use of inputs proportionally and the achievement of managerial skills is quite high. Meanwhile, the behavior in using inputs still varies from the use of seeds, fertilizers, or natural pesticides. In the use of seeds, IPM farmers use local superior seeds and are certified. They also employ pre-sowing treatments, such as soaking seeds in water treated with natural pesticides or salt water, as a preventive measure against pests. This practice results in reduced usage and the selection of high-quality seeds. The utilization of organic fertilizers and natural pesticides contains varying nutrient compositions and is applied at different frequencies, leading to variations in the level of technical efficiency attained.

Source of Technical Inefficiency of IPM and Non-IPM Farming

Education variables have a real effect on inefficiency, with a negative coefficient of -1.410 and -0.026 for IPM and non-IPM, indicating an inverse relationship. This is in line with a study conducted by Kusnadi *et al*. (2011), where highly educated farmers are more open to receiving information and technological changes that can increase or decrease efficiency. The level of formal education can affect knowledge, understanding, and wisdom in managing rice farming. Higher education corresponds to the openness of farmers, which contributes to their ability to adopt new information and technology in agricultural practices, specifically those related to rice. Therefore, several studies on different commodities also provide similar results, such as

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Tariq *et al*. (2018), Effendy *et al*. (2013), Banani *et al*. (2013), Gichimu *et al*. (2015), Amoah *et al*. (2014). Education is very important for farmers to improve their knowledge and ability to make decisions concerning technology implementation. According to the data, the majority of IPM farmers have attained junior high school (9 years) and high school (12 years) education levels, constituting 78% of the total. Conversely, the average education level of non-IPM farmers is lower, with 53% being either uneducated or have only completed elementary school (6 years). However, farmers can enhance their knowledge through informal education such as courses, and training programs, as well as by seeking out various print and electronic media.

Application of healthy plant cultivation on non-IPM farming significantly influenced at the level α = 1% with a coefficient of -0.007, indicating an inverse relationship between the variables. The healthy crop cultivation application level encompasses various practices, including the use of superior crop varieties, soil management techniques, timely seedling planting within 21 days, planting 1-3 stems per hole, providing organic matter, using the jajar legowo planting pattern, fertilization, irrigation, and weed control. The farmers also practice constant monitoring of crops, use of natural enemies, mechanical and physical control measures, use of vegetable pesticides, and judicious application of synthetic pesticides. The determination of the healthy plant cultivation application level is conducted by computing the percentage of practices implemented. Among non-IPM farmers, 38.2% have adopted these practices with an application level exceeding 50%.

CONCLUSIONS AND SUGGESTIONS

Conclusion

1. The average level of technical efficiency achieved by IPM and non-IPM farmers is 0.80 (80%) and 0.690 (69%). Therefore, IPM farmers in the study area allocate more proportional use of inputs and achieve fairly good managerial skills compared to non-IPM.
2. Land area and synthetic fertilizers have a positive effect on rice production in IPM farming, while in non-IPM, synthetic seeds and fertilizers have a positive effect. Furthermore, the interaction of synthetic pesticides with frequency has a negative effect on rice production.
3. Socio-economic factors that cause a source of technical inefficiency in IPM and non-IPM are the level of education. Meanwhile, the percentage of application of healthy crop cultivation affects non-IPM farming.

Suggestions

1) Increasing the efficiency of rice farmers in Kampar Subdistrict should be focused on improving skills and technical knowledge in rice farming to reduce the level of inefficiency.
2) The counseling material is more emphasized on how to implement healthy plant cultivation according to the location and application of IPM in controlling pests affecting production, efficiency, and environmental sustainability.
3) Efforts to promote the use of certified and local seeds should be made through extensive socialization campaigns, as well as the procurement of certified seeds by both the

government and private sectors. These measures aim to ensure that the community has easy access to high-quality seeds.

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