

Technical Efficiency of Siam Rice (*Oryza sativa* L.) and Betok Fish (*Anabas testudineus*) Farming in Banjar Regency, South Kalimantan Province, Indonesia

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ABSTRACT

Rice-fish farming has increasingly been promoted to improve the productivity and efficiency of rice cultivation. This study aimed to: (1) analyze the distribution of technical-efficiency scores in rice-fish and Siam rice farming; (2) identify factors affecting production and technical inefficiency; and (3) compare technical-efficiency levels between the two systems. The study was conducted in Abumbun Jaya Village, Sungai Tabuk District, Banjar Regency, using a descriptive quantitative design and Stochastic Frontier Analysis. Land area, family labor, rice-equivalent seed, and herbicide had significant positive effects on rice production, while urea fertilizer had a significant negative effect. Farmer age, farming experience, and the rice-fish technology dummy significantly affected technical inefficiency. The mean technical-efficiency score was 0.977 for rice-fish farming and 0.400 for Siam rice farming, and the difference between the two systems was statistically significant. These findings demonstrate that the integrated

cultivation system improved the technical performance of production-input use.

Keywords: *Rice-fish farming, Siam rice farming, stochastic frontier analysis, technical efficiency*

INTRODUCTION

Rice-fish farming (mina padi) is an integrated farming alternative developed to improve land-use efficiency and productivity by combining rice cultivation and fish culture in paddy fields. This approach has been shown to increase agricultural and fisheries yields, improve soil and water fertility, and suppress pests such as the brown planthopper. Rice-fish farming is therefore recognized as a technology that can make a positive contribution to rice farmers (Sauqie et al., 2017; Lantarsih, 2016).

Lestari and Bambang (2017) reported that rice-fish cultivation offers ecological, social, and economic benefits and produces better outcomes than monoculture farming. This finding is consistent with Lestari et al. (2019), who found that rice production under rice-fish farming in Sukoharjo

Regency was 8.1% higher than under rice monoculture. Farmers' total income also increased by 83.95% because of additional revenue from fish sales and higher rice output.

The Government of Indonesia, through the Ministry of Marine Affairs and Fisheries, has designated fish culture within rice-fish systems as a national priority program. The program was planned for implementation in six provinces covering nine regencies. Under Decree No. 156 of 2023 of the Head of the Agency for Marine and Fisheries Research and Human Resources concerning Smart Fisheries Village locations, Abumbun Jaya Village, Sungai Tabuk District, Banjar Regency, was selected as a pilot location.

A Smart Fisheries Village is a fisheries-based rural development concept that seeks to improve the local economy through information and communication technology and appropriate, sustainable business management. The selection of Abumbun Jaya Village as a pilot site encouraged local farmers to optimize rice-fish farming. Farmers act as the principal agribusiness operators and key actors in the program's success. Effective and efficient farm management is therefore essential for increasing production and improving farmers' income (Azizi & Riyanti, 2023).

Efficiency remains a common constraint in farming. Inefficiency may arise from excessive or insufficient production inputs, suboptimal labor management, declining land quality, weak production planning, and other factors. Nurhidayati et al. (2020) found that rice-fish farmers had not yet allocated inputs and production costs fully efficiently. Their average profit-efficiency score of 78.05% indicated a remaining potential profit improvement of 21.95%.

Firmana et al. (2017) similarly found that farmers' use of seed and fertilizer did not fully comply with technical recommendations, thereby preventing the achievement of technical efficiency.

Socioeconomic characteristics such as education, family size, and extension frequency also significantly influence technical inefficiency in rice farming (Kiron & Islam, 2023). These findings demonstrate the need for an integrated approach that addresses both technical and socioeconomic sources of inefficiency.

Accordingly, this study aimed to: (1) analyze the factors affecting rice production; (2) analyze the factors affecting technical inefficiency; and (3) compare the technical efficiency of rice-fish and Siam rice farming in Abumbun Jaya Village, Sungai Tabuk District, Banjar Regency.

MATERIALS & METHODS

Research Design, Location, and Population

This descriptive quantitative study was conducted in September 2026 in Abumbun Jaya Village, Sungai Tabuk District, Banjar Regency. The population consisted of all 30 rice farmers in the village: eight rice-fish farmers and 22 Siam rice farmers.

Population Stratification and Sampling

Each farming-system population was divided into three strata according to cultivated land area. The coefficient of variation (CV) calculated from preliminary secondary data was used as the classification basis because the population was heterogeneous and needed to be divided into relatively homogeneous groups (Sugiyono, 2013). Following Oktariani and Varania (2015), CV was used as an indicator of population variability.

1. $CV < 30\%$ indicates a homogeneous population.
2. $CV > 30\%$ indicates a heterogeneous population.

The calculated CV indicated a heterogeneous population. Table 1 presents the land-area strata used for each farming system.

Table 1. Population Strata by Farming System and Cultivated Land Area

Rice-Fish Stratum	Land Area (ha)	Siam Rice Stratum	Land Area (ha)
Stratum I	$0.05 < x \leq 0.50$	Stratum I	$0.01 < x \leq 0.50$
Stratum II	$0.51 < x \leq 0.75$	Stratum II	$0.51 < x \leq 1.00$
Stratum III	$x > 0.75$	Stratum III	$x > 1.00$

Source: Secondary data, processed (2026).

The sample size was determined using the Harry King nomogram at a 10% level. The resulting sample comprised all eight rice-fish farmers and 22 Siam rice farmers. Proportionate stratified random sampling was used because the population was heterogeneous and stratified (Sugiyono, 2013). The sample allocated to each stratum was calculated as follows:

$$n_h = (N_h / N) \times n$$

n_h = sample size in stratum h

n = total sample size

N_h = population size in stratum h

N = total population size

The proportional allocation based on land-area strata is presented in Table 2.

Table 2. Proportional Allocation of the Research Sample

Rice-Fish Stratum	Farmers (n)	Siam Rice Stratum	Farmers (n)
Stratum I	4	Stratum I	14
Stratum II	3	Stratum II	6
Stratum III	1	Stratum III	2
Total	8	Total	22

Source: Secondary data, processed (2026).

Data Collection and Stochastic Frontier Model

Primary data were collected through direct interviews with rice-fish and Siam rice farmers using structured questionnaires. Secondary data were obtained from relevant agencies. Technical efficiency was analyzed using Stochastic Frontier Analysis (SFA).

Rahmawati and Jamhari (2019) explained that SFA separates farmer-controlled internal inefficiency from random external disturbances such as weather, pest attacks, and environmental conditions. A Cobb-Douglas stochastic-frontier production function was transformed into a linear logarithmic form:

$$\ln Y = \ln \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + \beta_6 \ln X_6 + \beta_7 \ln X_7 + \beta_8 \ln X_8 + \beta_9 \ln X_9 + \beta_{10} \ln D + (v_i - u_i)$$

Y = rice-equivalent output (kg/growing season)

β_0 = constant

β_i = coefficient of the i th parameter

X_1 = land area (ha/growing season)

X_2 = family labor (person-days/growing season)

X_3 = hired labor (person-days/growing season)

X_4 = rice-equivalent seed (kg/growing season)

X_5 = Phonska fertilizer (kg/growing season)

X_6 = urea fertilizer (kg/growing season)

X_7 = TSP fertilizer (kg/growing season)

X_8 = insecticide (L/growing season)

X_9 = herbicide (L/growing season)

D = technology dummy: 0 = Siam rice; 1 = rice-fish farming

v_i = normally distributed random error associated with external factors

u_i = nonnegative random variable representing farmer-controlled technical inefficiency

Rice-fish farming produces two outputs, rice and fish, which must be converted to a common unit for SFA. Rice-equivalent output was calculated by adding primary rice output (kg) to secondary fish output (kg) multiplied by the fish price and divided

by the rice price (Rahmawati & Jamhari, 2019). The primary output was harvested dry grain, and the secondary output was market-size fish.

Technical Efficiency and Inefficiency Models

The stochastic-frontier production and technical-inefficiency functions were estimated simultaneously using Maximum Likelihood Estimation in Frontier 4.1. Technical efficiency was measured following Coelli et al. (1998):

$$TE_i = Y / Y^* = E(Y_i | U_i, X_i) / E(Y_i | U_i = 0, X_i) = E[\exp(-U_i) / \varepsilon_i]$$

TE_i = technical efficiency of the i th farmer

Y = actual production

Y^* = potential production obtained from the stochastic-frontier function

Technical-efficiency scores range from 0 to 1. A value approaching 1 indicates greater technical efficiency, whereas a value approaching 0 indicates technical inefficiency (Coelli et al., 1998).

3. Criterion 1: $TE_i = 1$ indicates that the farm is technically efficient.

4. Criterion 2: $TE_i < 1$ indicates that the farm has not achieved full technical efficiency.

The technical-inefficiency effect was assumed to be independently distributed as a nonnegative truncated-normal random variable (Coelli et al., 1998):

$$u_{it} = \delta_0 + z_{it}\delta + w_{it}$$

z_{it} = explanatory variables

δ = scalar parameter

w_{it} = random variable

The empirical inefficiency model for rice-fish and Siam rice farming was specified as:

$$u_i = \delta_0 + \delta_1 z_1 + \delta_2 z_2 + \delta_3 z_3 + \delta_4 D$$

u_i = technical-inefficiency effect

δ_0 = constant

δ_i = coefficient of the i th parameter

z_1 = farmer age (years)

z_2 = farming experience (years)

z_3 = number of household dependents (persons)

D = technology dummy: 0 = Siam rice; 1 = rice-fish farming

Comparison of Technical Efficiency

An independent-samples t-test was used to compare the technical-efficiency scores of rice-fish and Siam rice farmers. The test statistic was:

$$t = (\bar{x}_1 - \bar{x}_2) / \sqrt{\{[(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2] / (n_1 + n_2 - 2)\} \times (1/n_1 + 1/n_2)}$$

n_1 = number of sampled rice-fish farmers

n_2 = number of sampled Siam rice farmers

The hypotheses and decision rules were:

5. H_0 : There is no significant difference in technical efficiency between rice-fish and Siam rice farming.

6. H_1 : There is a significant difference in technical efficiency between rice-fish and Siam rice farming.

7. If Sig. (two-tailed) ≤ 0.05 , reject H_0 and accept H_1 .

8. If Sig. (two-tailed) > 0.05 , accept H_0 and reject H_1 .

RESULTS AND DISCUSSION

Distribution of Technical-Efficiency Scores

Technical-efficiency scores were classified to facilitate analysis and interpretation. Farms were categorized as highly efficient when $TE \geq 0.70$, moderately efficient when TE ranged from 0.40 to 0.69, and inefficient when $TE \leq 0.39$ (Adhiana et al., 2021). Table 3 presents the distribution of technical-efficiency scores for rice-fish and Siam rice farms in Abumbun Jaya Village.

Table 3. Distribution of Technical-Efficiency Scores by Farming System

TE Range	Category	Rice-Fish n	Rice-Fish %	Siam Rice n	Siam Rice %
≥ 0.70	Highly efficient	8	100	1	4.55
0.40-0.69	Moderately efficient	0	0	8	36.36
≤ 0.39	Inefficient	0	0	13	59.09
Total		8	100	22	100
Mean TE		0.977		0.400	
Maximum TE		0.981		0.886	
Minimum TE		0.971		0.258	

Source: Primary data, processed (2026).

Stochastic Frontier Analysis showed that all rice-fish farming respondents achieved efficiency scores above 0.70. Their mean technical-efficiency score was 0.977, with a maximum of 0.981 and a minimum of 0.971. This high level indicates that the farmers were able to allocate production inputs close to the stochastic frontier.

Rice-fish farming was more technically efficient than Siam rice farming. This advantage is consistent with Ma'Ruf et al. (2024), who found that polyculture was more beneficial than monoculture because it increased land productivity, diversified output, and reduced crop-failure risk. Ceunfin et al. (2017) explained that the productivity of polyculture depends on suitable crop combinations, planting arrangements, and mutualistic interactions. Nitrogen-fixing companion crops can support the nutrient needs of the main crop, while fish in rice fields contribute additional nitrogen through their waste and thereby strengthen input-use efficiency.

Syahputra et al. (2023) also supported the technical-efficiency advantage of polyculture by using a farming-system dummy to distinguish monoculture from polyculture. They obtained a negative elasticity of -0.31005 for the determinants of technical inefficiency, indicating that polyculture reduced inefficiency and significantly increased technical efficiency. This result has important implications for sustainable farming systems that integrate agriculture and fisheries within a single production system.

The mean technical-efficiency score was 0.977 for rice-fish farming but only 0.400

for Siam rice farming. The near-frontier score of rice-fish farms indicates that farmers used production inputs optimally. Integrating rice and betok fish culture therefore improved production performance and made rice-fish farming a more efficient alternative than the conventional Siam rice system, which displayed substantial resource-use inefficiency.

Factors Affecting Rice Production and Technical Inefficiency

Stochastic Frontier Analysis (SFA) estimates both the effect of inputs on output and the technical efficiency of each production unit. It evaluates how closely a farmer approaches the maximum theoretically attainable output, or production frontier. This is important because farm output depends not only on input quantities but also on how effectively farmers manage those inputs.

Unlike deterministic production models, SFA separates deviations from predicted output into two components: symmetric random error and one-sided technical inefficiency. This separation provides a methodological advantage because it permits more detailed identification of the sources of production inefficiency.

The Maximum Likelihood Estimation results in Table 4 show that land area (x_1), family labor (x_2), rice-equivalent seed (x_4), urea fertilizer (x_6), and herbicide (x_9) significantly affected rice production at the 1%, 5%, or 10% levels. Farmer age (z_1), farming experience (z_2), and the rice-fish technology dummy (z_4) significantly affected technical inefficiency.

Table 4. Maximum Likelihood Estimates of the Stochastic-Frontier and Inefficiency Models

Variable	Parameter	Coefficient	t-statistic	Significance
Production frontier constant	β_0	7.872	7.408	***
Land area	β_1	0.400	2.032	**
Family labor	β_2	0.122	2.124	**
Hired labor	β_3	0.006	0.502	ns
Rice-equivalent seed	β_4	0.847	9.419	***
Phonska fertilizer	β_5	-0.020	-0.206	ns
Urea fertilizer	β_6	-0.427	-2.757	***
TSP fertilizer	β_7	-0.002	-0.813	ns
Insecticide	β_8	-0.007	-1.375	ns
Herbicide	β_9	0.093	5.795	***
Inefficiency constant	δ_0	1.556	4.675	***
Farmer age	δ_1	-0.329	-2.975	***
Farming experience	δ_2	0.090	1.689	*
Household dependents	δ_3	-0.003	-0.071	ns
Rice-fish technology dummy	δ_4	-1.787	-6.204	***
Sigma-squared	σ^2	0.019	8.487	***
Gamma	γ	0.814	16.117	***
OLS log-likelihood			61.137	
MLE log-likelihood			77.956	
LR test of one-sided error			33.638	

*** Significant at 1%; ** significant at 5%; * significant at 10%; ns = not significant. Source: Primary data, processed (2026).

Production-Frontier Effects

Land area had a positive coefficient of 0.400 and was significant at the 5% level. Thus, a 1% increase in cultivated land was associated with a 0.400% increase in rice production. Larger farms provide greater capacity for planting and harvesting, provided that the additional area is managed appropriately and efficiently. This finding supports Andrias et al. (2018), who found that land area positively affected rice production and farm income in Jelat Village, Ciamis Regency.

Family labor had a positive coefficient of 0.122 and was significant at the 5% level, indicating that a 1% increase in family labor was associated with a 0.122% increase in rice production. Internal labor enables more intensive and continuous cultivation. Suratman (2015) found that family labor contributed an average of 27.86% to eggplant-farm income, although its use was not yet optimal. Replacing part of hired labor with family labor for land preparation and planting can reduce costs and improve productivity. Astuti et al. (2016) likewise emphasized that greater family-labor availability supports weeding, pest control,

irrigation, and harvesting while reducing hired-labor expenses.

Rice-equivalent seed had a positive coefficient of 0.847 and was significant at the 1% level. A 1% increase in seed use was therefore associated with a 0.847% increase in rice production. Adequate quantities of high-quality seed are essential for crop establishment and land productivity (Noer et al., 2018; Rahmawati & Jamhari, 2019; Adhiana et al., 2021). Excessive seed use should nevertheless be avoided because plant competition for water, light, and nutrients can reduce growth efficiency. Cynthia and Suryanto (2022) showed that fewer seedlings per planting hole combined with suitable spacing could improve production by reducing interplant competition.

Urea fertilizer had a negative coefficient of -0.427 and was significant at the 1% level, indicating that a 1% increase in urea use was associated with a 0.427% decrease in rice production. The negative coefficient suggests that application had exceeded the optimum threshold. The recommended rate cited by Sufriadi (2021) was 200 kg/ha per growing season, whereas mean use at the

study site reached 273.81 kg/ha for rice-fish farms and 275.44 kg/ha for Siam rice farms. Excessive fertilizer can reduce production and degrade soil quality over the long term; fertilizer inputs should therefore follow agronomic recommendations.

Herbicide had a positive coefficient of 0.093 and was significant at the 1% level. Its relatively low elasticity indicates a supporting rather than dominant role. Appropriate herbicide use reduces competition from weeds for nutrients, light, and water, but application must consider dose, timing, and active ingredient to limit costs and environmental residues. Baihaki et al. (2021) similarly stated that properly targeted pesticide use can increase agricultural output through effective pest and weed control.

Technical-Inefficiency Effects

Understanding technical inefficiency is necessary for identifying actions that can improve production and productivity. In this study, SFA separated farmer-controlled inefficiency from random disturbances that farmers could not control, such as weather, pest attacks, and other external shocks.

Farmer age had a negative and statistically significant coefficient at the 1% level, consistent with the expected sign. Increasing age was associated with lower technical inefficiency. Older farmers had accumulated agronomic and socioeconomic knowledge that supported decision-making, input management, adaptation, and avoidance of resource waste. This result is consistent with Ahdiningtyas et al. (2023), Rahmawati and Jamhari (2019), and Adhiana et al. (2021), who reported a negative relationship between farmer age and inefficiency.

Farming experience had a positive coefficient and was significant at the 10%

level, contrary to the expected negative sign. Longer experience did not automatically improve efficiency because experienced farmers may retain conventional practices and resist newer technologies. Barus et al. (2021) supported this interpretation, whereas Rahmawati and Jamhari (2019) and Adhiana et al. (2021) found that greater experience reduced inefficiency. The difference highlights the importance of local social context and farmer characteristics.

The rice-fish technology dummy had a negative coefficient and was significant at the 1% level, demonstrating that adoption of the integrated system reduced technical inefficiency. Rice-fish farming allows more efficient input management through beneficial ecological interactions among rice, fish, water, and soil (Nurhayati et al., 2016). Fish consume pests and weeds, improve soil aeration while foraging, and contribute organic nutrients through waste and uneaten feed. These mechanisms reduce competition for nutrients and light, improve soil fertility, support rice growth, and strengthen the environmental sustainability of the farming system (Sukri & Suwardi, 2016).

Comparison of Technical Efficiency

An independent-samples t-test was used to determine whether the mean technical-efficiency scores of the two farming systems differed significantly. Table 5 shows a two-tailed significance value of 0.000, which was below 0.05. The null hypothesis was rejected and the alternative hypothesis accepted, providing evidence of a significant difference in mean technical efficiency between rice-fish and Siam rice farming.

Table 5. Independent-Samples t-Test of Technical Efficiency

Variable	Sig. (two-tailed)	Significance Level (95%)
Technical-efficiency score	0.000	0.050

Source: Primary data, processed (2026).

The high technical efficiency of rice-fish farms was supported by the Ministry of

Marine Affairs and Fisheries through field extension officers and by universities

involved in community-service programs. The Smart Fisheries Village program, implemented in Abumbun Jaya Village since 2023, encouraged more efficient cultivation technology and farm management through technical assistance and research-based innovation.

Enterprise diversification also contributed to efficiency. Fish sales provided additional income that motivated farmers to manage land more intensively and could offset part of rice-production costs, as noted by the head of the Krido Yuwono fish-farmer group. The near-optimal efficiency of rice-fish farming therefore reflects the advantage of the integrated system over Siam rice monoculture.

The mean technical-efficiency score of only 0.400 for Siam rice farming indicates substantial room for improvement. Its low efficiency was associated with limited access to modern technology, information, and technical guidance. Strengthening extension services, access to innovation, and continuous training and mentoring could improve the efficiency of conventional farms.

CONCLUSION

Rice-fish farming in Abumbun Jaya Village integrates rice and fish culture on the same land and therefore provides fish income in addition to rice production, whereas Siam rice farming focuses only on rice. Land area, family labor, rice-equivalent seed, and herbicide had significant positive effects on rice production, while urea fertilizer had a significant negative effect. Farmer age, farming experience, and the rice-fish technology dummy significantly affected technical inefficiency. Overall, the two farming systems differed significantly in technical efficiency, demonstrating that the cultivation system influences how effectively production inputs are used.

Rice-fish farming represents a successful diversification model. Siam rice farmers should consider suitable diversification to increase total income. Government agencies and related institutions should promote

supporting technologies, including access to high-quality seed, fish-culture technology, and farm-management training. Future studies should examine a broader range of determinants and evaluate how farm diversification affects farmer welfare across wider geographic areas.

Declaration by Authors

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