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Technical Efficiency of Local Rice Farming in Tidal Swamp Areas of Central Kalimantan, Indonesia: Determinants and Implications

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ABSTRACT

Rice, as a staple food of Indonesia, is facing increasing demand while its availability stagnates due to the conversion of agricultural land in Java. This study explores a strategy to counteract this shortfall by accelerating rice production in non-Java tidal swamp areas. A key challenge in this context is to enhance the technical efficiency of local rice farming. Conducted in 2021 in the Kapuas and Pulang Pisau districts of Central Kalimantan province, Indonesia, this study aims to quantify the technical efficiency of local rice farming in these tidal swamp areas and identify factors contributing to its inefficiency. Empirical data were collected through surveys and focused group discussions, and subsequently analyzed using stochastic frontier production. The findings suggest that the average technical efficiency level is 0.58, albeit with variations across villages, ranging from 0.45 to 0.71. It was found that the size of landholding, the use of pesticides, labor, and harvesting tools have a significant positive impact on rice production. On the other hand, inefficiency is influenced by factors such as the number of household members aged 15 or above, education level, and the proportion of total household income derived from rice farming. These insights are valuable for policymakers and program planners aiming to improve the efficiency of rice farming in tidal swamp environments. It is recommended that government programs focus on the prerequisites for tidal farming, specifically water management infrastructures. Additionally, the application of location-specific technology may enhance the productivity of local rice varieties in tidal swamps.

1. INTRODUCTION

Rice, a staple food sustaining nearly 270 million people in Indonesia, plays a pivotal role in the nation's food security [1, 2]. With a rising population and income growth, the demand for rice is projected to escalate. Indonesia's food self-sufficiency policy, with a specific focus on rice, necessitates an increase in rice production. However, data from the past five years (2018-2022) reveals a decline in harvested rice area and production by 1.95% and 1.60% per year, respectively, despite a marginal productivity increase of 0.35% per year [3, 4].

The majority of rice in Indonesia is cultivated on irrigated (67.5%) or rainfed (27.5%) land, predominantly located on Java Island [5]. However, reliance on Java Island for rice production poses a risk due to a substantial conversion of agricultural fields for other purposes [6, 7]. Over 1994-2014, approximately 1.2 million hectares of rice fields on Java Island were transformed, equating to nearly 60 thousand hectares per year [8]. Coupled with the plateauing growth in rice field production [9-12], these factors pose a significant threat to the rice supply, underscoring the need for agricultural development outside Java.

Tidal swamp areas, despite currently contributing minimally to food production compared to their available land area, hold potential for bolstering food supplies [13]. Spread across 17 provinces, tidal swamp area encompasses 20.14 million hectares, with approximately 9.53 million hectares suitable for agriculture. However, only 5.27 million hectares are currently engaged in agricultural activities, including non-rice commodities [14]. The low productivity of these swamp areas can be attributed to land infertility, pest and disease threats, poor infrastructure, and their remote locations. Other factors contributing to underutilization encompass spatial development planning inaccuracies, low educational attainment of farmers, and inadequate working capital. Despite these challenges, the development of the swamp area as a food production center, or "food estate", is anticipated to bolster national food reserves [15].

Theoretically, two sources contribute to production growth:

the expansion of the harvested area and productivity [16]. Productivity growth can be further sub-divided into three categories: advancements in technology, increases in technical efficiency (TE), and economies of scale [17]. Enhancing TE is a crucial factor in stimulating productivity, and thus, studying TE is integral to evaluating farming efficiency and identifying methods to augment productivity, ultimately achieving optimal conditions. Numerous studies have been conducted on TE of rice farming and its determinants in various locations in Indonesia [18-23], Asia [24-31], and Africa [32-35], employing diverse approaches/methods.

Despite the abundance of studies on TE in rice farming, the focus has primarily been on irrigated and rainfed rice farms, while studies on tidal swamp areas remain limited. Similarly, studies have generally concentrated on improved rice varieties, whereas local ones are under-researched. This presents a notable gap, as comprehensive understanding of the TE in tidal swamp rice fields could substantially contribute to local rice availability and accessibility, stabilizing prices, and reducing logistics costs for rice distribution in remote areas. Investigating TE in tidal swamp areas, typically using local varieties, is complex due to factors such as water regime fluctuations, various physicochemical soil conditions, high soil acidity and organic acids, the presence of toxic substances, saltwater intrusion, low natural soil fertility, and the growth of harmful weeds. However, studying TE in local rice farming in tidal swamp areas also provides an intriguing opportunity to explore the role of local wisdom from social and institutional perspectives [36].

This study aims to evaluate the level of TE achieved by farmers in local rice farming in tidal swamp areas and analyze factors contributing to its inefficiency. Considering the complex biophysical conditions and challenges in tidal swamp areas, it is hypothesized that the TE level of local rice farming in these areas is low, indicating inefficiency, as will be discussed in this article. Furthermore, it is expected that farmers' socioeconomic factors, particularly landholding size, farm input use, age of the farmers, and application of machinery given the existing agricultural infrastructures, influence the inefficiency. The findings of this study will provide valuable insights for the government to formulate policies and regulations harnessing the potential of tidal swamp rice fields, with the aim of increasing rice production, farmers' welfare, and basing these on agroecosystem conditions and local culture.

This article is organized into four sections. Following the introduction (Chapter 1), the methodology is detailed (Chapter 2), succeeded by the presentation of results and the ensuing discussion (Chapter 3). The article culminates with the conclusions (Chapter 4), where policy implications and study limitations are explicitly laid out, followed by acknowledgments and references.

2. METHODOLOGY

2.1 Study site

Central Kalimantan province was chosen as the study area because, in that area, the government plans to develop a new food barn on suboptimal land, including swampland. In ten years, the total farm population in the Central Kalimantan Province has increased by 6.26% [37, 38]. According to Agriculture Census of 2013, farm households in the Kapuas district were 50,969, whereas in the Pulang Pisau district were 21,625. Furthermore, the tidal swamp area accounted for 26.4% in the Kapuas district and 48.1% in the Pulang Pisau district.

Many tidal swamps have not been utilized optimally in this province, especially in Pulang Pisau and Kapuas districts. Four villages were selected as study sites based on two main criteria: having the most expansive spatial area and having the most farmer group organizations. Of the four villages, one village is in Pulang Pisau district (Bahaur Tengah village, Kahayan Kuala subdistrict), while the other three are in the Kapuas district (Bandarraya village in Tamban Catur subdistrict, Sei Pitung village in West Kapuas subdistrict, and Mampai village in Kapuas Murung subdistrict) (Figure 1). Generally, the tidal swamp rice fields in the study areas are of type A overflow. This type of tidal swamp has the characteristic of overflowing at every high and low tide due to no effective embankment to control the inflow of water and drainage channels for disposal.

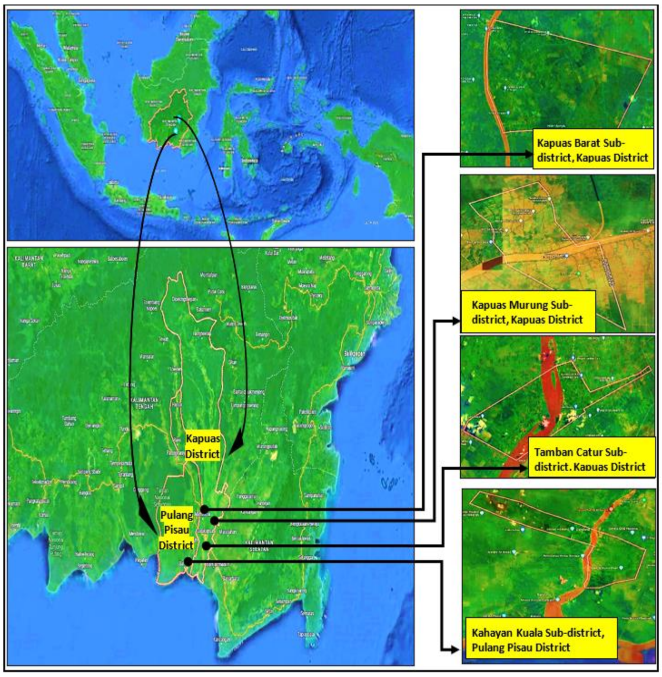

Figure 1. Map of the study areas

2.2 Data and data collection

Cross-sectional data were collected by surveying rice farmer households through face-to-face interviews using a structured questionnaire. Farmer respondents in this study were farmers who practiced local variety (Siam) rice farming with a rice-fallow cropping pattern (CI 100). This pattern was chosen in the hope that the information obtained could be used to increase the TE of rice farming and determine what factors caused farmer households to stick to CI 100. In each sample village, 35 farmers were randomly selected from the 2-3 farmer groups with the largest members. After validation, only data from 102 respondents were processed further.

In addition to collecting data through direct interviews with sample farmers, group discussions were also conducted with farmer groups, pest and disease control officers, and agricultural extension workers using a semi-structured questionnaire. Observations were also made at several locations to get an area overview. Data collection was carried out in 2021.

2.3 Method of analysis

Considering that one of the aims of this research is to identify the factors that influence inefficiency, the parametric approach was used in this study [39, 40], namely stochastic frontier analysis (SFA)-stochastic frontier production (SFP)-based on econometric tools. The advantage of parametric methods is that they permit the testing of hypotheses, such as those relating to the significance of included inputs and/or outputs, returns to scale, and so on [17]. Moreover, one of the essential characteristics of econometric models (SFA) is that it allows a specification for panel data and the construction of confidence intervals [41]. Several previous studies in various countries used SFA to assess the TE level of rice farming [19, 22, 25, 27, 28, 30, 32, 34, 42-44].

The stochastic frontier production model and the factors that influence inefficiency applied in this study are as follows:

$$ln\, y_i = ln\, \beta_0 + \sum_{k=1}^{6} \beta_k\, ln\, x_{ki} + \phi_1 D_{1i} + \phi_2 D_{2i} + v_i - u_i \quad (1)$$

where,

$v_i \sim N(0, \sigma_v^2)$ and $|u_i| = \delta_0 + \sum_{l=1}^{5} \delta_l\, z_{li}$;

y=rice production (kg);

x_1=cultivated area (hectare);

x_2=rice seed (kg);

x_3=fertilizer (N+P+K equivalent) (kg);

x_4=dolomite (kg);

x_5=labor (man-day equivalent);

x_6=pesticides (IDR 1000);

$D_1=\begin{cases} 0 \text{ if using machinery (mainly in land preparation)} \\ 1 \text{ if not using machinery} \end{cases}$;

$D_2=\begin{cases} 0 \text{ if using "ani-ani" for rice harvesting} \\ 1 \text{ if using sickle for rice harvesting} \end{cases}$;

z_1=household members aged≥15 years (person);

z_2=age of the household head (year);

z_3=education of the household head (years of schooling);

z_4=total landholding size, including non-rice farmland (hectare);

z_5=contribution of rice farming to total household income (%).

Three types of chemical fertilizer are combined into one variable due to the variability of dosage for the corresponding fertilizer. A dummy variable on the use of mechanization is used to capture variation in water deep and farm practices. On the factor determining inefficiency, we include total own land area because some farmers not only cultivate paddy land but also other types of land, which implies labor allocation across different land types.

Parameters of the SFP function and the corresponding factors that determine inefficiency are estimated simultaneously by a maximum likelihood estimation because they are more efficient and consistent. The Stata software version 15.1 is used to execute the estimation.

3. RESULTS AND DISCUSSION

3.1 Characteristics of the farmers in the study area

Respondent farmers are classified as old (48 years on average) and low in education (7.21 years of schooling). This condition is exceptionally influential on the speed of adoption of new technologies to increase farm productivity [45, 46]. Farmers' land ownership is 1.12 hectares per household (Table 1), which is quite large compared to the average cultivated rice field area in Indonesia, which is 0.46 hectares per household [47]. However, although the landholding size is quite large (1.82 hectares per household), the tidal swamp rice field is classified as marginal (suboptimal) land, implying low rice productivity [48].

Table 1. Descriptive statistics of the variables related to the characteristics of respondents

Variable	Obs	Mean	Std. dev.	Min	Max
Age of the household head (year)	102	48.30	10.50	28.00	70.00
Formal education level (year)	102	7.21	2.76	0.00	16.00
Number of household members aged≥15 years (person)	102	2.56	0.99	1.00	6.00
Land ownership size (ha)	102	1.12	0.57	0.20	2.80
Landholding size (ha)	102	1.82	0.91	0.28	5.50
Contribution of rice farming to total household income (%)	102	51.55	21.83	6.00	100.00

Rice farming, in general, is not the only source of household income. Most farmers in the study sites prioritize rice production to fulfill their families' consumption (subsistence). This is revealed by the proportion of farm income to total cash income, which is only 51.55%, ranging from 6% to 100%. This result is in line with a previous study showing that local rice varieties are only able to meet household consumption [49]. Hence, farmers rely on other sources of income to meet their family needs.

The wider the cultivated land, the lower the farmers' subsistence level. Efforts to reduce the subsistence level of rice farming are, among others, influenced by education and training, prices, and access to rice markets. Market-oriented farmers tend to produce higher rice yields than subsistence farmers [50].

3.2 Local rice farming in the study area

Swamp rice farming faces more severe challenges than irrigated rice fields. These include iron toxicity, salinity, acidity, flooding, and socio-economic, cultural, and infrastructural constraints [51]. The specific characteristics of swampland are the very acidic soil and the risk for iron toxicity and waterlogging, causing only the local variety to survive. This local rice variety is resistant to high iron concentrations [52].

In cultivating tidal swamp land local rice, from seeding to harvest, farmers apply local wisdom passed down from one generation to another [53, 54]. It is formed as a process of adaptation to biophysical ecosystems and social systems they have experienced for centuries [55]. This follows the concept of geographical determinism, which considers geographical conditions as the determining factor in society development [56], including its culture.

Farmers are forced to grow local rice (Siam) using traditional techniques because they cultivate marginal land (acid, pyrite, and submerged in water). A distinctive aspect is using a small quantity of seed (average 13.33kg/ha; Table 2), not certified as it was sourced solely from the previous harvest. In this case, the knowledge and information received by the farmers about seeds determines the farmers' preferences in each region [57].

Table 2. Descriptive statistics of the variables related to the characteristics of local rice farming

Variable	Obs	Mean	Std. dev.	Min	Max
Seed (kg)	102	13.33	8.04	2.50	50.00
N+P+K fertilizer (kg)	102	93.74	65.42	2.30	308.00
Dolomite (kg)	102	199.51	249.01	0.00	1,400.00
Pesticides (Rp000)	102	780.43	670.06	0.00	3,072.50
Labor (man-day)	102	114.86	51.11	12.46	278.33
Production (kg)	102	2,114.75	1,508.75	100.00	8,900.00

Local rice has a long maturity period, around 9-10 months from the time the seeds are sown to harvest. Farmers follow a three-stage seeding system (tugal-ampak-lacak), which takes 4-5 months before planting in the rice field. These steps are carried out so that the stems of the rice plants become tall and strong enough to be planted in a deep water level of rice fields. Planting occurs in March-April, and harvesting in August-September. Due to its long duration, most respondents only grow rice once a year during the dry season (banih rintak), and only a small proportion of land could be planted twice (banih surung and banih rintak). This is a typical cropping pattern in the swampy rice fields in South and Central Kalimantan [49].

Farmers plant various local varieties, including Siam, Bayar, Pandak, and Lemo. The Siam variety has several variations, including Siam Mutiara, Siam Saba, Siam Adil, Siam Palut, and Siam Unus. Likewise, there are variations for the Bayar variety, including Bayar Putih, Bayar Kuning, and Bayar Melintang [54]. Each type has its own characteristics, which are generally related to the strength of plant stems, tolerance to unfavorable climatic stress and iron toxicity, and the content of Fe and Zn in rice grain [58].

Farmers prefer local rice varieties because of their adaptability to acidic swampy lands, low cost of cultivation, preferred taste, higher selling price, and ease of marketing compared to improved varieties. However, the drawbacks are the long duration so that it can only be planted once a year with relatively low productivity (2-3 tons/ha). Over the past two decades, the government has released 35 rice varieties adaptive to the swampy environment [51]. These exceptional adaptability varieties have the potential for higher yields and shorter planting time, making them suitable options to substitute local varieties in tidal swamp lands areas [59, 60]. Unfortunately, those varieties have low adoption rates. Most farmers in the region prefer to cultivate local varieties that better suit their needs and plans, enabling them to save costs and devote more time to other tasks. Therefore, the most adaptive approach is to optimize local rice farming [61]. Cultivating local rice varieties does not require strict working hours, so farmers can use their spare time to seek another source of income. In addition, although the potential yield of local rice may be lower, the production value due to the relatively higher price is still the same as superior varieties.

Farmers use fertilizers with an average quantity of 93.74kg per ha, which is the accumulation of Urea, SP36, NPK, and others (Table 2). Farmers use dolomite to raise the pH value of the acidic land. However, the use of dolomite is still far below the recommended technology (an average of 199.51kg per ha), and many farmers do not even apply it. The tidal swamp rice fields in the study sites are acid-sulfate, requiring more dolomite. Akhmad et al. [62] found that combining 3 tons per ha of dolomite and 120kg per ha of NPK fertilizer yielded the most promising results in enhancing rice production in newly opened acidic sulfate tidal swamps.

Farmers use a lot of pesticides, including herbicides, insecticides, fungicides, and rodenticides, which burdens farming costs. The total cost of these pesticides averaged IDR 780,430 thousand, with the highest value being IDR 3,072 million per hectare (Table 2). However, some farmers did not use chemical pesticides at all despite the result being deficient production.

Rice cultivation by farmers is classified as minimalist, where the total use of labor from land preparation to harvest is only 114.86 man-days (Table 2). Most of the workforce is employed for planting and harvesting activities. Farmers maximize the use of family labor to offset the high labor cost, especially for land preparation and planting. Farmers rely on family labor to reduce cash costs, although it takes longer to use traditional tools in cultivation. Land preparation with tajak, harvesting using ani-ani, and threshing using trampling require a longer application time and a lot of labor [55]. Tajak is a straight-stemmed hoe for working rice fields, whereas ani-ani is a traditional harvesting tool.

In addition to low production, the grain quality is also poor. Local rice has unequal maturity characteristics, so the yield is not uniform; many are green and break easily when milled. Another cause of non-uniformity is the uneven surface of rice fields, some inundated and some drier. This lack of synchronism also causes farmers to use ani-ani, not a combine harvester. Harvesting activities take a long time because they are conducted manually one by one. Moreover, some farmers also have to use boats due to deep water.

Limited application of technology and low production yields are common conditions in tidal swamplands in Indonesia. This is particularly because of the high soil acidity and poor irrigation infrastructure. Production diversity is found both between rice fields and between planting seasons. Most rice fields are around the river. Specifically, Bahaur Tengah village is located at the mouth of the Kahayan River, not far from the sea.

Transportation facilities and infrastructure are very limited, which causes higher input costs. Generally, farmers use their own capital for farming costs because it is not easy to access bank loans. A previous empirical study conducted by Anang et al. [63] found that access to credit positively affects TE. The easier it is for farmers to access credit sources, the higher the TE of agricultural businesses. Furthermore, study results in the Philippines, Pakistan, and Bangladesh show that access to credit plays a role in increasing farming efficiency, leading to increased farmers' income [64]. However, in the study areas, rice production is primarily to meet household consumption (subsistence). Hence, farmers do not seek credit to increase business scale. Conversely, financial institutions are reluctant to disburse credit due to high repayment risk.

The use of agricultural machinery is still limited except in some parts of the Tamban Catur subdistrict, where land is fertile and irrigation infrastructure is good. Hence, farmers can plant rice twice a year. On the other hand, farmers in the Kahayan Kuala, West Kapuas, and Kapuas Murung subdistricts still use tajak for land preparation. Banjarese farmers have effectively managed the swamp soil layers through their local knowledge by avoiding excessive tillage, ensuring safety for rice plant growth. Using tajak in land preparation can prevent the exposure of the pyrite layer that can lead to increased soil acidity [65]. Farmers also do not use transplanters to plant rice because the size of the local Siam rice seedlings is not suitable (too high). In addition, some rice fields are difficult for transplanters to enter because of deep mud and the ineffective water level control in the areas.

Table 3. Feasibility analysis of local rice farming in the study sites

No.	Description	Value
1.	Total costs (IDR/ha)	9,117,984
	- Production input costs (IDR/ha)	1,620,780
	- Labor costs (IDR/ha)[1]	6,782,528
	- Other costs (IDR/ha)	714,676
2	Revenue (IDR/ha)	10,912,339
	- Production (kg GKG/ha)[2]	1,787
	- Price (IDR/kg GKG)[2]	6,108
3.	Profit	1,794,354
4.	R/C ratio	1.20

Note: [1] Excluding family labor; [2] GKG=dry unhusked grain

Although the rice productivity is only 1,787kg/ha (Table 3), the yield is enough to meet the family's needs for a year, considering the average landholding size of 1.82 ha (Table 1). Based on the cash costs incurred, in this case, without assessing the outpouring of working hours in the family, local rice farming on tidal swampland provides profit with an R/C ratio of 1.20 (Table 3). However, if family labor is considered, the result will be a loss with an R/C ratio of 0.64. In this case, local rice farming mainly supports farmer households' food security [66].

In very acidic conditions, production inputs such as seeds, fertilizers, and dolomite are far below the standards used in irrigated rice fields. Optimizing water management is essential for the effective and efficient use of adaptive crop varieties suitable for tidal swampland [67].

3.3 Factors affecting frontier production and inefficiency

3.3.1 Production frontier and inefficiency estimate

Table 4 shows that the significant factors affecting local rice production were landholding size, pesticides, labor, and dummy variable of harvesting method. Meanwhile, seeds, fertilizers, and the use of machinery in land preparation are not significant.

Landholding size has a positive and highly significant effect (α=0.01) on rice production. The elasticity value of the landholding size is relatively large, namely 0.743. This result implies that an increase in landholding size by 1% would increase the rice yield by 0.74% (ceteris paribus). This finding aligns with previous studies on this subject [68, 69] conducted in swampland ecosystems in South Kalimantan, Indonesia and the Mekong Delta in Vietnam.

The use of seeds, fertilizers, and dolomite at the study sites did not statistically significantly affect rice production. The use of the three production factors is ineffective in stagnated water conditions. The effect of seeds is negative, meaning that the more seeds are added, the more production decreases. Farmers prepare large quantities to anticipate the seeds being washed away and eaten by rats when the seeds are moved from the nursery to the rice fields. As a result, the number of rice seedlings per clump often becomes excessive, which makes the growth of the seedlings not optimal. Therefore, efforts to add seeds by farmers are ineffective. Decreasing the number of seeds used while enhancing their quality is necessary to achieve better results. This finding contrasts with previous studies on TE of irrigated rice using improved varieties, that the application of chemical fertilizers significantly affects rice yield [70, 71]. The distinction is due to differences in soil biophysical characteristics.

Table 4. Parameter estimates of the stochastic production frontier

	Coef.	Std. err.	P>z
ln production			
ln landholding size	0.743	0.160	0.000
ln seed	-0.142	0.138	0.306
ln fertilizers (N+P+K equivalent)	-0.057	0.088	0.515
ln dolomite	-0.007	0.008	0.364
ln pesticides (kg rice grain equivalent)	0.087	0.022	0.000
ln labor (man-day)	0.348	0.138	0.011
Dummy var mechanization in land preparation (0=no, 1=yes)	-0.053	0.113	0.643
Dummy var of harvesting tools used (0="ani-ani", 1=sickle)	0.336	0.122	0.006
_cons	6.332	0.784	0.000
lnsig2v			
_cons	-2.646	0.509	0.000
lnsig2u			
Household members aged≥15 years old	-0.355	0.180	0.049
Age of the household head	-0.019	0.016	0.221
Education level of the household head	-0.148	0.065	0.024
Total landholding size, including non-rice field	-0.012	0.212	0.956
Contribution of rice farming to total household income	-1.958	0.915	0.032
_cons	3.466	1.223	0.005
sigma_v	0.266	0.068	

Local rice varieties are not responsive to the use of fertilizers and dolomite. This condition is caused by two factors [72, 73]. First, genetic factors, that is, local varieties are relatively adaptive to the environment, so they are less responsive to fertilization and dolomite application. Second, environmental factors, that is, applying fertilizer in stagnated water, makes the fertilizer dissolve into water. It is carried away by the water when it recedes, leaving less fertilizer bound by soil and absorbed by the plants. The existence of waterlogging for a long time causes a reduction of various ions in the soil and an increase in soil pH. In this case, the application of dolomite is ineffective. Therefore, water management is a top priority in rice cultivation in the swamplands because almost all components of rice cultivation require adjusting the water level for optimal results [74, 75].

Different results are obtained by previous studies in South Kalimantan on tidal swamps with overflow types B and C, which show that seeds and fertilizers had a significant effect on rice production [68]. Due to the poor characteristics of overflow types B and C (soil and water), seeds and fertilizers have a significant impact compared to type A overflow. According to Sulakhudin and Hatta [76], the productivity of newly opened rice fields in tidal swampland could be increased by implementing good water management and applying ameliorants such as dolomite and organic matter. Unfortunately, the application of fertilizer, dolomite, and seed on type A swampland is ineffective due to deep waterlogging and less acidic soil caused by smooth tidal movements.

Pesticides, including herbicides, insecticides, fungicides, and rodenticides, have a positive and statistically significant effect (α=0.01). This result implies that an increase in the dose of pesticides (kg rice grain equivalent) by 1% will increase rice yield by 0.09%, ceteris paribus. The tidal swamp rice fields, being highly exposed and some being adjacent to uncultivated lands, have a vulnerable condition that leads to a high frequency of pest and disease attacks. Additionally, since the planting season occurs only once a year, there is a significant fallow period during which weed growth can become quite aggressive. The use of herbicides suppresses weed growth and avoids competition for nutrient use between weeds and rice plants, providing opportunities for rice plants to grow well and produce higher yields. Pesticides are generally used to control insects such as rice ear bugs and stem borers, as well as blast and tungro diseases. Thus, the increase in the cost of herbicides and pesticides indirectly causes production to increase. This aligns with the findings of the previous TE study on tidal swamp rice farming in South Kalimantan [68].

Labor has a positive and significant effect (α=0.01) on rice production.This shows that land preparation, planting, and harvesting of rice require a considerable amount of labor. Land preparation using a tajak, a traditional tillage tool, takes quite a long time and is, therefore, carried out by family labor due to high wages. Tidal swamp rice fields are generally flooded with relatively deep water, so the soil becomes muddy. Cultivating this type of soil using a tractor is difficult because the depth of the mud or peat layers hampers its movement. Given the limited labor and high wage conditions, agricultural mechanization becomes a dilemma. This finding aligns with the previous study conducted in locations with similar characteristics [68].

Although showing a positive correlation, the dummy variable for agricultural mechanization lacks of statistical significance. This can be attributed to the ineffective utilization of mechanization for land preparation in tidal swamp rice fields. The subsidence time, caused by the deep water conditions and muddy soil, is longer than the tractor's working time.

The method of harvesting significantly affects grain production (α=0.01). Farmers in some areas use different methods to harvest rice: an ani-ani or a sickle. When rice harvest is simultaneous, farmers can use a sickle for harvesting. Otherwise, they use an ani-ani. These two methods differ due to varying water depths and muddy soil conditions in the rice fields. When using traditional methods, the uneven and gradual harvest increases the chances of birds attacking and rice plants submerging in water, causing scattered and puso grain. Consequently, overall production decreases.

3.3.2 Factors affecting inefficiency

Table 4 shows that the number of household members aged≥15 years, the education level of the household head, and the share of income from rice farming significantly affect the inefficiency of local rice farming. This finding aligns with a previous study [77], which demonstrates that educational attainment and household size affect the TE of rice farming in the swamplands of the Ciamis district, West Java province.

Household members aged 15 years and over negatively and significantly affect inefficiency. The more household members aged 15 years and over, the more efficient rice farming is. Household members are involved in land preparation, planting, and harvesting activities to finish on time. The inaccuracy of working time can negatively impact the growth of rice plants, affecting both their vegetative and generative stages. This is due to the unsuitability of the depth of waterlogging and the duration of sunlight exposure. This influence also impacts harvest time, which can cause grain ready to be harvested to be submerged in water. Many farmers experience this condition, especially those who do not have cash to pay labor wages, causing the planting schedule to be delayed. However, this finding contrasts with previous studies on rice farming in irrigated rice fields, stating that farms with fewer household members involved in farming tend to be more efficient than those with more members working [34, 71]. This is because agricultural mechanization is more available and easily applicable in irrigated areas than in tidal swamp areas.

Education level has a negative and significant effect on inefficiency (α=0.05). The higher the education level of the head of the household, the more efficient farming is. These results align with previous studies [68, 78]. The education level influences the right decisions in managing rice farming through the introduction and/or modification of technological innovations that are adapted to local natural and cultural conditions, such as the use of seeds, agricultural mechanization, and rice cultivation. The education level of farmers is one of the crucial factors affecting the allocation of inputs during the production process [79]. Therefore, for efficient use of available resources, it is recommended that the government provide farmers with formal and informal education, along with appropriate training in rice farming practices. Likewise, Cao et al. [69] found that farmers taking multiple technical training classes achieved higher technical efficiency. Further research could consider variables related to informal education, such as participation in training programs. Another factor to consider is risks, measured by the degree of production variability, and distinguishing study sites based on overflow types A, B, and C.

The contribution of rice farming to total household income has a negative and significant effect (α=0.05). The higher the contribution of income from farming to the total income of the farmer's household, the more efficient rice farming is. This significant contribution may be because it is difficult for farmers to access businesses other than rice farming, so farmers are getting more serious about doing their rice farming. This seriousness encourages increased farming efficiency. This finding is supported by some previous studies [71, 80].

3.3.3 Distribution of TE rating

Table 5. Sample distribution according to TE rating

TE rating	Sample		TE		
	N	%	Mean	Min	Max
TE≤0.4	22	21.6	0.27	0.08	0.37
0.4<TE≤0.5	14	13.7	0.45	0.40	0.49
0.5<TE≤0.6	12	11.8	0.57	0.51	0.59
0.6<TE≤0.7	18	17.7	0.65	0.60	0.70
0.7<TE≤0.8	18	17.7	0.75	0.71	0.80
0.8<TE≤0.9	16	15.7	0.84	0.80	0.88
TE>0.9	2	2.0	0.91	0.90	0.91
Total	102	100.0	0.58	0.08	0.91

The average level of technical efficiency achieved by local rice farmers in the study areas is approximately 0.58 (Table 5). This TE value is much lower than those of improved (high-yielding variety) rice farming in technically irrigated rice fields, which generally demonstrate relatively high TE values, ranging from 0.80 to 0.96 [18, 43, 69, 71, 81, 82]. This high level of TE is attained because irrigation conditions and pest and disease attacks in technically irrigated rice fields are easier to control. Moreover, extension activities are more actively conducted in irrigated rice farming. As a result, farmers can enhance their rice farming capability by embracing modern agricultural technologies [46]. Haryanto et al. [83] showed that irrigation positively and significantly affects the TE level of rice farming. The TE level is also lower than that of rice farming on swampland in Ciamis district, West Java province, as much as 0.78 [77], due to the use of improved rice varieties.

The TE values of local rice farming in the study locations exhibit a wide range of diversity, varying from 0.08 to 0.91. Only 17.65% of the farmers have relatively high TE values (>0.8), which suggests that their rice farming is relatively efficient. On the other hand, the remaining farmers (64.71%) exhibit relatively low TE values, indicating inefficiency. This finding aligns with a study on local rice farming in tidal swampland in Barito Kuala district, South Kalimantan [13], which revealed that only 6.67% of the local rice farming practices are categorized as efficient. Similarly, another study demonstrated that most (52.69%) rice farming practices in the tidal swampland of South Sumatra are not efficient [84]. Meanwhile, a wide range of TE level diversity is also demonstrated by a study in Bangladesh, which shows TE values ranging from 0.16 to 0.94 [63] and in Ghana, ranging from 0.11 to 0.98 [32].

This study has shown that there is room for improvement in the efficiency of rice farming at the study site based on the various TE values obtained. The results indicate that 17.65% of respondents have a relatively high TE (>0.8), which can be used by extension officers to identify areas of cultivation that farmers can improve on to increase efficiency.

3.3.4 Variation of TE rating inter-village

The variation in TE values between villages at the study sites was quite considerable (Table 6). Bahaur Tengah village has the highest average TE value (0.71) with a relatively small standard deviation (0.14) compared to other villages. Meanwhile, Sei Pitung village has the lowest TE value (0.45) and the largest standard deviation (0.22). In addition to variations between villages, variations between farmers within one village are also relatively high, especially in Sei Pitung village, with a minimum TE value of 0.08 and a maximum of 0.84. This means that the diversity within one village is very high. The same thing happens in all villages.

The mean, standard deviation, and minimum-maximum values in Bahaur Tengah village are relatively better than in other villages. Compared to other study locations, Bahaur Tengah village is closest to the beach, so the overflow of sea and river water during high tide is very high. During low tide, the water runs out so that acidity washing becomes perfect and soil pH conditions are relatively neutral. Under these conditions, the amount of fertilizers (urea and NPK) and dolomite used is relatively small. Moreover, the rice variety used is Siam Karukut, a local rice variety that is relatively pest-resistant and has sturdy stems. It also needs a relatively small amount of seed, between 5-15kg/ha. Under these conditions, rice production reaches 2.0-3.8 tons of GKP (dry harvested grain) or 1.5-2.5 tons of GKG (dry ready-to-mill grain) per hectare. This relatively low use of inputs led to a higher TE value in Bahaur Tengah village than in other villages.

The high variation of TE values in Sei Pitung village is, among others, because a small portion of the farmers' rice fields is in the tidal type B category. A canal borders the rice fields on one side and a Galam forest on the other. There is no dike/bund on the boundary between the rice fields and the Galam forest, so water from the Galam forest can seep into the rice fields. Under these conditions, when the tide recedes, water from the expanse of the acidic Galam forest enters the rice fields, causing them to become relatively acidic. This finding is confirmed by the actual productivity and frontier limits presented in Table 6.

Table 6. Yield and efficiency

Village	Obs	Yield (kg/ha)	Frontier	eff2	Sd(eff2)
Bandar Raya	32	2,367.67	3,451.36	0.66	.1629844
Mampai	22	1,537.30	3,570.95	0.46	.1949829
Bahaur Tengah	24	2,757.75	3,505.03	0.71	.1449155
Sei Pitung	24	977.64	2,383.40	0.45	.2195307
Total	102			0.58	.2124996

The actual yield is low in Sei Pitung village (0.977 tons/ha). Likewise, the frontier is still low (2.38 tons/ha). On the other hand, in Bahaur Tengah village, the yield and frontier are already high. This TE and yield performance informs that the water system in tidal lowland rice fields determines the soil acidity (pH) level, which impacts productivity. Efforts to increase Siam local rice productivity at least require water management, both in the form of canals, embankments, shipyards, and floodgates. This is because water regimes, including river or tidal sea overflows and floods from upstream areas, significantly impact wetlands [85]. Therefore, water management is crucial in developing agriculture in tidal swampland, especially rice [86, 87]. Increasing rice productivity can also be done by applying appropriate technology specific to tidal swamp lands. In addition, within certain limits, the increasing business scale can increase rice productivity by achieving economies of scale.

4. CONCLUSIONS

As expected, the study results show that the TE level of local rice farming in the study locations (food estate area) is still low (inefficient), with an average value of 0.58. This figure is much lower than the average TE of improved rice farming in technically irrigated rice fields, even rainfed rice fields. The natural and biophysical conditions of tidal land that are characterized by fluctuations in the water regime, soil physicochemical conditions, soil acidity and organic acids, low fertility, weed growth, and toxic substances are the causes of low rice productivity. The use of relatively minimal input also contributes to low productivity.

Landholding size, pesticides, labor, and harvesting tools used positively and significantly affect rice production on tidal swamp rice fields. At the same time, the number of household members aged ≥15 years, the education level of the household head, and the share of income from rice farming significantly affect the inefficiency of local rice farming in the study areas.

There are two methods to consider to improve the cultivation of tidal swamp rice fields. They are firstly, adapting agricultural mechanization to fit the unique agroecological conditions of the area and secondly, constructing irrigation canal infrastructure, such as canal repairs, embankments, or water gates, to regulate water flow. These adjustments can enhance the farming process significantly.

The limited number of household members aged 15 years and over in rice farming can reduce the efficiency of rice production. The involvement of farmers with a higher level of education encourages the use of agricultural mechanization. This will, to some extent, overcome labor constraints, increase the use of quality seeds, and ability of rice cultivation techniques suitable for the agroecosystem of tidal swamp rice fields. It is expected that this can further encourage increased production efficiency.

Increasing landholding size can encourage agricultural mechanization and rice cultivation technology, leading to increased farming efficiency. The use of seed and fertilizer inputs in tidal swamp areas with overflow type A did not have a significant effect. Based on this, the site is more suitable for extensification efforts through area expansion, the introduction of selective agricultural mechanization, and the use of superior local variety seeds (short duration, preferred by consumers, expensive, and resistant to the acidity of tidal swamps).

Based on the fact that rice farming in the study sites shows low productivity and low technical efficiency, the government's strategy to develop rice food estate in the area does not seem to be a viable strategic option. Rice farming in the area should be limited to meet farm household needs. A more justified strategy to improve household livelihood security is promoting high-value commodities adaptive to local conditions and providing higher income.

This research contributes to a better understanding of the characteristics of rice farming in a tidal swamp environment, which is somewhat neglected compared to rice farming in favorable environments, such as irrigated rice areas. Enrichment of knowledge on this subject is critically important in formulating evidence-based policies and programs related to national and local rice production.

This study has some limitations, such as not including community culture variables, which are expected to correlate with the cultivation of local rice varieties, nor rice consumption patterns in the community, which can affect productivity. Moreover, this study is also limited to analyzing technical efficiency. For future studies, it is suggested to conduct a study on allocative efficiency to obtain more comprehensive information on the economic efficiency of local rice farming.

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NOMENCLATURE

CI	cropping index
Fe	iron
GKG	dry unhusked grain
GKP	dry harvested grain
IDR	Indonesian rupiah
NPK	nitrogen, phosphorus, and potassium
pH	logarithmic measure of the hydrogen ion concentration of an aqueous solution
R/C ratio	revenue-cost ratio
SFA	stochastic frontier analysis
SFP	stochastic frontier production
TE	technical efficiency
Zn	zinc