CHEMICAL ENGINEERING TRANSACTIONS
VOL. 106, 2023

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Peck Loo Kiew, Hon Huin Chin

ISBN 979-12-81206-05-2; **ISSN** 2283-9216

DOI: 10.3303/CET23106058

Technical Efficiency of Sustainable and Conventional Rice Farming: Evidence from the Mekong Delta of Vietnam

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Rice is the most important crop in Vietnam's agriculture sector for its contribution to economic stability and food security. Improving the efficiency of rice farming and expanding production towards sustainability has become one of the national economic development goals. This study aimed to empirically evaluate technical efficiency of rice farms based on their farming practices using observational data from face-to-face interviews with 152 rice farm households in Long An Province in the Mekong Delta, Vietnam. The data envelopment analysis model was applied to evaluate the technical and scale efficiencies. Results show that except for farmers applying one practice, the average technical efficiency exceeded 81 %. Farmers who adopted more sustainable practices obtained higher technical efficiency and scale efficiency with scores of 90 % and 91 % respectively. Many farmers with different combinations of farming practices operated under increasing returns to scale. The Tobit model was also applied to estimate the determinant factors of technical efficiency. The results of the Tobit model revealed that the farmer's education level and farming experience had a significant impact on rice farming efficiency. The study also found an inverted U-shaped relationship between education level and efficiency, which indicates that if farmers had higher education levels beyond the threshold point, their farming efficiency will decrease. The significance of adopting sustainable agriculture practices in rice-producing households was emphasized by the positive correlation observed between the number of sustainable agriculture practices applied and efficiency.

1. Introduction

Rice plays a crucial role in Vietnam's agricultural sector, ensuring food security for over 90 % of the population and constitutes more than 30 % of the country's total agricultural production value (Kamil et al., 2020). More than half of the total cultivated land area, about 72800 km^2, is dedicated to rice farming. The Mekong Delta (MKD) is the main area for rice cultivation, accounting for 54.5 % of the total rice land, 52 % of national rice production, and 90 % of the country's rice export (World Bank, 2022).
Vietnam's rice productivity has increased significantly with the adoption of advanced cultivation technologies and the intensification of high-yielding varieties. This excessive intensification of production, high water intensity, and overuse of agrochemicals pose multiple threats to the environment, economy, and society. Approximately 48 % of agricultural emissions and over 75 % of methane emissions originate from rice cultivation, which leads to adverse environmental effects, including the degradation of soil and pollution of groundwater and air (World Bank, 2022). Vietnam ranks third in terms of rice export volume, but the export price of Vietnam rice is typically the lowest among the top five rice-exporting countries in the world (General Statistics Office of Vietnam, 2020). Low rice prices, high production costs, and reduced cultivated land have contributed to a decreasing growth rate in both output and yield over the last decade, impacting the long-term sustainability of rice production and farmers' livelihoods.
Given the challenges faced by traditional farming, there has been growing interest in exploring alternative agricultural techniques, with a particular focus on Sustainable Agricultural Practices (SAPs), which are believed

Paper Received: 31 May 2023; Revised: 20 September 2023; Accepted: 2 October 2023
Please cite this article as: Hien N.T.T., Tam H.T., Shimada K., Anh H.H., Cuong N.V., Tru L.C., 2023, Technical Efficiency of Sustainable and Conventional Rice Farming: Evidence from the Mekong Delta of Vietnam, Chemical Engineering Transactions, 106, 343-348 DOI:10.3303/CET23106058

to benefit farmers by improving productivity and income while reducing adverse effects on the environment and society. According to the Food and Agriculture Organization (1995), SAPs involve utilizing alternative techniques and technologies to replace unsustainable farming practices and decrease reliance on agrochemical inputs used in traditional farming, to achieve economic, environmental, and social sustainability. In Vietnam, various practices have been implemented, including the national program “One Must Do, Five Reductions” (1M5R) in MKD, to promote the development of sustainable rice production. This eco-friendly farming package encourages farmers to use certified seeds (One Must Do) and reduces the use of seed rate, fertilizers and pesticides, water, and post-harvest losses (Five Reductions). Despite the government’s efforts, sustainable rice farming in the MKD still faces significant challenges. From the farmers’ perspective, the expansion of sustainable agriculture is primarily determined by its financial performance compared with traditional agriculture (Crowder and Reganold, 2015). Given the above, this study aims to understand production efficiency of sustainable-oriented rice production in the MKD, particularly in Long An province.

Several studies have estimated the technical efficiency (TE) of conventional and sustainable rice farming systems. Santos and Shimada (2021) found that environmentally friendly agriculture positively affected production efficiency. In Vietnam, Huy (2009) suggests that the average score of efficiency for advanced rice-farming practices is higher. Ho and Shimada (2019) and Le and Umetsu (2022) indicated that farmers who adopt Climate Smart Agriculture practices achieved significantly better efficiency scores. It is worth noting that these articles mainly evaluated the technical efficiency and the effects of binary adoption of SAPs on technical efficiency, with yes for adoption and no for non-adoption. Huang et al. (2015) showed that farmers tended to choose and apply farming practices that are most suitable to their specific conditions and needs. This present study contributes to current debate on sustainable farming by attempting to investigate the impact of adoption intensity (defined as the total number of individual SAPs adopted) on rice production efficiency based on unique data from rice farmers in Long An province in the MKD, using Data Envelopment Analysis (DEA) approach. It also adds to previous work on sustainable agriculture by assessing the factors that affect the adoption and intensity of SAPs in the backdrop of the MKD. Understanding heterogeneity impact of different adoption combinations is essential to provide policy support for sustainable rice farming in Vietnam.

2. Methodology and data

2.1 Methodology

The study utilized the two-stage econometric technique to achieve its objectives. The first stage involved using the DEA technique to estimate the overall, pure, and scale efficiencies of each farm household. In the second stage, the study employed Tobit regression to investigate the determinants of technical efficiency.

Technical efficiency is defined as a farm’s ability to achieve maximum output from a given level of input (output orientation) or produce a given level of output from the minimum inputs (input orientation) (Varian, 1992). TE measures the distance from each firm to the production frontier using an estimated parametric approach, and a non-parametric approach. TE can be measured under the assumption of constant returns to scale (CRS), known as the overall technical efficiency (TE_{CRS}),which consists of two components: pure technical efficiency (TE_{VRS}), which is TE under the assumption of variable returns to scale (VRS), and scale efficiency (SE) (Kumar and Gulati, 2008). Pure technical efficiency reveals the ability of a firm to utilize its inputs efficiently, with the exclusion of scale effects.

The non-parametric approach, DEA, is a linear programming technique and efficiency is measured among decision-making units (DMUs). The DEA method can be applied using either output or input-based approaches. Since farmers have more ability to control their inputs use than outputs, and the output-orientated measures are considered in the case of two outputs and a single input (Farrell, 1957), input-oriented measure under variable returns to scale is an appropriate approach for this analysis.

The efficiency score for a given farm n was obtained by solving the input-oriented DEA model in Eq (1):

$$TE_n = Min\, \theta_n \qquad \text{subject to } Y_{nk} \leq Y_{ik}\lambda_i,\ \theta_n X_{nj} \geq X_{ij}\lambda_i \text{ with } \lambda_i \geq 0 \qquad (1)$$

where X and Y are the input and output vector, respectively, θ_n is TE of farm n under CRS and λ_i is an n × 1 vector of weights. If θ_n is equal to 1, the firm is considered technically efficient. When θ_n is smaller than 1, the firm is technically inefficient, with the inefficiency level equal to 1 – TE_n. Adding the condition of $\sum \lambda_i$= 1, TE_n is calculated under the assumption of VRS (Coelli, 1998).

SE is measured as the ratio of OTE and VRS TE. In general, 0 ≤ SE ≤1, with SE =1 indicating an efficient economy of scale, which is a non-increasing return to scale (NIRS). SE ≠ 1 implies that the inputs are scale inefficient, which can be the result of increasing returns to scale (IRS) or decreasing returns to scale (DRS). The paper applies the Data Envelopment Analysis programme, version 2.1 (DEAP 2.1) to calculate technical efficiency scores for rice production in the study areas.

In the second stage, the study analyses the relationship between efficiency and farm characteristics using a Tobit model. Since the efficiency scores of rice farmers range from 0 to 1, the two-limit Tobit model is more appropriate than conventional OLS regression. The Tobit model used in this study was estimated using Eq (2):

$$TE = \beta_0 + \beta_1 EDU + \beta_2 EDU^2 + \beta_3 EXP + \beta_4 SIZE + \beta_5 SAPs + \beta_6 LOCATION + e \quad (2)$$

where TE is the pure technical efficiency of farmers in rice production; EDU is the education level of farmers in y, EDU^2 is the quadratic term of farmers' education level, EXP is the farming experience in y, SIZE is farm size in km^2, SAPs is the intensity of SAPs adoption (from 0 to 4) and LOCATION is the location of rice farm (dummy variable, 1 if farm located in Duc Hue district, 0 if farm located in Tan Hung district).

2.2 Data

The survey in this study was conducted in November 2022 for the Winter-Spring 2021-2022 rice growing season, collecting farm-level data from rice farmers in Long An province, MKD. This province ranks fourth in the MKD in terms of total rice volume of approximately 3 Mt/y. Two largest rice production districts with different geographic characteristics (one located near Ho Chi Minh City, Vietnam's largest city, and one near the Mekong River) were purposively selected for face-to-face interviews and 163 farms were randomly chosen in the community. After removing 11 outlier observations, the final sample used to estimate the technical efficiency was 152 farms. With over 90 % of the farmers reporting using certified seed and no available data for post-harvest loss, the SAPs captured in the data include reducing seed rate, reducing chemical fertilizer and using organic fertilizer, reducing pesticides and reducing water use.

3. Empirical results

3.1 Descriptive statistics

Figure 1 shows the proportion of farmers applying SAPs in isolation within the study area. The survey showed that about 93.42 % of the farms had implemented at least one SAPs practice. Reducing agrochemical and seed rates was practiced by most farmers. Common seed types used by the farmers include OM18, IR4625, Dai Thom 8 or ST25, which are all high-quality certified seeds. The adoption rate of water-saving techniques was modest, which may arise from the geographical characteristics of rice farms at the study site. Most rice fields are near irrigation systems and main rivers with abundant water sources, especially in the Duc Hue district. They can easily pump more water into the plot when necessary. In addition, irrigation costs only account for a smart part of production costs but adopting the practice of water reduction requires significant effort. These obstacles may make this practice inapplicable to current conditions. In terms of the adoption of SAPs practices, the data showed that the combination of three practices accounts for 43.42 % of the whole sample, followed by the combination of all four practices (30.26 %), and two practices (11.18 %). 8.55 % of farmers reported applying only one practice and 6.58 % did not apply any practice.

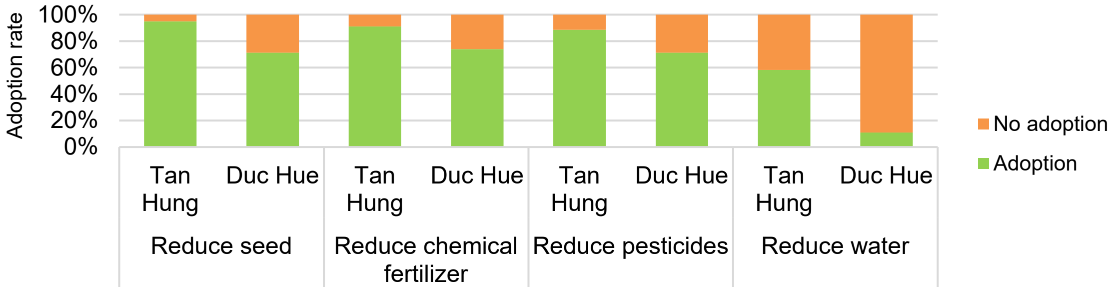

Figure 1: Sustainable rice farming practices implemented by farmers by location.

Table 1 provides summary statistics for input-output variables, by the intensity of SAPs adoption. Rice yields appear to vary across SAPs practices, with higher yields observed among farmers adopting all four practices and who did not adopt any practices. The amount of seed rate tends to reduce with the increase of SAPs applied, with the lowest under the combination of four practices, except for farms that applied one practice. Average chemical fertilizer use is higher if farmers use fewer SAPs practices. Organic fertilizers are used most by farms under the implementation of two and four practices. Pesticide cost is generally lower in farms that adopted more sustainable practices. The cost of irrigation is higher on average under the adoption of SAPs. Except for those applying one and three practices, hired labor cost and family labor are higher for farmers applied fewer SAPs.

Table 1 also summarizes farm and farmers' characteristics that could affect the technical efficiency of rice production. Farmers in the survey site had an average of 27 y of rice cultivation experience and about 7 y of education. Descriptive statistics show that rice farms in the sample operate on a large scale with an average of over 0.03 km^2compared to the national average, where over half of farms are smaller than 0.01 km^2 (World Bank, 2022). Farmers with larger scales are more likely to implement more sustainable rice farming practices. Farmers in Tan Hung District apply more numbers of practices than those in Duc Hue District, with 89.13 % of farms implementing a combination of four practices located in Tan Hung.

Table 1: Summary statistics of output, input, and farm characteristics used in DEA Analysis, by the intensity of SAPs adoption.

	Variables	0 (n=10)	1 (n=13)	2 (n=17)	3 (n=66)	4 (n=46)
Output	Rice yield (kg/km^2)	713,785.7 (148,282.7)	706,263.7 (114,893.5)	686,234.7 (140,812.4)	689,766.9 (108,267)	714,701.9 (102,269.9)
Inputs	Seed rate (kg/km^2)	15,961.9 (4,480.85)	17,344.32 (3,072.15)	15,511.2 (3,612.17)	13,105.61 (3,002.16)	13,031.57 (2,868.80)
	Chemical fertilizer (kg/km^2)	50,004.76 (26,495.69)	49,516.48 (22,425.04)	44,444.07 (26,813.61)	41,945.12 (21,232.49)	34,696.65 (15,791.21)
	Organic fertilizer (kg/km^2)	-	1,538.46 (5,547.00)	3,599.44 (10,565.06)	1,894.28 (5,122.29)	3,860.15 (12,701.20)
	Pesticides (USD/km^2)	8,115.26 (3,165.98)	5,567.22 (2,584.52)	4,905.44 (2,862.89)	5,130.49 (2,995.52)	4,278.76 (2,744.04)
	Irrigation (USD/km^2)	2,630.84 (2,076.73)	4,692.43 (3,826.91)	4,066.38 (4,121.03)	3,639.10 (3,534.74)	3,978.98 (1,892.74)
	Family labor (man-day/km^2)	204.5 (366.99)	270.62 (290.66)	200.53 (216.41)	271.15 (355.35)	106,76 (214.04)
	Hired labor cost (USD/km^2)	29,669.62 (17,015.31)	24,645.26 (11,288.30)	20,442.76 (12,333.17)	21,880.39 (12,329.19)	20,076.05 (7,886.68)
Farm and farmers' characteristics	Education	7.70 (2.71)	7.54 (2.40)	6.35 (2.74)	7.23 (3.11)	7.15 (3.29)
	Experience	28.30 (14.75)	23.38 (12.36)	29.65 (12.02)	27.61 (11.99)	25.17 (12.69)
	Farm size	0.027 (0.02)	0.023 (0.02)	0.028 (0.02)	0.038 (0.05)	0.050 (0.04)
	Location	0.90 (0.32)	0.69 (0.48)	0.76 (0.44)	0.56 (0.50)	0.11 (0.31)

Note: 1 USD = 23,677 VND (exchange rate as of November 2022). Standard deviations are in parentheses.

3.2 Technical efficiency

The input-oriented TE scores of rice farms estimated using the DEAP 2.1 program are shown in Table 2. Except for farmers under adoption of one practice, the remaining rice producers obtained a fairly high technical efficiency score of above 0.8. A similar result was found in the study by Khai and Yabe (2011). The mean technical efficiency under the CRS and VRS models appeared to increase when farmers adopted more sustainable practices, with the highest under combination of all four practices. This result indicates that applying a greater number of SAPs will improve efficiency of rice production thanks to reduction in inputs used, which can encourage the transition of traditional farmers to sustainable practices. The farmers under one practice had the lowest efficiency scores. These farmers mostly applied only reducing seed rates practice, suggesting that this practice might not contribute to enhancing technical efficiency of farms.

Table 2: Technical efficiency score from DEA estimate.

Number of practices adopted	0 (n=10)	1 (n=13)	2 (n=17)	3 (n=66)	4 (n=46)
Overall technical efficiency	0.69	0.57	0.69	0.76	0.82
Pure technical efficiency	0.81 (40.00 %)	0.65 (0.00 %)	0.82 (23.10 %)	0.85 (31.82 %)	0.90 (34.78 %)
Scale efficiency	0.85	0.87	0.84	0.89	0.91

Source: Author's calculation. Note: In parentheses is percentage of technical efficient farms (TE=1)

Specifically, except for farmers applying only one practice, the input-based TE for farmers is range from 0.81 to 0.90. This means that farmers can increase technical efficiency by at least 18 %. In principle, farmers can reduce their production input by $(1/TE_{VRS} - 1)$ and still achieve the same level of output from the existing technology. The results imply that implementing all four sustainable practices could reduce 10.9 % of input use without changing the level of output obtained. Around 35 % of farmers who applied four practices were fully efficient under the VRS, while the number is 40 % for farmers who are not applying any practices. None of farmers applying one practice achieve full efficiency in production.

Regarding scale efficiency, the mean score was found to range from 0.84 to 0.91 with the highest score of farmers adopting all four practices, implying that, on average, rice producers who adopt more SAPs achieved more scale efficiency. Table 3 shows that approximately 22.70 % of farms are achieving scale efficiency under combination of three practices, followed by 19.60 % of farmers adopting four practices and only 10 % of farmers who do not apply SAPs practices are scale efficiency. Among the scale-inefficient farms, over 50 % have increasing returns to scale. This suggests that many rice farms in the sample may need to increase their operational scale to achieve optimal scale efficiency.

It is worth noting that the pure technical efficiency score for all combinations of farming practices was slightly lower than the scale efficiency score. This indicates that the technical inefficiency of rice farms at the survey site was mainly affected by management rather than the operating scale. This result is in line with the finding of Linh et al. (2015) for crop and maize production in Northwest Vietnam. Farmers on the survey site should focus on improving their capacity to efficiently manage input use.

Table 3: Return to scales of conventional and sustainable farms.

Number of practices adopted	0 (n=10)	1 (n=13)	2 (n=17)	3 (n=66)	4 (n=46)
DRS	40.00 %	30.80 %	17.60 %	15.20 %	23.90 %
IRS	50.00 %	61.50 %	70.60 %	62.10 %	56.50 %
NIRS	10.00 %	7.70 %	11.80 %	22.70 %	19.60 %

3.3 Determinants of technical efficiency

A Tobit model is applied to estimate the relationship between farm and household characteristics and the efficiency performance of rice farms. The results of the Tobit model are summarized in Table 4.

Table 4: Determinants of the technical efficiency for the rice farmers.

Variables (n = 152)	Coefficient	Standard Error
Education	0.049***	0.019
Education squared	-0.003**	0.001
Farming experience	0.002*	0.001
Farm size	-0.001	0.004
Intensity of SAPs adoption	0.056***	0.015
Location	-0.017	0.037
Prob > chi2	0.0003	
Pseudo R2	0.6283	

Note: *, **, and *** indicate significance at the 90 %, 95 %, and 99 % confidence intervals, respectively.

Three main variables are found to be associated with the technical efficiency of rice farms in this study area including farmer education level, farmer's farming experience, and the intensity of SAPs adoption. It was also observed that farm size and location did not contribute to the fluctuation of farming efficiency at the study sites. The result from the Tobit model suggested that there is an inverse U-shaped relationship between farmers' education level and technical efficiency. The linear term of farmers' education is positive and significant, indicating that when farmers obtain a higher education, they might have better knowledge and skills to achieve higher production efficiency. This result is consistent with Linh et al. (2017), which confirms the importance of human capital in improving efficiency. The quadratic term of education is found to have a significantly negative impact on TE, which means that over a turning point, higher education might have limited effects on TE. A similar result is reported by Linh (2012) which explained that farmers with higher education are more likely to pursue the non-farm jobs, which indicated that their education might not contribute to improving TE of the farm.

Farming experience is positively associated with TE, which indicates that farmers with more years of farming experience obtain higher levels of TE. This result is in line with the findings of Khanal et al. (2018). More experienced farmers can do better in managing production activities and adapting to new cultivating practices, resulting in improved increasing production efficiency.

An important result from the Tobit model is that the adoption of more advanced rice farming practices has the largest positive impact on production efficiency at a signification level of 1 %. This indicates that if farmers apply more SAPs practices, they will obtain better production efficiency, thanks to the significant reduction requirements in seed rate, agrochemicals, and labor requirements. This finding confirms the importance of encouraging farmers to join more intensively into sustainable agriculture, which contributes to boosting production efficiency, and ultimately improves farmers' income and welfare.

4. Conclusions

This study applied two-stage DEA to estimate and evaluate the difference between the technical efficiency of conventional and sustainable rice farms in the Long An Province of Vietnam. The estimated results indicated that except for farmers applying one practice, farmers implementing more sustainable practices obtained higher technical efficiency. The inefficiency of farmers under all types of practices combination derived from management rather than the operating scale. The study also found an inverted U-shaped relationship between farmers' education level and efficiency, where technical efficiency appeared to first increase with education level, but beyond a threshold, efficiency decreased if farmers achieve higher years of schooling and moved to the non-farm sector. Finally, the positive correlation between the intensity of adoption of SAPs and efficiency highlights the importance of understanding the impact of adopting multiple sustainable rice farming practices in rice-producing households with the significant reduction in the use of critical inputs such as seed, agrochemicals and labor. The results could serve as a reference for farmers and policymakers to promote engagement in sustainable agriculture to improve the production efficiency and sustainability of the rice farming sector in the Mekong Delta of Vietnam.

Acknowledgments

This research is a part of the International Collaboration Project between Asia-Japan Research Institutes, Ritsumeikan University and Faculty of Economics, Nong Lam University, Ho Chi Minh City, Vietnam.

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