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Investigating technical and scale efficiencies of the rice-shrimp system in the Mekong Delta, Vietnam

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ABSTRACT

The current study was organized to measure the economic efficiency of rice-shrimp farms in the Mekong Delta. Thus, a survey on 84 rice-shrimp farmers was conducted in 28 villages of 24 districts in Ca Mau and Kien Giang in the western coastal region of the Mekong Delta. Data were selected using random sampling, and data envelopment analysis was applied to assess the economic efficiency of the rice-shrimp system. The overall average for technical efficiency (TE) and scale efficiency (SE) were 0.665 and 0.509, respectively, implying substantial inefficiency in farming operations by the households in the sample. This indicates that there is still potential for improving the economic efficiency of the rice-shrimp system. In addition, the land ownership status, the area cultivated, and the type of seed are statistically significant determinants of the TE while factors of gender, age, education level, irrigation system, saltwater drains, area, type of seed, and practices of fertilizing and weeding are the determinants of the SE. Based on the data recorded it was confirmed that farms in Kien Giang attain higher economic profit, TE, and SE than farms in Ca Mau.

INTRODUCTION

In the context of climate-induced risk, the Mekong Delta (MD) is currently coping with saltwater intrusion and adverse weather changes that present serious challenges to its traditional intensive rice system **(Wassmann *et al*., 2004)**. Since 2019, there has been a shift toward the rice-based system **(Danh *et al*., 2019)**. Under Resolution No. 09/2000/ND-CP, the area of rice-shrimp cultivation was extended from 71,000 ha in 2000 to 153,000 ha in 2015 and 200,000 ha in 2020. The MD is the main area of rice-based production systems such as rice and rice-shrimp cultivation. In the coastal regions, the rice-shrimp system is the most popular given the brackish water resource available; Kien Giang, Ca Mau, Bac Lieu, Soc Trang, and Ben Tre are the largest rice-shrimp producers in the MD. The yields in the rice-shrimp system are 4–7 ton/ha and 300–500 kg/ha for rice and shrimp, respectively **(General Statistics Office, 2021)**. Extensive rice-shrimp models are found in Ca Mau and Kien Giang, while semi-intensive rice-shrimp models are mainly used in Bac Lieu, Soc Trang, and Tra Vinh. The need to cope with the constraints of irrigated water resource availability and irrigation system investment indicates that the efficiency of the rice-shrimp system is still under question **(Keskinen *et al*., 2010)**.

The concept of efficiency has been widely used to assess the productivity of decision-making units such as farms. **Fraj (2011)** uses data envelopment analysis (DEA) – a nonparametric method – to analyze the technical efficiency (TE), water-use efficiency, and productivity dynamics of the irrigated areas in Tunisia. Their findings show that the TE of the farms increases by 17% due to improvements in water-use efficiency of up to 22%, and this has a positive impact on the farm's productivity. **Anuradha and Zala (2010)** estimated the TE in rice production by applying a stochastic frontier production function and identify the impact on TE of farm-specific socio-economic factors using regression analysis. The findings revealed that farm-specific TEs range from 71.39% to 99.82%, with a mean of 72.78%. The determinants of TE are identified as operational area, experience, education, and distance of field; the number of working family members has a negative relationship with TE.

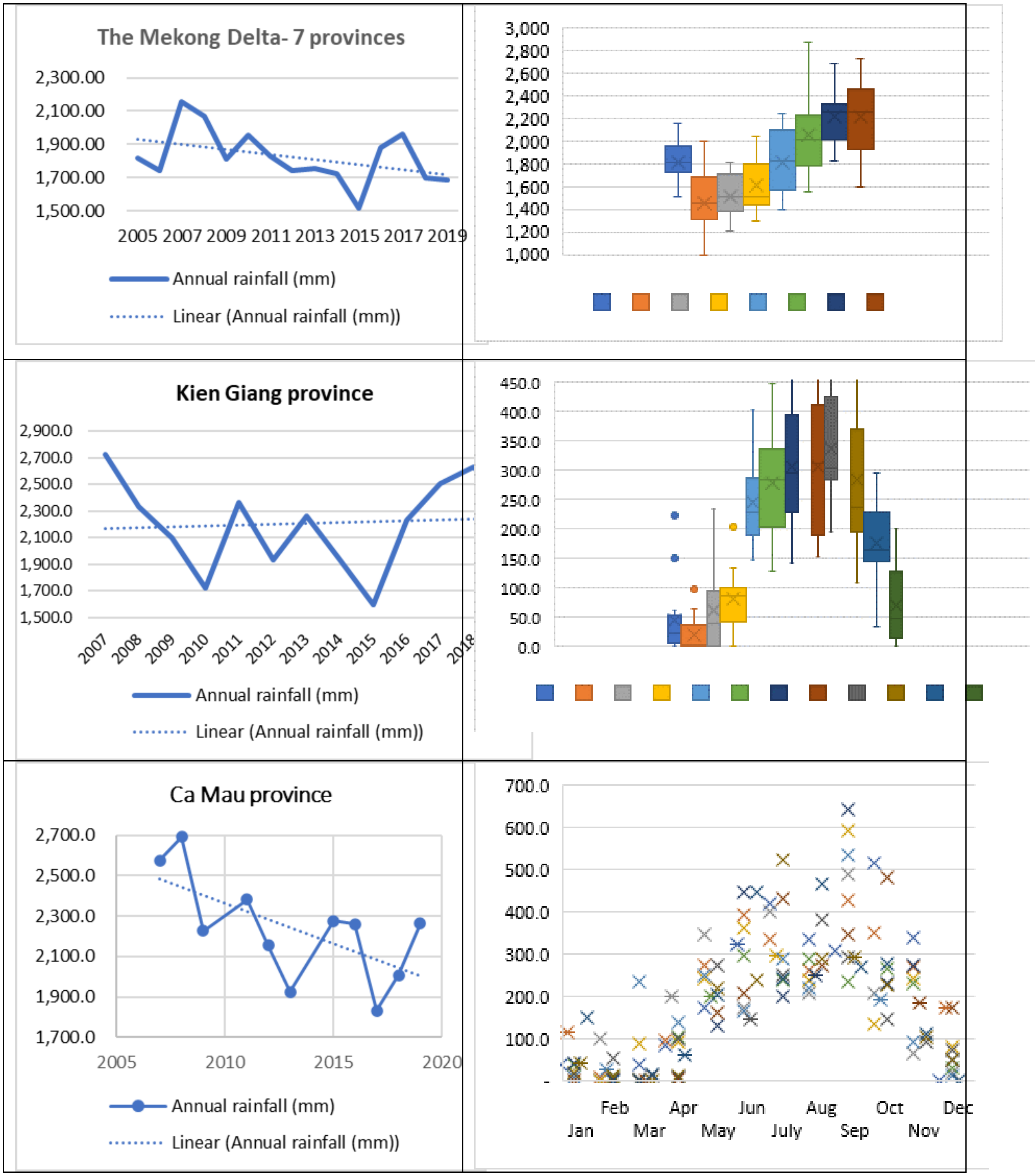
Malana and Malano (2006) conducted an economic efficiency (EE) analysis of selected wheat areas in Pakistan and India using the DEA method. The authors ranked EE based on four inputs, including irrigated water to assess the EE of the rice-shrimp system in the MD. The paper consists of four sections. The description of the study location and sampling procedure are set out in the first section. The theoretical framework and methodology of the DEA are presented in the second section. The assessment of the EE of the rice-shrimp system is discussed in the third section. Finally, the conclusion and recommendations are presented in the final section.

MATERIALS AND METHODS

Study location and sample selection

Study location

***Climate patterns*.** The extreme weather patterns in the coastal areas of the MD in the period 2005–2019 show that climate shocks are happening. Annual temperatures and sunshine hours have tended to increase, while annual rainfall and humidity have tended to decrease in the most recent 15-year period. Furthermore, the fluctuation of monthly climate means over the years reveals abnormal changes in these climate drivers (Fig. 1) **(General Statistics Office, 2021)**. It also indicates that the MD follows a heterogeneous climate pattern. According to **Tuong *et al*. (2003)** and **Triet *et al*. (2017)**, the combined impact of these climate factors – the sea level rise and upstream impacts on the Mekong River – have worsened the salinity intrusion in the MD.



Note: Source from General Statistics Office (2020)

Fig. 1. Climate patterns in the period 2005–2019

Rice-shrimp system. The MD rice-shrimp system mainly follows an extensive model, with some using a semi-intensive approach **(Danh *et al*., 2019)**. The rice-shrimp system has, since 2000, been employed in Ca Mau Province; this includes production in the districts of Thoi Binh, U Minh, Tran Van Thoi, Cai Nuoc, and provincial-level city, Ca

Mau. Similarly, since 2002 the rice-shrimp system has been developed in Kien Giang Province. This rice-shrimp system is mainly found in the districts of An Bien, An Minh, U Minh Thuong, Vinh Thuan, Go Quao, Hon Dat, and Kien Luong. Table (1) presents the development of the rice-shrimp cultivation areas in the period 2015–2019 in Ca Mau and Kien Giang.

Table 1. Rice-shrimp area in seven coastal provinces in the Mekong Delta, 2015–2019 (unit: ha)

Province	**2015**	**2016**	**2017**	**2018**	**2019**	**Change (%)**
Ca Mau	278,745	276,433	271,535	268,062	269,869	−3.18
Kien Giang	98,753	104,935	117,336	122,701	126,822	28.42
Total	377,498	381,368	388,871	390,763	396,691	25.24

Note: Source from General Statistics Office (2020)

Sampling procedure

This study employed a random sample of eighty-four rice-shrimp households in Ca Mau and Kien Giang provinces. The study sites were in the salinity-prone western coastal areas. Household selection is conducted in three stages. First, based on a salinity-intrusion map of twenty-four districts (**SIWRR, 2015**), we selected nine salinity-prone districts on the recommendation of local authorities. Second, we drew a population-weighed random sample of twenty-three communes from a total of 245. From this, twenty-eight villages were selected for the face-to-face interviews. Finally, eight households were selected within each village. Where a list of all village farmers was available, eight households were randomly chosen; otherwise, the village head was invited to provide a list of twenty households, of which five households are well-off, ten have a medium, and five households are less well-off. Eight households were then randomly selected from the list of twenty households applying a function of RAND() in EXCEL. The farmers selected are rice and rice-shrimp farmers with three or more years of experience in rice-based production. The interview was implemented using a well-designed questionnaire. Among the 224 rice-based farmers selected for an interview, there are eighty-four rice-shrimp farmers, forty-one from Ca Mau, and forty-three from Kien Giang.

Fig. 2. Sampling village-level map in Ca Mau and Kien Giang provinces https://www.google.com/maps/d/edit?mid=1kS-AU9iMyZFgQHGnHaJySUtwUUuLBzgh&usp=sharing

Methodology

This study used a nonparametric DEA approach to assess the EE of the rice-shrimp model. Measures of efficiency included TE and scale efficiency (SE). The TE referred to the functional relationship between inputs (including irrigated water) and output; TE is attained when the maximum possible improvement in an output is obtained from a set of inputs. The SE measures the potential productivity gain from attaining optimal farm size. The EE refers to the maximization of output for a given cost. Methodologically, in the nonparametric procedure, a mathematical DEA programming method is used to overcome the limitations of the parametric Cobb-Douglas production function. Using actual observations, a frontier is defined concerning all the farms in the sample set. The frontier uses the efficient farms in the set as a benchmark to measure the efficiency of other farms. A farm's efficiency is analyzed by comparing its performance with that of other farms located along the frontier. The assumption of constant returning to scale (CRS) assumes that all farms operate optimally **(Coelli, 2008)**. In addition, a variable return is calculated to scale (VRS) as proposed by **Banker *et al*. (1984)**.

First, the CRS DEA model was used for a single output to compute output-oriented measures of the TE and the SE as described below:

$$\begin{aligned} &\text{Min}_{\theta,\lambda}\ \theta, \\ &\text{Subject to}\quad -y_i + Y\lambda \geq 0, \\ &\qquad \theta x_i - X\lambda \geq 0, \\ &\qquad \lambda \geq 0, \end{aligned} \tag{1}$$

Where, ϑ_i is the proportional increase in output possible for the *i*-th farm, and λ is the weight relative to efficient farms. Equation (1) with the CRS assumption states that farms are operating at their optimal scale **(Fraser & Cordina, 1999)**.

Second, the VRS DEA model uses the CRS specification when not all farms are operating at the optimal scale. The CRS linear programming problem is then modified to account for VRS by adding the convexity constraint as follows:

$$\begin{aligned} &\text{Min}_{\theta,\lambda}\ \theta, \\ &\text{Subject to}\quad -y_i + Y\lambda \geq 0, \\ &\qquad \theta x_i - X\lambda \geq 0, \\ &\qquad N1'\lambda = 1 \\ &\qquad \lambda \geq 0, \end{aligned} \tag{2}$$

Where, N1 is an Nx1 vector of convexity constraints. This model determines the TE scores that are greater than or equal to those obtained using the CRS model. The SE, ranging of (0, 1), and reflecting the role of return to scale in the TE, is measured by comparing the TE, CRS and VRS scores. A difference between the two TE scores indicates that the SE limits the possibility of achieving an optimal (constant) scale:

$$SE_i = TE^{VRS}{}_i \,/\, TE^{CRS}{}_i \tag{3}$$

Where, $SE_i = 1$ indicates full scale efficiency and $SE_i < 1$, indicates scale inefficiency.

This study applied the DEA to measure the TE and the SE of the farms in relation to the optimal situation for irrigated water use in the MD. The second step taken was to analyze the determinants of efficiency. To cover this step, a tobit model with a censored variable of range 0–1 was estimated as a function of farm attributes to identify the determinants of inefficiency via the estimation of a second-stage process as follows:

$$\begin{aligned} \theta^{k*} &= \beta_0 + \beta_1 Z_1 + \beta_2 Z_2 + \cdots + \beta_j Z_j + e \\ &= Z\beta + e \\ \theta^k &= \theta^{k*} \text{ if } 0 < \theta^{k*} < 1 \\ &= 0 \text{ if } \theta^{k*} < 0 \\ &= 1 \text{ if } \theta^{k*} > 1 \end{aligned} \tag{4}$$

where θ^K is the DEA efficiency index for water as dependent variables (k = 1 for the TE^{VRS} and k = 2 for the SE), and Z is a vector of independent variables related to farm attributes. The estimation of the Tobit model is based on maximum likelihood procedures **(Rodríguez Díaz *et al*., 2004)**.

RESULTS & DISCUSSION

Characteristics of sample

In the sample, the average household has a cultivation time of at least seven years and an average of forty-five years. For the respondents, 87% are men. For the heads of households, 12% of them have an education of high school or above, and 99% of households who participated in the survey are Kinh. The area of rice cultivation is 2.27 ha per household. For the households surveyed, 48% and 83% invest in irrigation water and saltwater drains, respectively. Regarding the farmers surveyed, 92%, 81%, and 61% use marketed, certificated, and salt-tolerant seeds, respectively. The average rice yield in 2019 for the winter-spring crop is 4.23 tons per ha. The result of the t-test showed that there is a statistically significant difference in rice yield between Ca Mau and Kien Giang (P = 0.02). The number of times at which the households applied fertilizer or pesticide or undertook weeding efforts in the surveyed period are three, two, and one time, respectively. Finally, 88% of the farmers surveyed are landowners.

Table 2. Household characteristics

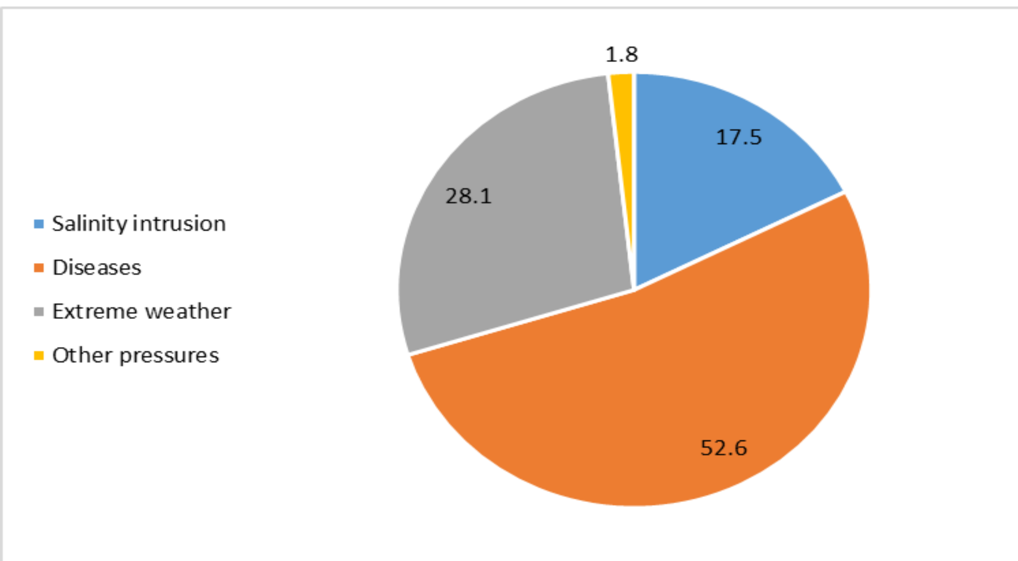
Item	Unit	N	Minimum	Maximum	Mean	Standard deviation
Head's age	Years	84	29	72	50.12	11.71
Head's gender	1: Male 0: Female	84	0	1	0.87	0.339
Head's education level	1: high school or above 0: otherwise	84	0	1	0.12	0.326
Ethnic	Kinh: 1 Other: 0	84	0	1	0.99	0.109
Number of years living in the area	Years	84	7	72	44.26	15.96
Landownership status	Landlord: 1 Leaser: 0	84	0	1	0.88	0.326
Salinity protection gate	Yes: 1 No: 0	84	0	2	0.83	0.929
Source of production water	Irrigation: 1 Other: 0	84	0	1	0.48	0.502
Salinity impact	Yes: 1 No: 0	84	0	1	0.18	0.385
Rice cultivation	Ha	84	0.26	15.60	2.27	1.94

Item	Unit	N	Minimum	Maximum	Mean	Standard deviation
area						
Rice yield	(ton/ha)	84	0.80	8.65	4.23	1.69
Marketed seed	Yes: 1 No: 0	84	0	1	0.92	0.278
Certificated seed	Yes: 1 No: 0	84	0	1	0.81	0.395
Salt-tolerant seed	Yes: 1 No: 0	84	0	1	0.61	0.491
Number of fertilizer applications	Time	84	0	5	2.62	0.968
Number of pesticide applications	Time	84	0	10	1.54	1.746
Number of weeding efforts	Time	84	0	1	0.77	0.421

Note: Source from survey (2019)

Salinity impact

Regarding the impact of salinity intrusion in the study location, the study showed that nearly 26% of farmers in the survey have to cope with agricultural hazards. For the sample households, 52.6%, 28.1%, 17.5% are impacted by diseases, extreme weather, and salinity intrusion, respectively.



Note: Source from survey (2019)

Fig. 3. Issues in rice production in the study location

Economic analysis of rice production

Economic efficiency

In this study, the financial and economic profits for the 2019 winter–spring rice crop were compared. Our results revealed a rice revenue or rice sales of VND 22.4 million per ha. The costs of rice production are VND 9.9 million per ha, and VND 12 million per ha for financial and economic assessment, respectively. As a result, the financial and economic profits are VND 12.5 million per ha and VND 10.2 million per ha, respectively. Furthermore, the financial and economic returns on sales are 46.8% and 33.6%, respectively. Our results indicate that compared to **Danh *et al*. (2019)**, the rates of return of the rice-shrimp model are lower than those for the intensive rice model. In the intensive rice model, the financial and economic profits WERE VND 23.9 million per ha and VND 21.9 million per ha, respectively; the financial and economic returns on sales are 59% and 52.6%, respectively.

Table 3. Statistical summary of financial and economic inputs and outputs

Index	Unit	Rice-shrimp model	
		Financial efficiency	Economic efficiency
Revenue	VND 1.000 /ha	22,387	22,387
Land preparation cost	VND 1.000 /ha	926	926
Seed cost	VND 1.000 /ha	83	83
Pesticide cost	VND 1.000 /ha	604	604
Fertilizer cost	VND 1.000 /ha	2,353	2,353
Irrigation cost	VND 1.000 /ha	235	235
Rent-labor cost	VND 1.000 /ha	3,652	3,652
Own-labor cost	VND 1.000 /ha	-	2,083
Harvesting cost	VND 1.000 /ha	4,937	4,937
Financial cost	VND 1.000 /ha	9,880	-
Economic cost	VND 1.000 /ha	-	11,963
Financial profit	VND 1.000 /ha	12,507	-
Economic profit	VND 1.000 /ha	-	10,190
Financial return-to-sale	%	46.77	-
Economic return-to-sale	%	-	33.64

The EE of irrigated-water used in rice production was measured using a DEA function of irrigated-water efficiency to assess the impact of costs for irrigated water, fertilizer, pesticides, labor and seed. The results in Table (4) show that the average overall technical efficiencies for the TE and the SE are 0.665 and 0.509, respectively. This implies that there are substantial inefficiencies in the farming operations of the sample households.

In addition, the results revealed that the distribution of the SE is widely scattered with a range of 0.100–1.000. The highest proportion of farmers are those with an SE of 0.100–0.200 (18.3%) and 0.900–1.000 (17.2%). In terms of the "optimal" TE, the results showed that 47.6% of the farmers surveyed attain the low TE (below 0.500) while 28.9% of farmers attain the high TE (0.800–1.000). In terms of "normal" TE, the results indicate that 49% of farmers attain the low TE (below 0.500) while 22.1% attain the high TE (0.800–1.000). Regarding returns to scale of the farmers surveyed, 86.9% of them achieve decreasing returns to scale (DRS), 2.4% achieve CRS, and 10.7% achieve increasing returns to scale (IRS). The results showed that there is still potential for improving the EE of the rice-shrimp system.

Table 4. Results of the overall economic efficiency analysis under constant and variable returns-to-scale specifications

Efficiency	**TE^{CRS}**		**TE^{VRS}**		**SE**	
	N	**%**	**N**	**%**	**N**	**%**
<0.100	8	9.5	0	0	0	0
0.101 - 0.200	9	10.3	16	18.8	15	18.3
0.201 - 0.300	8	10.1	9	10.8	10	11.4
0.301 - 0.400	7	8.5	8	9.9	8	9.6
0.401 - 0.500	8	9.2	8	9.5	9	10.3
0.501 - 0.600	10	11.4	9	10.6	4	5.1
0.601 - 0.700	6	7.4	8	9.1	12	14.7
0.701 - 0.800	4	4.7	8	9.2	8	9.0
0.801 - 0.900	10	11.7	6	6.6	4	4.4
0.901 - 1.000	14	17.2	13	15.5	14	17.2
Total	84	100.0	84	100.0	84	100.0
Mean		0.361		0.665		0.509
Max		0.022		0.122		0.127
Min		1.000		1.000		1.000
Standard deviation		0.279		0.245		0.256

Determinants of economic efficiency

For Model 1, results showed that land ownership and area cultivated are statistically significant determinants of economic profit; these factors have positive effects on economic profit. In addition, there are differences in economic profit between locations. Notably, farms in Kien Giang have a higher economic profit than farms in Ca Mau. While, the results in Model 2 showed that, irrigation systems, saltwater drains, and salinity are statistically significant determinants of the economical use of irrigated water. It is surprising that the efficiency of irrigated-water use is reduced if the farm has an irrigation system. Meanwhile, those who have saltwater drains or cope with salinity impact achieve higher efficiency in their use of irrigated water. Additionally, the results in Model 3 showed that land ownership status, the area cultivated, and the type of seed are statistically significant determinants of the TE. While the land ownership status has a positive effect on the TE, the area cultivated and seed type both have a negative effect on the TE. Furthermore, there are differences in the TE between locations. Remarkably, farms in Kien Giang have higher TEs than farms in Ca Mau. Furthemore, the results in

Model 4 indicate that gender, age, education level, irrigation system, saltwater drains, area of cultivation, type of seed, and practices of fertilizing and weeding are statistically significant determinants of the SE. Gender, age, saltwater drains, and weeding frequency have a positive effect on the SE, and a high-school level of schooling, irrigation system, area cultivated, use of market seed, and frequency of fertilizing have a negative effect on the SE. It is surprising that SEs are reduced if the farm household head has either a high-school level of education, an irrigation system, or cultivates a large area. There are differences in the SE between locations. That is, farms in Kien Giang have higher SEs than farms in Ca Mau.

Table 5. Results of regression estimations on the economic profit of the irrigated rice production model

Variable	Unit	Model [a/]	Model 2[a/]	Model 3[b/]	Model 3[b/]
(Constant)		−28,537.69 (−0.6193)	−0.656 (−1.2128)	0.727* (1.7900)	0.705*** (2.8900)
Gender	1: Male 0: Female	6,507.05 (0,5980)	0.283** (2.2156)	0.140 (1.4500)	0.111* (1.9400)
Age	Years	−10.15 (−0.0266)	0.004 (0.8399)	0.003 (1.0100)	0.004** (2.1200)
LivYear	Years	−348.67 (−1.2759)	0.001 (0.3878)	−0.004 (−1.4300)	−0.002 (−1.3100)
Ethnic	Kinh: 1 Other: 0	−2,924.95 (−0.0973)	0.097 (0.2759)	0.036 (0.1400)	0.182 (1.1500)
D_Primary	Primary: 1 No: 0	−1,252.85 (−0.1171)	−0.203 (−1.6168)	−0.050 (−0.4800)	0.0134 (0.2400)
D_Secondary	Secondary: 1 No: 0	−4,699.84 (−0.4299)	−0.050 (−0.3906)	−0.023 (−0.2400)	−0.045 (−0.7800)
D_HighSchool	High school: 1 No: 0	1,263.52 (0.0800)	−0.106 (−0.6272)	−0.078 (−0.6200)	−0.171** (−2.2600)
Land ownership	Landlord: 1 Leaser: 0	22,766.12** (2.1688)	0.033 (0.2646)	0.200** (2.1600)	0.050 (0.9000)
Irrigation system	Irrigated: 1 No: 0	− 7,667.11 (−0.3710)	−0.516** (−2.1278)	−0.076 (−0.4100)	−0.223** (−2.0500)
SalProteGate	Saltwater drain: 1 No: 0	5,402.11 (0.4885)	0.368*** (2.8390)	−0.009 (−0.0900)	0.097* (1.6800)
Salinity_Impact	salinity: 1 No: 0	−10,027.29 (−0.9886)	0.293* (2.4632)	−0.081 (−0.9100)	−0.017 (−0.3300)
Area	Ha	17,105.63* (8.4575)	−0.028 (−1.1925)	−0.049** (−2.0800)	−0.149*** (−10.500)
Marketed_Seed	Marketed seed: 1 No: 0	−6,306.00 (−0.3853)	0.227 (1.1826)	−0.317** (−2.1300)	−0.287*** (−3.3100)
Certificated_Seed	Certificated seed: 1 No: 0	11,269.63 (0.9993)	0.103 (0.7760)	0.0708 (0.7200)	0.029 (0.4900)
SaltToletant_S	Salt−tolerant	6,245.29	0.078	0.062	0.032

Variable	Unit	Model a/	Model 2a/	Model 3b/	Model 3b/
eed	seed: 1 No: 0	(0.8736)	(0.9339)	(0.9700)	(0.8400)
NumberFert	Times	2,857.23 (0.7406)	−0.019 (−0.4210)	−0.008 (−0.2300)	−0.079*** (−3.6800)
NumberPes	Times	−3,190.35 (−1.4228)	0.008 (0.2911)	−0.012 (0.0001)	−0.003 (−0.2200)
NumberWeeding	Times	−7,545.68 (−0.8564)	−0.138 (−1.3369)	−0.048 (−0.6100)	0.093* (1.9800)
D_KG	Kien Giang: 1 No: 0	15,247.12* (1.8191)	−0.139 (−1.4122)	0.159** (2.1100)	0.160*** (3.5900)
R^2		0.747	0.347	-	-
F-value		9.3086 (0.0000)	1.6724 (0.0630)	-	-
LR chi-square		-	-	38.68 (0.0095)	110.00 (0000)
Pseudo R^2		-	-	0.5990	0.3554

Note: a/ Models 1 and 2 are estimated in OLS with the dependent variables of the economic profit and the ratio of irrigated water cost to economic profit, respectively

b/ Models 3 and 4 are estimated in Tobit truncated regression with the dependent variables of the variable return to scale technical efficiency and the scale efficiency, respectively

*, **, *** statistically significant level at 10%, 5%, 1% respectively

Numbers in parenthesis () show t-values

Descriptive of variable is presented in Annex 1

CONCLUSION

The DEA approach was used to assess the EE of the rice-shrimp system in the MD. In terms of productive outcomes, the financial and economic profits are VND 12.5 million per ha and VND 10.2 million per ha, respectively. The results showed that the rates of return of the rice-shrimp model are lower than those of the rice-intensive model. For the EE, results showed that the average overall technical efficiencies are 0.665 for the TE and 0.509 for the SE, implying that there are substantial inefficiencies in the farming operations of households in the sample. In terms of the EE of economic returns to scale, 86.9% of farmers have DRS, 2.4% achieve CRS, and 10.7% reach IRS. Our results showed there is potential for improvement of the EE of the rice-shrimp system. Furthermore, land ownership and the area cultivated are the statistically significant determinants of economic profit; the irrigation system, saltwater drains, and salinity impact are significantly significant determinants of the economical use of irrigated water; land ownership status, area cultivated, and type of seed used are statistically significant determinants of TE; gender, age, education level, irrigation system, saltwater drains, area cultivated, type of seed, and practices of fertilizing and weeding are statistically significant determinants of SE. The results also indicate that farms in Kien Giang Province attain higher economic profit, TE and SE than those in Ca Mau Province.

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