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Environmental Efficiency of Ecologically Engineered Rice Production in the Mekong Delta of Vietnam

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Ecologically engineered rice cultivation was first introduced in the Mekong Delta of Vietnam in 2009. Although such cultivation is essential for environmental protection, the diffusion rate of the model was considered to be low. The low rate of diffusion is probably associated with the insufficient evidence about potential environmental benefits. Hence, this study applied the stochastic frontier analysis to estimate and compare the environmental, technical and pesticide use efficiency of ecological rice with those of normal rice. We conducted the survey by face-to-face interviewing 74 ecological rice farmers and 125 normal rice farmers in An Giang Province. Results revealed that the pesticide cost of ecological rice was appreciably lower than that of normal rice while the output was insignificantly different. The environmental efficiency of ecological rice was estimated about 85.54% and 84.54% for normal rice. Further, the technical efficiency of ecological rice and normal rice were 92.24% and 92.17%, respectively. The eco rice had a significantly higher pesticide use efficiency than the normal rice. Our findings suggest that the introduction of ecological engineering into rice production had positive impacts on the environmental and technical efficiency.

Key words: environmental efficiency; stochastic frontier analysis; ecological engineering

INTRODUCTION

With an annual cultivated area of 4.3 million hectares, rice is one of the major crops in the Vietnamese Mekong Delta (VMD). The VMD annually contributes more than 50% (about twenty-five million tons in 2013) of total rice production in Vietnam and earned more than USD 2 billion from exports in 2013 (GSO, 2013). The VMD, a “rice bowl” of Vietnam, was also approved by the Prime Minister to be one of the four regions to ensure national food security.

Despite being blessed with ideal weather conditions and good irrigation systems, water pollution from rice production, overuse of agro-chemicals (Dung & Dung, 1999; Ecobichon, 2001) and outbreaks of brown plant hoppers (Heong KL, 2009) caused considerable damage to the VMD’s ecological system and contributed to public health issues.

Owing to the importance of rice production as a means of livelihood for the majority of the population of the VMD, environmental protection is one of the first priorities in the region. In 2009, the use of ecological engineering in rice production (abbreviated as eco rice production hereafter) was firstly introduced in the Tien Giang Province through the Rice Plant Hopper Project, which was technically coordinated by the International

Rice Research Institute (IRRI) and financially supported by the Asian Development Bank. Methodologically, ecological engineering, which is a biological control based approach, requires farmers to cultivate flowering plants around the periphery of paddy fields to attract more natural enemies or beneficial organisms. Those natural enemies contribute to suppress pest populations under damaging levels. Farmers therefore use lower pesticides. After the first introduction, the model was expanded to other provinces because evidence showed despite higher labor cost for flower planting, the use of pesticides was much lower leading to lower total production cost for eco rice production (PPDAG, 2012). However, since the added economic and environmental benefits of this eco rice model are not awareness or underestimated, the model does not receive strong supports from local authorities and thus the coordination between them and the Rice Plant Hopper Project was low. As a result, the popularity of the eco rice model is low and some farmers do not want to apply this model.

According to Belbase and Grabowski (1985) and Shapiro and Müller (1977), the application of existing technologies was more cost-effective than the introduction of new ones if farmers were using existing methods inefficiently. However, the studies on the specific reduction of environmentally detrimental inputs (referred to as bad inputs hereafter) at the production possibility frontier, which means reducing bad inputs while increasing output, did not consider the VMD even though the eco rice production model was considered to be environmentally and economically efficient (Heong KL, 2009; PPDAG, 2012).

In recent years, some studies have focused on the technical efficiency (TE), which means the ability to reduce both normal and bad inputs, conditional on

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observed level of output in case of input-oriented TE or the ability to maximize output level, conditional on observed level of inputs in case of output-oriented TE of rice production in Vietnam. Kompas (2004) used panel data from 60 provinces in Vietnam for 1991–1999 and stochastic frontier analysis to estimate such TE. The study showed that the average TE of rice production was 59.2%, and increased from 55% in 1991 to 65% in 1999, while the estimated TE in the VMD was about 78% in 1999. However, this study was limited in scope, as it did not consider TE at the farm level. By contrast, Khai and Yabe (2011) used stochastic frontier analysis and farm-level data from the 2006 Vietnam Household Living Standards Survey to estimate the TE of 3,733 farmers. In their study, the mean TE was 81.6%, which is higher than that of Kompas (2004). Although these studies estimated the TE (the ability to reduce both normal and bad inputs together) of rice production in Vietnam, neither of them considered environmental efficiency (EE).

Environmental pollution as undesirable outputs was first introduced by Pittman (1983), followed by Färe *et al.* (1989). Pittman (1981) was also the first to propose pollution as an input vector. This approach was applied and modified by Reinhard *et al.* (1999) and Reinhard and Thijssen (2000). They have defined EE as the ratio of the feasible minimum to observed levels of bad inputs, conditional on observed levels of outputs and normal inputs. In other words, EE is the ability to reduce bad inputs to optimal levels while holding output and normal inputs constant.

Following those studies and the earlier-stated problems in eco rice production, this study aims at measuring and comparing EE of eco rice farmers in terms of the potential reduction of bad input vectors, that is, the possibilities of reducing bad inputs to those of traditional rice, using stochastic frontier analysis. The remainder of this paper is structured as follows: Section 2 describes the analytical framework and data collection procedure. Section 3 discusses the empirical results and compares the environmental and technical efficiencies between eco and normal rice. Section 4 presents a summary and conclusions.

METHODOLOGY

To measure and compare comprehensive EE scores of eco rice farmers to those of normal rice, we use stochastic frontier analysis. The detailed way to estimate EE scores for each farmer is described as follows:

A firm is assumed to use two types of inputs, X and Z , to produce a single output Y ($Y \in R_+$), where X ($X \in R_+$) contains normal input vectors and Z ($Z \in R_+$) are bad input vectors that adversely affect the environment.

The stochastic production function is defined as follows:

$$Y_i = f(X_i, Z_i, \beta, \alpha, \delta) \exp(v_i - u_i) \quad (1)$$

where β , α and δ are parameters to be estimated; v_i is a symmetric independently and identically distributed (i.i.d) random error term ($v_i \sim N[0, \sigma_v^2]$) that represents

exogenous effects beyond the farmers' control (e.g., the impact of adverse weather, natural disasters, and acts of God) and other measurement errors; u_i is a one-sided i.i.d. random error term ($u_i \geq 0$); $u_i \sim N^+(0, \sigma_u^2)$. The variance parameters of the model are computed as follows:

$$\sigma_s^2 = \sigma_v^2 + \sigma_u^2; \lambda = \frac{\sigma_u^2}{\sigma_v^2}; \gamma = \frac{\lambda^2}{1 + \lambda^2} = \frac{\sigma_u^2}{\sigma_s^2}$$

where λ is used for testing the presence of technical inefficiency and γ measures the general effect of technical inefficiency with the variation of actual output (Bravo-Ureta & Pinheiro, 1997).

The stochastic output-oriented TE of each farm can be estimated by multiplying $\exp(-v_i)$ on both sides of equation (1). This yields equation (2) as follows:

$$y_i^\circ = f(X_i, Z_i, \beta, \alpha, \delta) \exp(-u_i) = y_i \exp(-v_i) \quad (2)$$

where y_i° is the actual output of the i -th farm adjusted for v_i , the statistical noise effect (Bravo-Ureta & Rieger, 1991).

The TE measure is captured by the expression:

$$\begin{aligned} TE_i = \exp(-u_i) &= \frac{y_i \exp(-v_i)}{f(X_i, Z_i, \beta, \alpha, \delta)} \\ &= \frac{y_i}{f(X_i, Z_i, \beta, \alpha, \delta) \exp(v_i)} \end{aligned} \quad (3)$$

Where $u_i \geq 0$ and $0 \leq \exp(-u_i) \leq 1$. u_i is predicted by the conditional expectation of u_i , given the value of random composed error term ($v_i - u_i$) (Jondrow *et al.*, 1982). Based on this together with the given multiplicity of the production frontier model in equation (1), Battese and Coelli (1988) proposed the TE measure as:

$$TE_i = E[\exp\{-u_i\} | (v_i - u_i)] \quad (4)$$

In this study, we use the translog functional form, which is widely applied to estimate the stochastic production frontier (Coelli *et al.*, 2005) and to measure environmental efficiency (Reinhard *et al.*, 2000; Reinhard *et al.*, 1999; Reinhard & Thijssen, 2000). Equation (1) is then re-expressed in translog form as follows:

$$\begin{aligned} \ln Y_i &= \beta_0 + \sum_k \beta_k \ln X_k + \sum_m \alpha_m \ln Z_m \\ &+ \frac{1}{2} \sum_k \sum_n \beta_{kn} \ln X_k \ln X_n + \frac{1}{2} \sum_m \sum_h \alpha_{mh} \ln Z_m \ln Z_h \\ &+ \sum_k \sum_n \delta_{kn} \ln X_k \ln X_n + v_i - u_i \end{aligned} \quad (5)$$

where $\ln Y_i$ represents the natural logarithm of the output of the i -th farm.

EE is considered as one facet of TE because EE only estimates the possible reduction of bad inputs while input-oriented TE considers all inputs. A farm that is

considered to be technically efficient is necessarily environmentally efficient. For this reason, Reinhard *et al.* (2000); and Reinhard *et al.* (1999) proposed setting u_i equal to zero and replacing all bad inputs Z_{im} in equation (5) with ΦZ_{im} , where Φ is the EE score, in order to estimate EE. As a result, the reduction of bad inputs at the production frontier are adjusted for statistical noise v_i . This measure is more in line with the practical demands of farmers, whose economic goal is to expand output to the production frontier and reduce bad inputs to optimal levels.

The EE of the i -th farm is obtained by replacing Z_{im} in equation (5) with ΦZ_{im} and setting $u_i = 0$, which yields

$$\begin{aligned} \ln Y_i = & \beta_0 + \sum_k \beta_k \ln X_k + \sum_m \alpha_m \ln \Phi Z_m \\ & + \frac{1}{2} \sum_k \sum_n \beta_{kn} \ln X_k \ln X_n + \frac{1}{2} \sum_m \sum_h \alpha_{mh} \ln \Phi Z_m \ln \Phi Z_h \\ & + \sum_k \sum_n \delta_{kn} \ln X_k \ln \Phi Z_m + v_i \end{aligned} \quad (6)$$

As defined Section 1, EE is the ability to reduce bad inputs to an optimal level on the production frontier, holding the output and normal inputs constant (Figure 1 and 2). As such, the output in equation (6) is considered to be equal to that in equation (5). Setting equations (6) and (5) equal to one another yields

$$\begin{aligned} & \sum_m \alpha_m \ln \Phi Z_m - \sum_m \alpha_m \ln Z_m \\ & + \frac{1}{2} \sum_m \sum_h \alpha_{mh} \ln \Phi Z_m \ln \Phi Z_h - \frac{1}{2} \sum_m \sum_h \alpha_{mh} \ln Z_m \ln Z_h \\ & + \sum_k \sum_m \delta_{km} \ln X_k \ln \Phi Z_m - \sum_k \sum_m \delta_{km} \ln X_k \ln Z_m + u_i = 0 \end{aligned} \quad (7)$$

It should be noted that $\ln \Phi_i = \ln \Phi_i Z_{im} - \ln Z_{im}$

$$= \ln \left(\frac{\Phi_i Z_{im}}{Z_{im}} \right) = \ln EE_i. \text{ Some manipulation of equation (7)}$$

yields

$$a_i (\ln EE_i)^2 + b_i (\ln EE_i) + u_i = 0 \quad (8)$$

where $a_i = \frac{1}{2} \sum_m \sum_h \alpha_{mh} \forall a_i \neq 0$;

$$\begin{aligned} b_i = & \sum_m \alpha_m + \frac{1}{2} \sum_m \sum_h \alpha_{mh} (\ln Z_m + \ln Z_h) \\ & + \sum_k \sum_m \delta_{km} \ln X_k \end{aligned}$$

From equation (8), we can then calculate EE_i as follows:

$$EE_i = \exp \left(\frac{-b_i \pm \sqrt{b_i^2 - 4a_i u_i}}{2a_i} \right) \quad (9)$$

According to Reinhard *et al.* (1999), Reinhard *et al.* (2000) and Kouser and Mushtaq (2010), because a technically efficient firm must be environmentally efficient, we choose only the solution with $+\sqrt{}$ ($u_i = 0 \Rightarrow EE_i = TE_i = 1$). As a result, EE is obtained by the following expression:

$$EE_i = \exp \left(\frac{-b_i + \sqrt{b_i^2 - 4a_i u_i}}{2a_i} \right) \quad (10)$$

Following the same procedure, we can estimate pesticide use efficiency as a non-radial contraction of pesticide cost.

Figure 1 and 2 are the graphical illustrations that provide better understanding about the production frontier and the measures of technical and environmental efficiency in surface and cross-section, respectively.

Figure 1 represents the best practice frontier by the increasing, quasi-concave surface $OX_R R^F Z_R$. Point R is the observed farm that has output level Y_R produced using X_R and Z_R . The surface ABCR is the identical output quantity, Y_R , of farm R. From this surface, we can derive figure 2 as cross-sectional production frontier in normal (X) and bad (Z) input space, holding output level constant at Y_R .

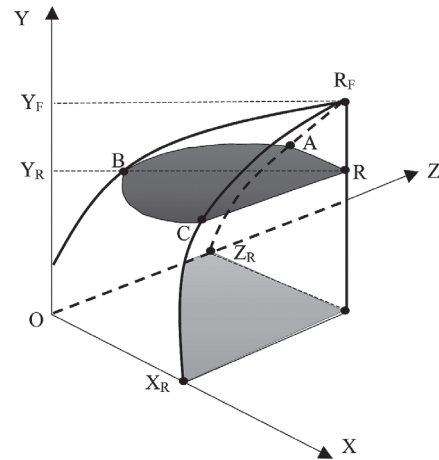


Fig. 1. 3-D graphical illustration of technical and environmental efficiency measures.

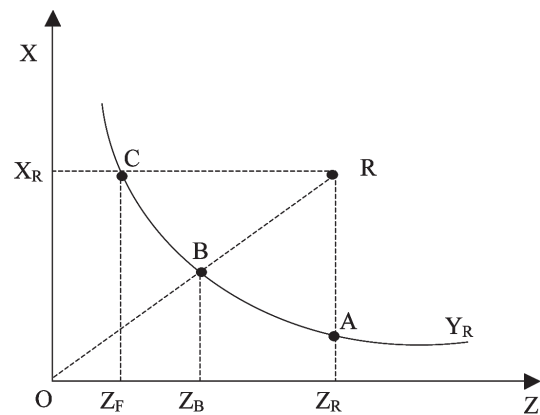


Fig. 2. Cross-sectional graph of input-oriented technical and environmental efficiency measures.

In figure 1, it is easy to obtain a measure of output-oriented technical efficiency, which is provided by the ratio of $|OY_R|/|OY_F|$. In figure 1, it is also possible to measure input-oriented technical efficiency as a radial contraction by the ratio of $|Y_R B|/|Y_R R|$. In figure 2, such measure (input-oriented technical efficiency) is provided by $|OB|/|OR|$.

Environmental efficiency, in turn, is measured as the ratio of minimum possible input use to observed input level, which is reflected by $|OZ_F|/|OZ_R|$ in figure 2. Stata software version 11 was used to estimate the stochastic production frontier and to calculate the TE and EE.

COLLECTION AND CHARACTERISTICS OF DATA

In 2012, An Giang Province contributed 3,941,526 tons of rice with a total cultivated area of 625,862 hectares, which was more than 16% of the VMD's total production from approximately 15% of the total cultivation area. It is the second largest rice producer in the VMD after Kien Giang Province (GSO, 2013; SOAG, 2013).

In March 2011, An Giang Province commenced adopting ecological engineering in rice production, starting with five districts as demonstration plots under the project "Technical Training and Demonstration of Ecological Engineering on Paddy Fields to Attract Natural Enemies against Pests and Brown Plant-Hoppers". In the winter and spring of 2011–2012, four other districts were selected to integrate ecological engineering, thus expanding the initial 50 hectares of farmland by another 40 (PPDAG, 2012). Since then, hundreds of farmers throughout the province have adopted ecological engineering.

Based on the suggestions from local authorities, the primary data of this study are collected in four districts (Thoai Son, Chau Doc, An Phu, and Tan Chau) where were considered to be the most crowded farmers who apply ecological engineering in their rice production. We

conducted face-to-face interviews with 199 farmers using the structured questionnaires. In which, 74 farmers had adopted ecological engineering and 125 farmers used traditional methods of producing rice.

Based on the moisture content, the rice output quantities of production function are catalogued two metrics: "wet" output has moisture content ranging from 20 to 25% and "dry" output has moisture content of around 14%. In the sample, since we found that approximately 75% of the farmers sold their products "wet" after harvesting, the 'wet' metric of output quantity was applied.

There are two types of inputs used in the stochastic frontier analysis, namely bad and normal one. The former includes active nutrients of nitrogen in kilograms per hectare (kg/ha), active nutrients of phosphorus and potash in kg/ha, and total pesticide and energy used in cost/ha. The latter includes seed quantity (from market and self-production), family labors capital (calculated based on the revaluation principle of capital stocks), and other expenditures (including harvester services, and pumping services), which were all measured in hectares. Table 1 describes the characteristics of the data set used in detail.

Table 1 shows that the output levels of eco rice (at the mean value of 7,097 kg/ha) is insignificant lower than that of normal rice (at the mean of 7,147 kg/ha), while pesticide costs of eco rice are about one million VND lower than that of normal rice. The difference in pesticide costs is significant at the 1% level, showing that the model of ecological engineering had positive effects on environment.

RESULTS

Prior to estimating the stochastic production frontier using the translog form, we have to test it against Cobb–Douglas form (Khalil, 2005; Reinhard *et al.*, 2000). Based on likelihood ratio of 55.44, which is larger than $\chi^2_{(28,1\%)}$ critical value of 48.27, suggesting that we reject

Table 1. Characteristics of data set[¶] used for environmental efficiency measurement

Indicator	Eco rice			Normal rice			T-value
	Mean	Min	Max	Mean	Min	Max	
Output quantity [†] (Y)	7097.03	5902.78	8865.43	7147.79	5015.43	8217.59	−0.51
<i>Bad inputs</i>							
Nitrogen quantity [†] (Z ₁)	101.73	50.62	152.01	112.54	70.85	176.85	−3.27***
Potash and phosphorus [†] (Z ₂)	119.98	63.27	192.52	116.12	74.13	199.85	1.17
Pesticide cost ^ω (Z ₃)	3570.76	1697.53	7330.25	4539.16	2341.82	10030.86	−4.65***
Energy costs ^ω (Z ₄)	1511.11	430.17	2808.06	1576.32	614.53	3169.14	−0.81
<i>Normal inputs</i>							
Seed quantity [†] (X ₁)	100.18	23.15	216.05	153.61	11.57	366.51	−5.11***
Labor ^ω (X ₂)	261.02	188.27	335.65	245.76	169.75	349.15	2.83***
Others ^ω (X ₃)	5262.18	2338.70	8046.77	8257.51	3233.00	24634.27	−8.97***

ω: in thousand VND/ha; †: kg/ha; ¶: average values for one year;

*** indicates the 1% level of significance

Source: Own estimates, data available from the authors

the null hypothesis or the restricted model is inappropriate to our data. We therefore decided to use the translog function for MLE regression.

We now estimate the stochastic frontier production and calculate EE. Table 2 shows the results of MLE regression models that estimate TE and EE.

It is clear that the estimated value of λ is non-zero

($\lambda = 5.07$). The null hypothesis of the inefficiency absence is rejected at the significant level of 0.1% using Z-statistic (z-value = 453.14) or using LR-test (LR value = 34.35), showing the existence of technical inefficiency for these rice farmers (see Table 2). This result is consistent with Khai and Yabe (2011) and Kompas (2004). Based on the estimated value of $\gamma = 0.9626$, which means

Table 2. Coefficients of translog function form with MLE

Predictor	MLE		Predictor	MLE	
	Coefficient	Std. error		Coefficient	Std. error
$\ln Z_1$	8.4285	2.6322	$\ln Z_2 \ln X_2$	0.0045	0.3538
$\ln Z_2$	-0.2990	2.0779	$\ln Z_2 \ln X_3$	-0.0382	0.0970
$\ln Z_3$	-0.5218	1.2569	$(\ln Z_3 \ln Z_3)/2$	-0.1367	0.0778
$\ln Z_4$	0.1494	1.1283	$\ln Z_3 \ln Z_4$	-0.0791	0.0470
$\ln X_1$	-0.5249	0.6797	$\ln Z_3 \ln X_1$	0.0279	0.0288
$\ln X_2$	4.0396	6.1533	$\ln Z_3 \ln X_2$	0.3145	0.1816
$\ln X_3$	0.8232	1.5476	$\ln Z_3 \ln X_3$	-0.0298	0.0638
$(\ln Z_1 \ln Z_1)/2$	-1.0024	0.1979	$(\ln Z_4 \ln Z_4)/2$	-0.0105	0.0534
$\ln Z_1 \ln Z_2$	-0.0173	0.1399	$\ln Z_4 \ln X_1$	-0.0716	0.0296
$\ln Z_1 \ln Z_3$	0.0141	0.0965	$\ln Z_4 \ln X_2$	0.0969	0.1332
$\ln Z_1 \ln Z_4$	-0.0839	0.0767	$\ln Z_4 \ln X_3$	0.0326	0.0600
$\ln Z_1 \ln X_1$	0.1263	0.0455	$(\ln X_1 \ln X_1)/2$	-0.0259	0.0163
$\ln Z_1 \ln X_2$	-0.7918	0.3329	$\ln X_1 \ln X_2$	0.079	0.0942
$\ln Z_1 \ln X_3$	0.1010	0.1212	$\ln X_1 \ln X_3$	-0.0184	0.0247
$(\ln Z_2 \ln Z_2)/2$	-0.2004	0.2186	$(\ln X_2 \ln X_2)/2$	-0.5827	1.0421
$\ln Z_2 \ln Z_3$	0.1065	0.0827	$\ln X_2 \ln X_3$	-0.0522	0.2089
$\ln Z_2 \ln Z_4$	0.1135	0.0566	$(\ln X_3 \ln X_3)/2$	-0.0724	0.1005
$\ln Z_2 \ln X_1$	0.0129	0.0308	Constant	-24.2995	22.7102
λ	5.0752	0.0112	Wald χ^2 value	387.16	
γ	0.9626		LR test $\sigma_u=0$	34.35	
Log Likelihood	265.96				

Source: Own estimates, data available from the authors

Table 3. Comparison of environmental efficiency between eco and normal rice

EE levels	Eco rice		Normal rice	
	No. farmer	Percentage	No. farmer	Percentage
≥ 90	30	40.54	51	40.80
80–90	22	29.73	42	33.60
70–80	16	21.62	21	16.80
60–70	6	8.11	5	4.00
≤ 60	0	0.00	6	4.80
Mean EE	85.54		84.54	
Min	67.92		52.96	
Max	98.42		98.34	
Standard Deviation	8.97		10.94	
T-value		0.66		

Source: Own estimates, data available from the authors

that 96.29% of the total variation of output levels is due to technical inefficiency.

We now turn to estimate environmental, technical and pesticide use efficiency. As expected from the eco rice model, its environmental and pesticide use efficiency are higher than that of normal rice. The EE scores of both eco and normal rice are presented in Table 3.

Table 3 shows that although the average EE of eco rice (85.54%) is slightly higher than that of normal rice (84.54%), this difference is insignificant at the 5% level. These values indicate that eco rice farmers and normal rice farmers can reduce approximately 14.46% and 15.46%, respectively, of their current use of bad inputs if holding output and normal inputs constant. However, the normal rice farmers had greater variation in EE scores than the eco rice ones. In fact, there was about 5% of the normal rice farmers who had EE scores distributed below 60% while none of the cases were found for the eco rice farmers. This result partially implies that the introduction of ecological engineering into rice production had positive effects on the environment.

In order to produce more holistic policy implications to disseminate the model, we also estimated the ability to contract only pesticide use (pesticide use efficiency), given other inputs and output constant, and to maximize actual output levels (output-oriented TE), given both bad and normal inputs. Table 4 and 5 illustrate the pesticide use efficiency and TE results, respectively, of both eco rice farmers and normal rice farmers.

It is clearly shown in Table 4 that the eco rice farmers had a significantly higher pesticide use efficiency than those of normal rice. The average pesticide use efficiency of eco rice was 33.95% and 20.77% for normal rice, suggesting that the eco rice and normal rice farmers could realize to reduce about 72.05% and 79.23%, respectively, of their current use of pesticide if holding other inputs and output constant.

We now turn to estimate the output-oriented TE, which is summarized in Table 5 below:

Table 5 shows that the average output-oriented TE is a bit higher for eco rice (92.24%) than that for normal rice (92.17%), but in general, the difference is insignifi-

Table 4. Comparison of pesticide use efficiency between eco and normal rice

Levels	Eco rice		Normal rice	
	No. farmer	Percentage	No. farmer	Percentage
≥ 70	5	6.76	4	3.20
60–70	4	5.40	2	1.60
50–60	8	10.81	4	3.20
40–50	8	10.81	6	4.80
30–40	12	16.22	14	11.20
20–30	15	20.27	17	13.60
≤ 20	22	29.73	78	62.40
Mean	33.95		20.77	
Min	6.37		2.67	
Max	80.25		85.74	
Standard deviation	18.95		17.17	
T-value			5.03	

Table 5. Comparison of technical efficiency between eco and normal rice

TE levels	Eco rice		Normal rice	
	No. farmer	Percentage	No. farmer	Percentage
≥ 90	53	71.62	94	75.20
80–90	21	28.38	21	16.80
≤ 80	0	0.00	10	8.00
Mean TE	92.24		92.17	
Min	80.21		71.16	
Max	99.31		99.04	
Standard deviation	5.14		6.37	
T-value			0.09	

Source: Own estimates, data available from the authors

cant at the 5% level. These values of TE indicate that the eco rice and normal rice farmers could expand their output levels about 7.76% and 7.83%, respectively, holding all inputs constant. The variation of TE scores was also greater for the normal rice than for the eco rice. As shown in Table 4 that 8% of the normal rice farmers had the TE scores distributed under 80%, suggesting that those farmers could realize to expand their output levels by more than 20%. Whereas, as regards the eco rice, 100% of the farmers had the TE scores distributed above 80%.

In conclusion, although the comprehensive EE and TE scores of eco rice insignificantly differ from that of normal rice, the pesticide use efficiency of eco rice was significantly higher. In addition, based on the overall distribution and variation and the significant lower use of pesticides, we can suggest that the ecologically engineered rice production is more environmentally friendly and technically efficient than conventional rice cultivation.

CONCLUSIONS

In 2009, ecological engineering rice production was introduced in the Mekong Delta of Vietnam coordinated by the IRRI. Despite its positive effects on environmental protection, the model was not so popular even after four years of implementation. Results from our descriptive statistics showed that the output quantity of eco rice production was slightly but insignificant lower than that of normal rice (approximately 7,097 kg/ha and 7,147 kg/ha, respectively), while the costs of pesticide were much lower for eco rice than for normal rice.

We used the approach of stochastic frontier analysis to estimate and compare the EE, output-oriented TE and pesticide use efficiency of ecologically engineered rice cultivation with that of traditional rice cultivation. We estimated that the average comprehensive EE score of eco rice cultivation was approximately 1% higher than that of normal rice. Similarly, the average TE was also higher for eco rice (92.24%) than for normal rice (92.17%). Although these differences were insignificant, the variations of both the EE and TE scores were greater for the normal rice than for the eco rice. Further, the pesticide use efficiency of eco rice was significantly higher than that of normal rice. These results suggested that ecologically engineered rice cultivation was more environmentally friendly and to some extent had more potential to expand actual output to the production function frontier.

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