ISSN 1533-9211

DOI 10.5281/zenodo.7418084

MEASURE RICE PRODUCTION EFFICIENCY BY APPLYING DEA MODEL

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Abstract

The objective of the study is to measure the production efficiency of farmers by Data Envelopment Analysis (DEA). The data in the study were collected from 750 rice-farming households in the Mekong Delta region, Vietnam. The DEA helps estimate the production efficiency of rice-producing farmers with the following criteria: technical efficiency (TE), allocative efficiency (AE), cost efficiency (CE), and scale efficiency (SE). The research results show that rice-farming households achieve high SE. Meanwhile, the CE is relatively low. Based on the DEA result, the study indicates that rice farmers should adjust their production scale and input resources to improve production efficiency.

Keywords: scale efficiency, farmer, rice production, DEA

1. INTRODUCTION

The Mekong Delta region, with its strength in natural conditions and resources, has become a key food region and the leading agricultural product exporter of Vietnam. The Mekong Delta is the largest rice-producing region in Vietnam, with a cultivated area of about 4.2 million hectares, accounting for 54.5% of the rice-growing area of the nation (General Statistics Office, 2020). Rice production and export is one of the main economic sectors of the region and the source of residential livelihood (Dung et al., 2019). Several studies have shown that the rice production efficiency in the Mekong Delta has not been optimized (Thong et al., 2011; Dang, 2012; Nghi et al., 2014; Nguyen, 2017). This is because farmers predominantly plant rice based on their habits and lack new technique application, which increases production costs and reduces efficiency (Nghi, 2011; Son and Thanh, 2014; Dung et al., 2016). Currently, rice farmers in the Mekong Delta region face huge changes in market prices (Thanh and Nghi, 2019), farming methods, and climate change (Dung et al., 2019). In recent years, most farmers in the region have changed their production methods to increase output and productivity (Nghi and Nam, 2021). It is essential to analyze the production efficiency, allocative efficiency, and cost efficiency to help farmers realize the unreasonable distribution of input resources, propose solutions to improve productivity and enhance efficiency.

2. THEORETICAL FRAMEWORK AND RESEARCH MODEL

2.1. Theoretical framework

According to Coelli et al. (2005), production efficiency contains technical efficiency (TE), allocative efficiency (AE), and cost efficiency (CE). It can be measured using the Constant returns to scale input-oriented DEA Model, the CRS-DEA Model. The model is suitable for rice production using multiple inputs – one output as in this study. To estimate the TE, AE, and

ISSN 1533-9211

DOI 10.5281/zenodo.7418084

CE of each household, a set of linear equations is established. The CRS Input-Oriented DEA model below helps solve the problem.

Minimize [$\square_{,x_i*}$ $w_i{}' x_i^*$] with the condition:

$$\left\| \begin{array}{l} \sum_{i=1}^{N} \lambda_i x_{ji} - x_{ji}^{*} \le 0, \forall j \\ \sum_{i=1}^{N} \lambda_i y_{ki} - y_{ki} \ge 0, \forall k \\ \lambda_i \ge 0, \forall i \end{array} \right\| \qquad (1)$$

In which:

w_i = "unit price" vector of production factors that belong to the i-th DMU

x_i^* = "the number of inputs" vector in the direction of minimizing production costs of the i-th DMU, determined by model (1),

i = 1 to N (the number of DMUs),

k = 1 to S (the number of products),

j = 1 to M (the number of inputs),

y_{ki} = quantity of product k produced by the i-th DMU,

x_{ji} = the number of input j used by the i-th DMU,

$\square_i$ = dual variables

The estimation of TE, AE, and CE in the model (1) can be performed by various computer programs. However, to be convenient for the study, the authors applied DEAP 2.1 software support analyses.

Figure 1 illustrates a simple geometric method to measure TE, AE, and CE. If a production unit is at point A, the estimated values of TE, AE, and CE at this point are calculated as follows:

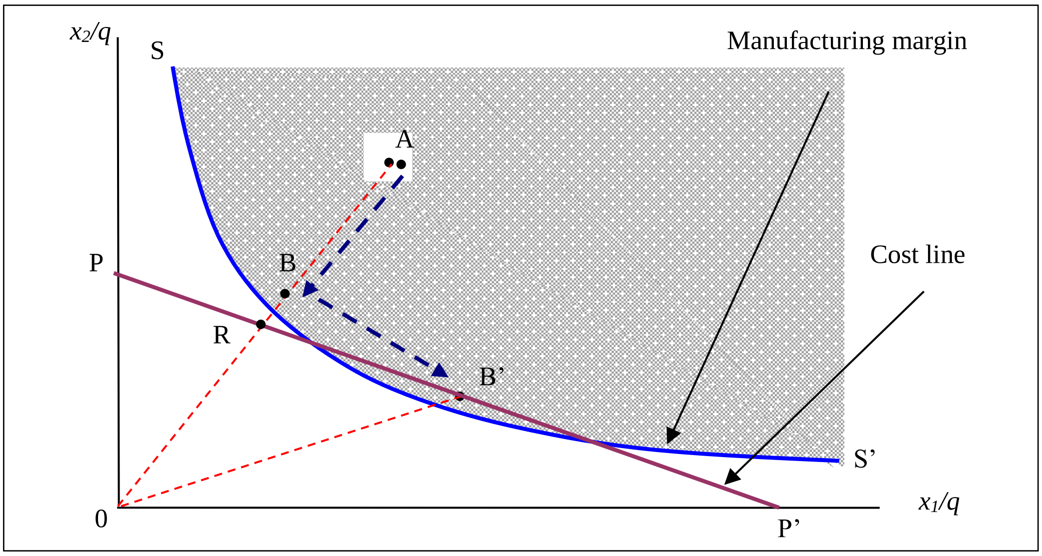
$$TE_A = \overline{OB} / \overline{OA}$$

$$AE_A = \overline{OR} / \overline{OB}$$

$$CE_A = \overline{TE}_A x \overline{AE}_A = (\overline{OB} / \overline{OA}) x (\overline{OR} / \overline{OB}) = \overline{OR} / \overline{OA}$$

ISSN 1533-9211
DOI 10.5281/zenodo.7418084

Figure 1: Technical efficiency, allocative efficiency, and cost efficiency (Coelli et al., 2005)



Scale efficiency (SE) model

In recent decades, plenty of studies separated the technical efficiency (TE) obtained from the constant returns to scale (CRS) into "pure" technical inefficiency and scale inefficiency. Therefore, the scale efficiency (SE) method can be used to measure the quantity. Hence, productivity can be enhanced by varying the production scale following a defined optimal scale (Coelli et al., 2005).

To measure SE by the DEA method, there should be an additional margin of production: Constant returns to scale - Data enveloped analysis (CRS-DEA). The SE measurement can then perform for each producer by comparing the TE obtained from the CRS-DEA with the TE obtained from the Variable returns to scale-DEA (VRS-DEA). If there is a difference in TE between CRS-DEA and VRS-DEA for a particular producer, it implies that there is scale inefficiency (Scale Inefficiency = 1 – Scale Efficiency).

According to Coelli et al. (2005), SE can be measured using the Variable Returns to Scale Input - Oriented DEA Model, VRS-DEA Model. Concerning the multi-input multi-output case as in this study. Assume a situation with N decision-making units (DMUs), each of which produces S products using M different input variables. According to the above case, to estimate the SE of each DMU, a set of linear programs is established.

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DOI 10.5281/zenodo.7418084

The VRS-DEA model helps solve this problem in the following form:

$$\text{Minimize } \left\| _{\theta_p,\lambda}\{\theta_p\} \right\|$$

$$\text{With the condition: } \begin{Bmatrix} \sum_{i=1}^{N} \lambda_i x_{ji} - \theta x_{jp} \le 0, \forall j \\ \sum_{i=1}^{N} \lambda_i y_{ki} - y_{kp} \ge 0, \forall k \\ N1'\lambda_i = 1 \\ \lambda_i \ge 0, \forall i \end{Bmatrix} \quad (2)$$

In which:

□p = efficiiency value,

i = 1 to N (the number of DMUs),

k = 1 to S (the number of products),

j = 1 to M (the number of inputs),

y_{ki} = quantity of product k produced by i-th DMU,

x_{ji} = the number of input j used by i-th DMU,

N1= Nx1 vector 1,

□$_i$ = dual variables.

Estimating SE in model (2) is performed by the DEAP 2.1 software.

2.2. Research methodology

The data of the study were collected by direct interviews with 750 farmers in Cho Moi, Chau Phu, and Tri Ton District (An Giang Province); Phung Hiep, Long My, Chau Thanh, Vi Thanh District (Hau Giang Province); Tan Hiep, Hon Dat, An Bien District (Kien Giang Province) by stratified random sampling. Survey criteria include administrative location, production scale, and rice cultivation characteristics.

Assessing the production efficiency of rice farmers in the Mekong Delta, there are several different methods to apply. In this study, the Data Envelopment Analysis (DEA) is used to measure technical efficiency (CE), allocative efficiency (AE), cost efficiency (CE), and scale efficiency (SE). Collected data includes characteristics of rice production models at three periods: Winter-Spring, Summer-Autumn, and Autumn-Winter crop. The criteria include output, input quantity, and input price (seed, fertilizer, pesticide, fuel, workday, and equipment). These variables in the Input-Orientated DEA Model used to measure TE, AE, CE, and SE by DEAP 2.1 software are presented in the below table.

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DOI 10.5281/zenodo.7418084

Table 1: Varibles in DEA model

Variable	Unit	Mean	Max	Min
Winter-Spring crop				
Quantity	Kg/ha	7,587.65	13,500.00	5,000.00
Input				
Seed	Kg/ha	176.04	300.00	4000
UREA fertilizer	Kg/ha	145.84	580.00	0.00
DAP fertilizer	Kg/ha	116.56	500.00	0.00
LAN fertilizer	Kg/ha	45.05	500.00	0.00
KALI fertilizer	Kg/ha	88.07	500.00	0.00
NPK fertilizer	Kg/ha	75.91	700.00	0.00
Herbicide	Litter/ha	606.67	1,200.00	280.00
Pesticide	Litter/ha	2,808.26	6,000.00	1,000.00
Growing medicine	Litter/ha	550.78	1,920.00	0.00
Fuel	Litter/ha	36.10	150.00	0.00
Workday	Workday/ha	15.34	50.00	3.75
Equipment	Hour/ha	15.62	36.75	7.55
Input price unit				
Seed	1.000 VND/kg	11.09	110.00	4.00
UREA fertilizer	1.000 VND/kg	10.18	16.00	0.00
DAP fertilizer	1.000 VND/kg	13.67	19.60	0.00
LAN fertilizer	1.000 VND/kg	1.07	7.00	0.00
KALI fertilizer	1.000 VND/kg	11.98	17.00	0.00
NPK fertilizer	1.000 VND/kg	7.40	19.20	0.00
Herbicide	1.000 VND/litter	1.09	3.32	0.10
Pesticide	1.000 VND/litter	1.45	4.13	0.12
Growing medicine	1.000 VND/litter	1.19	5.50	0.00
Fuel	1.000 VND/litter	22.07	26.30	000
Workday	1.000 VND/day	136.33	160.00	75.00
Equipment	1.000 VND/hour	237.76	350.00	120.00
Summer-Autumn crop				
Quantity	Kg/ha	6,280.19	10,000.00	4,230.0
Input				
Seed	Kg/ha	191.98	300.00	54.00
UREA fertilizer	Kg/ha	149.30	580.00	0.00
DAP fertilizer	Kg/ha	123.91	500.00	0.00
LAN fertilizer	Kg/ha	60.29	500.00	0.00
KALI fertilizer	Kg/ha	102.84	300.00	0.00
NPK fertilizer	Kg/ha	73.00	500.00	0.00
Herbicide	Litter/ha	584.40	1,200.00	0.00
Pesticide	Litter/ha	3,048.33	6,000.00	1,000.00
Growing medicine	Litter/ha	550.67	2,400.00	0.00
Fuel	Litter/ha	37.66	180.00	0.00
Workday	Workday/ha	15.73	52.26	3.75
Equipment	Hour/ha	15.30	34.67	5.58
Input price unit				
Seed	1.000 VND/kg	8.92	40.00	4.30
UREA fertilizer	1.000 VND/kg	10.23	15.20	0.00

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DOI 10.5281/zenodo.7418084

Variable	Unit	Mean	Max	Min
DAP fertilizer	1.000 VND/kg	13.75	18.30	0.00
LAN fertilizer	1.000 VND/kg	1.04	5.00	0.00
KALI fertilizer	1.000 VND/kg	12.15	16.60	0.00
NPK fertilizer	1.000 VND/kg	7.50	18.30	0.00
Herbicide	1.000 VND/litter	1.01	2.92	0.00
Pesticide	1.000 VND/litter	1.25	4.55	0.11
Growing medicine	1.000 VND/litter	1.10	5.24	0.00
Fuel	1.000 VND/litter	22.31	26.33	0.00
Workday	1.000 VND/day	129.98	155.00	55.00
Equipment	1.000 VND/hour	238.39	350.00	120.00
Autumn - Winter crop				
Quantity	Kg/ha	5,912.26	9,000.00	3,970.00
Input				
Seed	Kg/ha	187.43	300.00	54.00
UREA fertilizer	Kg/ha	158.33	580.00	0.00
DAP fertilizer	Kg/ha	131.24	300.00	0.00
LAN fertilizer	Kg/ha	799	385.00	0.00
KALI fertilizer	Kg/ha	96.18	300.00	0.00
NPK fertilizer	Kg/ha	77.61	600.00	0.00
Herbicide	Litter/ha	619.94	1,725.00	0.00
Pesticide	Litter/ha	3,160.49	4,500.00	344.62
Growing medicine	Litter/ha	792.20	3,232.00	0.00
Fuel	Litter/ha	38.77	95.65	0.00
Workday	Workday/ha	14.45	52.82	3.75
Equipment	Hour/ha	13.20	26.13	6.28
Input price unit				
Seed	1.000 VND/kg	8.76	19.50	1.30
UREA fertilizer	1.000 VND/kg	10.21	18.00	0.00
DAP fertilizer	1.000 VND/kg	13.88	1870	0.00
LAN fertilizer	1.000 VND/kg	0.29	5.50	0.00
KALI fertilizer	1.000 VND/kg	11.36	17.30	0.00
NPK fertilizer	1.000 VND/kg	7.00	19.00	0.00
Herbicide	1.000 VND/litter	0.95	2.97	0.00
Pesticide	1.000 VND/litter	1.37	3.84	0.12
Growing medicine	1.000 VND/litter	1.02	4.78	0.00
Fuel	1.000 VND/litter	22.49	25.00	0.00
Workday	1.000 VND/day	134.79	150.00	92.50
Equipment	1.000 VND/hour	269.16	350.00	120.00

3. RESEARCH RESULTS AND DISCUSSION

3.1 The TE, AE, and CE value of rice-farming households

The TE, AE, and CE minimize the input quantity under the condition that scale does not affect production results (in the range of 0 to equal to 1). The coefficient equal to 1 shows the efficiency in rice production. If it achieves a value less than 1, the production is not efficient.

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DOI 10.5281/zenodo.7418084

Table 2: Technical efficiency, allocative efficiency, and cost efficiency of rice farmers in the Mekong Delta region

Efficiency value	Winter-Spring crop		Summer-Autumn crop		Autumn - Winter crop	
	Number of households	Percentage (%)	Number of households	Percentage (%)	Number of households	Percentage (%)
Technical efficiency						
1.00	136	18.1	149	20.7	103	27.5
0.90 – 0.99	124	16.5	123	17.1	63	16.8
0.80 – 0.89	173	23.1	168	23.3	77	20.6
0.70 – 0.79	175	23.3	151	20.9	84	22.5
0.60 – 0.69	96	12.8	97	13.5	40	10.7
0.50 – 0.59	36	4.8	30	4.2	7	1.9
0.40 – 0.49	10	1.3	3	0.4	0	0.0
< 0.40	0	00	0	0.0	0	0.0
Total	750	100.0	721	100.0	374	100.0
Mean	0.827		0.837		0.859	
Max	1		1		1	
Min	0.416		0.460		0.511	
Allocative efficiency						
1.00	0	0.0	0	0.0	1	0.3
0.90 – 0.99	2	0.3	1	0.1	0	0.0
0.80 – 0.89	5	0.7	21	2.9	25	6.7
0.70 – 0.79	142	18.9	219	30.4	70	18.7
0.60 – 0.69	337	44.9	296	41.1	72	19.3
0.50 – 0.59	189	25.2	136	18.9	143	38.2
0.40 – 0.49	57	7.6	36	5.0	52	13.9
< 0.40	18	2.4	12	1.7	11	2.9
Total	750	100.0	721	100.0	374	100.0
Mean	0.624		0.652		0.607	
Max	0.909		0.936		1	
Min	0.337		0		0.298	
Cost efficiency						
1.00	0	0.0	0	0.0	1	0.3
0.90 – 0.99	2	0.3	1	0.1	0	0.0
0.80 – 0.89	1	0.1	11	1.5	6	1.6
0.70 – 0.79	23	3.1	32	4.4	15	4.0
0.60 – 0.69	97	12.9	161	22.3	57	15.2
0.50 – 0.59	282	37.6	271	37.6	119	31.8
0.40 – 0.49	250	33.3	193	26.8	121	32.4
< 0.40	95	12.7	52	7.2	55	14.7
Total	750	100.0	721	100.0	374	100.0
Mean	0.511		0.542		0.517	
Max	0.909		0.936		1	
Min	0.231		0		0.258	

Source: Estimated result from DEAP 2.1 software

ISSN 1533-9211
DOI 10.5281/zenodo.7418084

Technical efficiency (TE)

The average TE value in all three crops is relatively high: Winter-Spring crop - 0.827, Summer-Autumn crop - 0.837, and Autumn-Winter crop - 0.859. In which, most farmers achieve TE with a value of over 0.60. The proportions of farmers achieving the optimal TE values are as follows: Winter-Spring 18.10%; Summer-Autumn 20.7%, and Fall-Winter 27.5%. Households with TE < 0.6 accounted for only 1-5% in all three crops. These results show that farmers gain high technical efficiency. Production experiences accumulated over years along with the application of advanced technologies and the participation in field-training sessions have helped farmers to use inputs reasonably. This leads to higher technical efficiency. On the other hand, the result suggests that households whose TE values less than 1 should reduce the quality of input factors. With the output achieved, farmers should use about 80% of the input resources to avoid input waste and obtain higher technical efficiency.

Allocative efficiency (AE)

The average AE value of rice production in the Mekong Delta is over 0.6 in all three crops, with the highest variation of 1.00 in the Autumn-Winter crop and the lowest value of 0.00 in the Summer-Autumn crop. Besides, the AE value tends to revolve around a column of values from 0.6 to 0.7, although this value does not reach the optimal AE (1.00), it is relatively high. Compared with the other two crops, the Summer-Autumn crop achieves the highest average AE (0.652). In the Autumn-Winter crop, the percentage of farmers reaching the low level of AE from 0.5 to 0.59 (38%) is higher than the other two crops. Meanwhile, both Winter-Spring and Summer-Autumn crops achieve the AE value from 0.60 - 0.79. This indicates that the coordination of inputs such as seed, fertilizer, pesticide, labor, etc. is still not reasonable. This reason can be the unstable input prices recently. Besides, farmers purchase inputs at different prices depending on their status and relationship with sellers. Therefore, the inconsistency in input prices (selling and hiring), especially the recent rapid increase in prices has reduced the AE of most farmers in rice production.

Cost efficiency (CE)

Cost efficiency or general economic efficiency of rice-producing households is calculated based on technical efficiency and allocative efficiency in production. The result in table 2 shows that the CE of rice production in the Mekong Delta is low and has a high level of dispersion. The Summer-autumn crop achieves the highest CE at 0.542, followed by the Autumn-Winter crop (0.517), and the Winter-Spring crop is 0.511. The dispersion of CE value is quite large: Winter-Spring crop [0.231; 0.909], Summer-Autumn crop [0.00; 0.936], and Autumn-Winter [0.258; first]. Also, the result confirms that, if a household whose CE is at average level tries to meet the same level as the most-efficient household, that household may save a significant amount of money. The amount of Summer-Autumn, Autumn-Winter, and Winter-Spring crops that can be achieved will be 0.394 (0.936-0.542), 0.483 (1-0.517), and 0.398 (0.909-0.511). Similarly, the producer with the lowest CE value in each crop may save an amount of 0.936 (0.936-0), 0.742 (1-0.258), and 0.678 (0.909- 0.231).

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ISSN 1533-9211
DOI 10.5281/zenodo.7418084

3.2. Scale efficiency (SE)

Based on table 3, the average SE in all three production crops Winter-Spring, Summer-Autumn, and Autumn-Winter is 0.901, 0.908, and 0.916, respectively. This points out that the SE of rice farming is high. Most production households (from 79.3%, 73.5%, and 67.9%) can increase efficiency by increasing the scale of investment. The number of households that need to reduce the investment scale is small. Besides, the number of households achieving optimal scale efficiency is significant. According to the survey result, most rice-farming households cultivate in small and fragmented areas. The number of households with an area of more than five hectares is small, the average area reaches 25,500 square meters. This has reduced the rice-farming productivity.

Table 3: Scale efficiency of households in the Mekong Delta region

Scale efficiency	Winter-Spring crop		Summer-Autumn crop		Autumn-Winter crop	
	Household	Percentage (%)	Household	Percentage (%)	Household	Percentage (%)
Total number of rice-producing households	750	100.0	721	100.0	374	100.0
Households with increasing returns to scale (IRS)	595	79.3	530	73.5	254	67.9
Households with decreasing returns to scale (DRS)	13	1.7	22	3.1	10	2.7
Households with constant returns to scale (CRS)	142	18.9	169	23.4	110	29.4
Mean SE	0.901		0.908		0.916	
Min	0.573		0.611		0.603	
Max	1.000		1.000		1.000	

Source: Estimated result from DEAP 2.1 software

4. CONCLUSION AND IMPLICATIONS

Overall, considering the constant returns to scale, rice farmers in the Mekong Delta achieve a high level of TE, an average level of AE and CE. Considering the variable returns to scale, most rice-producing households are to the extent that the efficiency can be improved if the scale increases. To improve production efficiency, rice-producing households need to improve production techniques and AE to increase CE, and at the same time change the scale. The majority of households enhance the scale to increase efficiency. The survey result also shows that rice farmers can reduce costs by the rational allocation of input resources. Farmers can refer to the proposed resource allocation from the DEA result below to increase productivity and efficiency.

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ISSN 1533-9211

DOI 10.5281/zenodo.7418084

Table 4: Input allocation according to the actual survey and the DEA proposed result

Input	Winter-Spring crop		Summer-Autumn crop		Autumn-Winter crop	
	Reality	Proposal	Reality	Proposal	Reality	Proposal
Seed (kg/ha)	176.04	114.86	191.98	112.29	187.43	136.61
UREA fertilizer (kg/ha)	145.84	78.90	149.30	39.74	158.33	65.02
DAP fertilizer (kg/ha)	116.56	34.43	123.91	73.39	131.24	36.47
LAN fertilizer (kg/ha)	45.05	2.07	60.29	0.00	7.99	0.00
KALI fertilizer (kg/ha)	88.07	53.65	102.84	55.72	96.18	45.78
NPK fertilizer (kg/ha)	75.91	90.65	73.00	115.14	77.61	210.60
Herbicide (litter/ha)	606.67	467.06	584.40	538.02	619.94	525.51
Pesticide (litter/ha)	2.808.26	2.047.29	3.048.33	486.11	3.160.49	1.660.39
Growing medicine (litter/ha)	550.78	376.12	550.67	348.94	792.20	564.81
Fuel (litter/ha)	36.10	21.35	37.66	32.15	38.77	19.96
Workday (workday/ha)	15.34	9.58	15.73	8.28	14.45	6.91
Equipment (hour/ha)	15.62	6.39	15.30	9.33	13.20	7.76

Source: Calculation, result from survey data and DEA model

In addition to this, the number of households with small and fragmented areas accounts for 70%. The small area is one of the causes of production efficiency reduction. On the one hand, it is difficult to move and run machines in the harvesting, thereby wasting input resources. Also, due to low output, it is difficult to find consumption markets. From the assessment result of variable returns to scale, farmers can increase efficiency by increasing their scale. Insofar as input factors cannot increase, the production area can be expanded in many ways such as regrouping lands, cooperation in cultivating, or participating in large-field models are effective solutions to increase productivity.

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