Technical efficiency of rice farming in Aceh Province, Indonesia

H Gunawan¹, M S A Majid²*, R Masbar²

¹BPS-Indonesian Statistics, Banda Aceh, Indonesia and Department of Economics, Faculty of Economics and Business, Universitas Syiah Kuala (USK), Banda Aceh, Indonesia
²Department of Economics, Faculty of Economics and Business, Universitas Syiah Kuala (USK), Banda Aceh, Indonesia

*Email: mshabri@unsyiah.ac.id

Abstract. This study measures the technical efficiency of rice farming in Aceh Province, Indonesia. A sample of 5,351 households from the 2017 Household Farming Cost Structure Survey conducted by the Central Bureau of Statistics of Aceh Province, Indonesia were gathered and analysed using the Data Envelopment Analysis (DEA). Three inputs (i.e., number of labour working days, fertilizer, and seeds) and one output (i.e., number of rice harvest) were used to measure the technical efficiency of rice farming in the province. The study recorded a very low average level of technical efficiency either using a Constant Return to Scale (CRS) or a Variable Return to Scale (VRS) approaches. Two inputs were found not optimal for rice farming activities, namely the number of labour working days and the use of fertilizers, while the use of seeds was found optimal. The study suggests that the farmers should use fertilizers proportionately to the land area. The use of agricultural technology should be intensified to minimize the use of excess labour to reduce wage spending.

1. Introduction

The agricultural sector, especially the food crop sector, has an important role in the Indonesian economy. The food crop sector accounts for 3.07% of Indonesia's GDP. This value is greater than the contribution of Extraction of Crude Petroleum, Natural Gas, and Geothermal which were around 2.15%[1], but the food crops sector can absorb more labour, especially in rural areas. The food crop sector plays a crucial role in fulfilling the basic consumption needs of Indonesian citizens. Therefore, the government has included the food security program as one of the national priorities to ensure the fulfilment of the people's food needs. Increasing rice production to achieve rice self-sufficiency is the main focus of the government to achieve national food security.

Food is the most important basic human need in addition to housing, clothing, education, and health because without food there is no life. In the Food Law, Number 18 of 2012, food is defined as everything that comes from biological sources of the agricultural, plantation, forestry, fishery, livestock, aquatic, and water products, both processed and unprocessed, which are intended as foods or drinks for consumption of human beings, including food additives, food raw materials, and other materials used in the process of preparing, processing, and/or making foods or beverages.
Based on the report of the Food and Agricultural Organization (FAO), rice production in Indonesia has decreased during the 2015-2019 period [2]. Over the period, the rice production in the country was 61.03 million tons in 2015, 59.39 million tons in 2016, 59.43 million tons in 2017, 59.20 million tons in 2018, and 54.60 million tons in 2019. The decline in rice production was due to a decreasing trend in rice productivity with an average of 1.61 tons per hectare. The shrinkage of the number of raw rice fields during 2013-2019 has also contributed to the decline of rice production. The National Land Agency of the Republic of Indonesia reported that the standard rice field area was 7.46 million hectares in 2019 as compared to 7.75 million hectares in 2013, indicating a decline by 290 thousand hectares. Increasing rice production through improving the production side is important to realize food sovereignty, security, and self-sufficiency. The growth rate of rice production in 2015-2019 was still quite low at 1.02% and productivity growth was on average 0.6% per year [2]. The slow growth rate of rice production was influenced by the decline in land area, production, and productivity in the rice centre areas of Java and outside Java within the 2015-2019 period.

Aceh, which is one of the provinces that has become a national food barn, is ranked 8th as the largest rice-producing area in Indonesia. Rice production in Aceh Province in 2015 reached 2.15 million tons[3] but declined to 1.71 million tons in 2019[4]. From a macroeconomic perspective, the food crops sub-sector contributed 6.1% to the GDP of Aceh Province [5] with 37.40% of Aceh's population working in the agriculture, forestry, and fisheries sectors [6].

Previous studies documented that increased production of agricultural products can be materialized in three possible ways, namely by increasing land area, developing and adopting new technologies, and using available resources in more technically efficient ways [7]. Efforts to increase production through extensification or expansion of paddy fields are difficult to do. The limited government budget for clearing irrigated land and the high competition for land use for non-agricultural activities have been obstacles to increasing rice production through the expansion of paddy fields in some parts of Indonesia [8]. Thus, efforts to increase rice production through technical efficiency are the best alternative that is guided by aspects of efficiency of farming which includes the use of superior seeds, fertilizers, pesticides, labour, and other production inputs to reduce farming costs and increase the income of farmers [9]. Efforts to increase production should focus on increasing the efficiency of food crop farming to generate profits [10]. Countries such as Indonesia and India are expected to lead regional agricultural development [11].

Many previous studies have explored rice efficiency and productivity worldwide. For example, previous studies found the insignificant contribution of fertilization to rice productivity or efficiency in Bangladesh [12], gender and household size contributed to technical efficiency of rice farmers in Nigeria [13], farming experience, income level, and distance to the market were found to be significant determinants of technical efficiency in Kenya[14], and salinity negatively impacted technical inefficiency of rice farms in Vietnam[15].

In the Indonesian context, previous studies found the significant contribution of land use, fertilizer, labour, and climate [16], rainy [17] land size, income, and source of funding [18], farmer groups, agricultural counsellors [19], land rent, price of urea fertilizer, labour wage [20], training in relevant agricultural methods, the creation of wetlands, and an improvement in irrigation infrastructure [21] were among the important determinants of rice and paddy efficiency and productivity. Other studies found that age, formal education, participation of agricultural extension, and certified seeds [22], the level of effectiveness of standard operational procedure implementation [23] were also contributed to the increased rice productivity. Many studies found a low level of rice productivity in Indonesia [18] and [24].

Different from previous studies on rice productivity and efficiency in Indonesia, this study has several strengths and superiorities. First, unlike previous studies on rice productivity and efficiency in Indonesia that focused on certain areas and provinces, this study focuses its analysis on rice technical efficiency in Aceh Province, the 8th ranked of the rice production in the country. Second, different from previous studies that used the parametric approach; this study utilizes the most commonly adopted non-parametric approach of Data Envelopment Analysis (DEA) to measure the technical
efficiency of rice farming in the province. Finally, unlike previous studies that used a small sample size, this study uses a large sample size of 5,351 households across 23 districts and cities in Aceh Province is believed could offer more comprehensive and robust findings.

Thus, this study intends to measure the technical efficiency of rice production in Aceh, Indonesia using the DEA approach. The findings of this study are hoped to offer references for the relevant government authorities in formulating policies to enhance rice efficiency and productivity specifically in Aceh province, and Indonesia at large.

2. Materials and methods

2.1. Site and time
This research focused on the agricultural sector across 23 districts/cities in Aceh Province, Indonesia. The study is conducted in 2021 using the data sourced from the 2017 Household Farming Cost Structure Survey, the Central Statistics Agency of Aceh Province, Indonesia.

2.2. Sampling and measurement
This study gathered secondary data from the 2017 Household Farming Cost Structure Survey, the Central Bureau of Statistics of Aceh Province, Indonesia. Of 1.5 million Aceh households who worked as farmers in the agricultural sector across 23 districts/cities in the province in 2017, the survey has selected 5,351 of them as the sample of the study using a stratified random sampling technique. The number of selected sample and the technique used in the study represented the entire population. To measure the technical productivity of the agricultural sector, the study used three inputs (i.e., number of labours working day, number of urea fertilizer, and number of seeds) and one output (i.e., number of rice production) per hectare per harvest season.

2.3. Data and analysis
This study uses the Data Envelopment Analysis (DEA) approach based on Constant Return to Scale (CRS) and Variable Return to Scale (VRS) to measure the relative efficiency level of the rice farming commodities in Aceh Province, Indonesia. DEA is a linear programming-based technique to evaluate the relative efficiency of Decision-Making Units (DMUs). It compares a DMU with another DMU that utilizes similar resources to produce the same output [25]. The ultimate goal of DEA is intended as a method for performance evaluation and benchmarking [26]. DEA is the best method for calculating productivity efficiency compared to other methods as it is able not only to identify the use of inputs or outputs that are used as references to see inefficiencies by DMUs [27] and [28], but it also able to consider all inputs or outputs based on differences in technology use, capacity, competition, and demographic factors. The findings of DEA could be used to compare the efficiency level of a DMU with the best-practice (efficient) frontier method against other DMUs [29].

Referring to findings of the DEA, a unit of economic activity is said to be technically efficient if the ratio of the production output and input used is equal to one. This implies that the unit of economic activity is no longer wasting production inputs and can utilize its potential production capabilities optimally to produce the highest outputs [30]. The measurement of technical efficiency in this study is based on input-oriented or input minimization. With an input-oriented model, the study can identify if each DMU can reduce its current input to produce the same amount of output.

To measure the relative efficiency of the rice farming commodities, the study estimates the following DEA equations based on the CCR (Charnes, Cooper, and Rhodes) [31] and BCC (Banker, Charnes, and Cooper) [32] input-oriented models as illustrated in Table 1. The relative efficiency of a DMU is measured by estimating the output weight ratio for input and comparing it with other DMUs. DMUs that achieve 100% efficiency are considered efficient, while DMUs with values below 100% are considered inefficient. The DEA identifies a set of efficient DMUs and is used as a
benchmark for the improvement of inefficient DMUs. DEA also allows calculating the amount needed for improvements in inputs and outputs on the DMU so that it becomes efficient [33].

**Table 1.** Input-oriented of the DEA models.

| Input-oriented CCR model | Input-oriented BCC model |
|--------------------------|--------------------------|
| $\text{Max } \theta_0 = \sum_{j=1}^{m} u_j y_{j0}$ | $\text{Max } \theta_0 = \sum_{j=1}^{m} u_j y_{j0} + u_0$ |
| Subject to | Subject to |
| $\sum_{i=1}^{s} v_i x_{i0} = 1$ | $\sum_{i=1}^{s} v_i x_{i0} = 1$ |
| $\sum_{j=1}^{m} u_j y_{jk} - \sum_{i=1}^{s} v_i x_{ik} \leq 0$ | $\sum_{j=1}^{m} u_j y_{jk} + u_0 \leq 0$ |
| $v_i, u_j \geq 0; u_0 \text{ free in sign}$ | $v_i, u_j \geq 0; u_0 \text{ free in sign}$ |

This study selects three inputs, namely number of working days of labour, number of fertilizers, and number of seeds, and one output, namely production value of rice per harvest season to measure the relative efficiency of the rice farming commodities in Aceh Province, Indonesia.

### 3. Results and discussion

Table 2 reports the number of output (i.e., rice production) and inputs (number of seeds, number of labours working days, and number of urea fertilizer) per hectare per harvest season of the rice farming productivity based on the 5,351 sample of the rice farmers in Aceh Province, Indonesia.

**Table 2.** Distribution of output and inputs of the rice farming productivity.

| Productivity (Ton/Ha) | Mean = 4.60 Ton/Ha | Seeds (Kg/Ha) | Mean = 45.99 Kg/Ha |
|-----------------------|---------------------|---------------|---------------------|
| Number of farmers     | %                   | Number of farmers | %                   |
| <1                    | 126                 | 2.35           | <10                 | 35                  | 0.65               |
| 1-2                   | 285                 | 5.33           | 10-20               | 526                | 9.83               |
| 2-3                   | 701                 | 13.10          | 20-30               | 976                | 18.24              |
| 3-4                   | 1,016               | 18.99          | 30-40               | 691                | 12.91              |
| 4-5                   | 1,028               | 19.21          | 40-50               | 763                | 14.26              |
| 5-6                   | 993                 | 18.56          | 50-60               | 856                | 16.00              |
| >6                    | 1,202               | 22.46          | >60                 | 1,504              | 28.11              |
| Total                 | 5,351               | 100            | Total               | 5,351              | 100                |

| Urea fertilizer (Kg/Ha) | Mean = 160.48 Kg/Ha | Labour (WD/Ha) | Mean = 79.00 WD/Ha |
|-------------------------|----------------------|-----------------|---------------------|
| Number of farmers       | %                    | Number of farmers | %                   |
| <100                    | 1,609                | 30.07           | <10                 | 227                | 4.24               |
| 100-200                 | 1,771                | 33.10           | 10-20               | 344                | 6.43               |
| 200-300                 | 1,231                | 23.01           | 20-30               | 353                | 6.60               |
| 300-400                 | 372                  | 6.95            | 30-40               | 401                | 7.49               |
| 400-500                 | 341                  | 6.37            | 40-50               | 446                | 8.33               |
| 500-600                 | 8                    | 0.15            | 50-60               | 474                | 8.86               |
| >600                    | 19                   | 0.36            | >60                 | 3,106              | 58.05              |
| Total                   | 5,351                | 100             | Total               | 5,351              | 100                |
As observed from Table 2, the average productivity of rice farming in Aceh Province was 4.60 Tons/Ha. The majority of the rice farmers (92.32%) recorded productivity of greater than 2 Kg/Ha, while only 7.68% of them experienced productivity of smaller than 2 Tons/Ha. The number of rice farmers recorded productivity below 1 Tonn/Ha was 126 farmers (2.35%), followed by productivity between 1 to 2 Tons/Ha (285 farmers or 5.33%), between 2 to 3 Tons/Ha (701 farmers or 13.10%), between 3 to 4 Tons/Ha (998 farmers or 18.56%), between 4 to 5 Tons/Ha (1,016 farmers or 18.99%), and productivity of more than 6 Tons/Ha (1,202 farmers or 22.46%).

Table 2 also shows that, on average, the distribution of seeds per hectare used in rice farming in Aceh Province was 45.99 Kg/Ha. The majority of the farmers (89.52%) utilized more than 20 kilograms of seeds/Ha, while only 10.48% used less than 20 kilograms of seeds/Ha. The number of rice farmers who used seeds below 10 Kg/Ha was 35 farmers (0.65%), followed by the use of seeds between 10-20 Kg/Ha (526 farmers or 9.83%), between 30-40 Kg/Ha (691 farmers or 12.91%), between 40-50 Kg/Ha (763 farmers or 14.26%), between 50-60 Kg/Ha (856 farmers or 16.00%), between 20-30 Kg/Ha (976 farmers or 18.24%), and more than 60 Kg/Ha (1,504 farmers or 28.11%). The findings indicated a low level of rice production in Aceh Province Indonesia. The productivity of 4.60 tons of rice per hectare in the province was lower than the productivity of rice at the national level (5.70 Ton/Ha) in 2018.

Furthermore, in terms of the use of urea fertilizer, on average, the farmers used 160.48 Kg of urea fertilizer/Ha. The majority of the farmers (86.17%) utilized urea fertilizer of less than 300 Kg/Ha, while only 13.83% of them used urea fertilizer of more than 300 Kg/Ha. The number of rice farmers who used urea fertilizer between 500 to 600 Kg/Ha was 8 farmers (0.15%), followed by the use of urea fertilizer of more than 600 Kg/Ha (19 farmers or 0.36%), between 400 to 500 Kg/Ha (341 farmers or 6.37%), between 300 to 400 Kg/Ha (371 farmers or 6.95%), between 200-300 Kg/Ha (1,231 farmers or 23.01%), between 100-200 Kg/Ha (1,771 farmers or 33.10%), and 1,609 farmers (30.07%) used of less than 100 Kg/Ha of the urea fertilizer. These findings indicated an unequal distribution of urea fertilizer to the size of the farming area.

Finally, on average, the rice farmers spent 79 Working Days (WD) per hectare. The majority of them (58.05%) spent more than 60 WD/Ha, while the rest 41.95% of the farmers spent less than 60 WD/Ha. A number of 227 farmers (4.24%) spent less than 10 WD/Ha, followed by 10 to 20 WD/Ha (344 farmers or 6.43%), between 20 to 30 WD/Ha (353 farmers or 6.60%), between 30 to 40 WD/Ha (401 farmers or 7.49%), between 40 to 50 WD/Ha (446 farmers or 8.33%), between 50 to 60 WD/Ha (474 farmers or 8.86%), and spent of more than 60 WD/Ha (3,106 farmers or 58.05%). These findings indicated the inefficiency of time spent by farmers to cultivate their rice farming land.

Table 3 reports the results of the DEA estimation. The study found that rice farmers in Aceh Province have an average CRS technical efficiency of 0.088 (8.8%) and VRS technical efficiency of 0.152 (15.2%) in the range of 0.00 to 1.00. A business unit is said to be efficient if its technical efficiency is equal to 1, while the value of less than 1 indicates technical inefficiency. The difference between the estimated value and 1 shows the amount of inefficiency that can be suppressed to achieve an optimal output.

As illustrated in Table 3, the technical efficiency of rice farming recorded the low average value of technical efficiency, namely 0.088 for CRS and 0.152 for VRS. The cause of inefficiency can be viewed from the value of the slack input used. To produce the same amount of output, the number of working days and amount of fertilizer could be reduced. Excessive uses of inputs lead to greater expenditures for agricultural business activities. Agricultural technology can reduce the dependence of agricultural production activity on a greater number of labour [34]. These findings show the importance for the relevant government authorities to further improving the provision of assistance for the procurement of agricultural types of machinery and technology, such as tillage machines, planting machines, harvesting machines, and threshing machines.

Table 3 further shows that the majority of rice farmers in Aceh Province have technical efficiency values ranging from 0.001 to 0.100, namely 4,053 farmers (75.74% - CRS) and 3,103 farmers
(57.99%-VRS), ranging from 0.101 to 0.200, namely 820 farmers (15.32%-CRS) and 978 farmers (18.28%-VRS), 0.201 to 0.300, namely 275 farmers (5.14%-CRS) and 551 farmers (10.30%-VRS), 0.301 to 0.400, namely 71 farmers (1.33%-CRS) and 269 farmers (5.03%-VRS), 0.401 to 0.500, namely 38 farmers (0.71%-CRS) and 181 farmers (3.38%-VRS), 0.501 to 0.600, namely 28 farmers (0.52%-CRS) and 91 farmers (1.70%-VRS), 0.601 to 0.700, namely 20 farmers (0.37%-CRS) and 58 farmers (1.08%-VRS), 0.701 to 0.800, namely 20 farmers (0.37%-CRS) and 47 farmers (0.88%-VRS), 0.801 to 0.900, namely 10 farmers (0.19%-CRS) and 25 farmers (0.47%-VRS), while the number of farmers who are in the range of technical efficiency of 0.901-1.000 were 16 farmers (0.30%-CR) and 48 farmers (0.90%-VRS).

Table 3. Distribution of rice farming efficiency levels based on CRS and VRS.

| Efficiency Level | CRS (Mean = 0.088) | VRS (Mean = 0.152) |
|------------------|---------------------|---------------------|
|                  | Number of DMUs | Percentage | Number of DMUs | Percentage |
| 0.000-0.100      | 4,053             | 75.74      | 3,103             | 57.99      |
| 0.101-0.200      | 820               | 15.32      | 978               | 18.28      |
| 0.201-0.300      | 275               | 5.14       | 551               | 10.30      |
| 0.301-0.400      | 71                | 1.33       | 269               | 5.03       |
| 0.401-0.500      | 38                | 0.71       | 181               | 3.38       |
| 0.501-0.600      | 28                | 0.52       | 91                | 1.70       |
| 0.601-0.700      | 20                | 0.37       | 58                | 1.08       |
| 0.701-0.800      | 20                | 0.37       | 47                | 0.88       |
| 0.801-0.900      | 10                | 0.19       | 25                | 0.47       |
| 0.901-1.000      | 16                | 0.30       | 48                | 0.90       |
| Total            | 5,351             | 100        | 5,351             | 100        |

The average value of slack for the input of the number of working days, total use of urea fertilizer, and the number of seeds were 3.17, 6.13, and 0.00 respectively. Based on the average slack value, it shows that only the use of seeds has been optimal, while the number of working days and amount of use of urea fertilizer could be further reduced by 3 units and 6.13 units, respectively to produce the rice production at the technical efficiency level.

Measuring efficiency using the VRS assumption, the DEA could estimate the trend of rice productivity in Aceh Province, Indonesia. As illustrated in Table 4, three possible conditions of productivity trend of the rice farmers could be identified, namely Increasing Return to Scale (IRS), Decreasing Return to Scale (DRS), and Constant Return to Scale (IRS). If the value of the technical efficiency of the VRS is greater than the CRS, then the farmers are classified into the IRS category. The scale efficiency measurement is intended to determine the relative output loss caused by constant returns to scale, which is indicated by a value of one or close to one. The majority of farmers (3,850

Table 4. Return to scale distribution.

| Efficiency Type | DMU | Percentage |
|-----------------|-----|------------|
| CRS             | 73  | 1.36       |
| DRS             | 1,428 | 26.69     |
| IRS             | 3,850 | 71.95     |
| Total           | 5,351 | 100        |

As observed from Table 4, overall, the majority of rice farmers have a VRS technical efficiency value that was greater than its CRS, thus the rice farmers are classified into the IRS category. The scale efficiency measurement is intended to determine the relative output loss caused by constant returns to scale, which is indicated by a value of one or close to one. The majority of farmers (3,850
farmers or 71.95%) who were technically inefficient were in a position to increase their returns to scale. This shows that the majority of farmers could increase their rice production at a greater level as compared to the additional use of inputs. The study also shows that 1,428 farmers (26.69%) were in the position of increasing the use of inputs resulted in a smaller number of additional rice production. Finally, only a minority of farmers (1.36%) were in the position of using additional inputs could only produce the same level of outputs.

Overall, our findings suggest that the use of additional inputs efficiently could further improve rice production. The farmers are suggested to work efficiently and do not waste their time for unproductive activities while they are at the paddy farms and utilize fertilizers proportionately to the size of the farm area. The use of advanced agricultural-related technology could further improve farmers’ productivity. Thus, the relevant government authorities are suggested to further improve the provision of assistance for the procurement of agricultural machinery, such as tillage machines, planting machines, harvesting machines, and threshing machines as part of efforts to continuously promote rice productivity in Aceh Province, Indonesia.

4. Conclusions
This study measured the relative technical efficiency of rice production using the DEA approach in Aceh Province, Indonesia. The study documented that the rice farmers in the province recorded a very low average level of efficiency. The levels of technical efficiency of the rice production were 8.8% and 15.2%, respectively based on the CRS and VRS models. These findings showed that the rice farmers have an opportunity of 91.2% (CRS) and 84.8% (VRS) to further improve their technical efficiency by optimally utilize the number of working days and proportionately use fertilizers to the paddy area. To further promote agricultural sector efficiency, the government through the relevant agencies is expected to improve agricultural extension activities and farmer mentoring programs, prioritize improving efficiency in the areas that experienced a high level of inefficiency, initiate a training program to improve the ability of the farmers to use fertilizer per the area of rice land, socialize the use of appropriate fertilizers needs sustainably based on farmer groups in the area, and intensify the use of agricultural-related technology to minimize the use of excess labour to reduce the cost of labour. Future studies are suggested to assess the efficiency of different types of agricultural commodities nationwide to offer a detailed picture of the efficiency and their sources. Finally, future studies might utilize a mixed approach of both parametric and non-parametric to enrich the existing empirical findings of rice farming efficiency.

References
[1] BPS-Indonesian Statistics 2021 National Income of Indonesia 2016-2020
[2] Food and Agriculture Organization 2021 Crops and livestock products
[3] BPS-Indonesian Statistics 2016 Paddy production of Aceh Province 2011-2015
[4] BPS-Indonesian Statistics 2021 Luas Panen dan Produksi Padi di Indonesia 2020 Ber. Resmi Stat. 1–20
[5] BPS-Indonesian Statistics 2021 Gross Regional Domestic Product of Aceh Province by Industry 2016-2020
[6] BPS-Indonesian Statistics 2021 State of Employment February 2021 19 1–12
[7] Khuda Bakhsh, Bashir Ahmad and S H 2006 Food security through increasing technical efficiency Asian J. Plant Sci. 5(6) 970–6
[8] Helmi H, Munawar A A, Bakhtiar B and Zulfahmi Z 2021 Comparisons among soil tillage system and their impacts to the tested rice varieties on lowland rainfed alluvial in aceh jaya Food Res. 5 173–8
[9] Benton T G and Bailey R 2019 The paradox of productivity: Agricultural productivity promotes food system inefficiency Glob. Sustain. 2 1–8
[10] Haryanto T, Talib B A and Salleh N H M 2015 An Analysis of Technical Efficiency Variation
in Indonesian Rice Farming *J. Agric. Sci.* 7 144–53

[11] Liu J, Wang M, Yang L, Rahman S and Sriboonchitta S 2020 Agricultural productivity growth and its determinants in south and southeast Asian countries *Sustain.* 12

[12] Haque M M, Saleque M A, Shah A L, Biswas J C and Kim P J 2015 Long-term effects of sulfur and zinc fertilization on rice productivity and nutrient efficiency in double rice cropping paddy in Bangladesh *Commun. Soil Sci. Plant Anal.* 46 2877–87

[13] Kadiri F A, Eze C C, Orebiyi J S, Lemchi J I, Ohajianya D O and Nwaiwu I U 2014 Technical Efficiency in Paddy Rice Production in Niger Delta Region of Nigeria *Glob. J. Agric. Res.* 2 33–43

[14] Omondi, Samuel Onyango and K M S 2013 An analysis of technical efficiency of rice farmers in Ahero Irrigation Scheme, Kenya. *J. Econ. Sustain. Dev.* 4(10) 9–16

[15] Dam T H T, Amjath-Babu T S, Zander P and Müller K 2019 Paddy in saline water: Analysing variety-specific effects of saline water intrusion on the technical efficiency of rice production in Vietnam *Outlook Agric.* 48 237–45

[16] Makki M F, Ferrianta Y and Suslinawati R 2012 Impacts of climate change on productivity and efficiency paddy farms: Empirical evidence on tidal swamp land South Kalimantan Province–Indonesia *J. Econ. Sustain. Dev.* 3 66–72

[17] Saeri M, Hanani N, Setyawan B and Koestiono D 2019 Technical Efficiency of Rice Farming During Rainy and Dry Seasons in Ngawi District of East Java Province, Indonesia *Russ. J. Agric. Socio-Economic Sci.* 91 270–7

[18] Heriqbaldi U, Purwono R, Haryanto T and Primanthi M R 2015 An analysis of technical efficiency of rice production in Indonesia *Asian Soc. Sci.* 11 91–102

[19] Sudrajat I S, Rahayu E S, Supriyadi and Kusnandar 2018 Effect of institution on production cost efficiency of organic rice farming in Indonesia *DLSU Bus. Econ. Rev.* 28 166–75

[20] Zhu J 2015 *Data Envelopment Analysis: A Handbook of Models and Methods* vol 221, ed J Zhu (Boston: Springer, Boston, MA)

[21] Darusman D, Juwita I R, Munawar A A, Zainabun Z and Zulfahrizal Z 2021 Rapid
determination of mixed soil and biochar properties using a shortwave near infrared spectroscopy approach IOP Conf. Ser. Earth Environ. Sci. 667

[31] Charnes, A., Cooper, W. W., & Rhodes E 1978 Measuring the efficiency of decision making units. Eur. J. Oper. Res. 2(6), 429-444. 2(6) 429–44

[32] Banker, R. D., Charnes, A., & Cooper W W 1984 Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis Manage. Sci. 30(9) 1078–92

[33] Lee K H and Farzipoor Saen R 2012 Measuring corporate sustainability management: A data envelopment analysis approach Int. J. Prod. Econ. 140 219–26

[34] Oyetunde-Usman Z and Olagunju K O 2019 Determinants of food security and technical efficiency among agricultural households in Nigeria Economies 7 1–13