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DOES CLIMATE CHANGE ADAPTATION IMPROVE TECHNICAL EFFICIENCY OF RICE FARMING? FINDINGS FROM YOGYAKARTA PROVINCE INDONESIA

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Abstract: Food security of the Indonesian population is threatened because climate change has the potential to reduce technical efficiency of rice production. To adapt and reduce these negative impacts, farmers implement climate change adaptation strategies. This study aims to determine how the effect of climate change adaptation on the technical efficiency of rice farming. Research data was collected through interviews with 112 rice farmers in Sleman Regency. We carried out two stages of analysis, namely stochastic frontier analysis to determine the production function and efficiency level, and tobit regression to determine the effect of adaptation strategy on technical efficiency. The findings indicate that most farmers use short-lived varieties and apply two types of adaptation strategies in one growing season. By increasing the number of adaptation strategies, the technical efficiency of rice farming will increase. These results have important policy implications for increasing the adoption of adaptation strategies by farmers. The government and farmers should collaborate to formulate adaptation strategy policies to provide farmers with a choice of adaptation strategies.

Keywords: adaptation, agricultural development, climate change, rice farming, technical efficiency

Abstrak: *Ketahanan pangan penduduk Indonesia terancam karena perubahan iklim menurunkan efisiensi teknis produksi beras. Untuk menyesuaikan diri dan mengurangi dampak negatif tersebut, petani menerapkan strategi adaptasi perubahan iklim. Penelitian ini bertujuan untuk mengetahui bagaimana pengaruh adaptasi perubahan iklim terhadap efisiensi teknis usahatani padi. Data penelitian dikumpulkan melalui wawancara dengan 112 petani padi di Kabupaten Sleman. Kami melakukan dua tahap analisis, yaitu stochastic frontier analysis untuk mengetahui fungsi produksi dan tingkat efisiensi, dan tobit regression untuk menentukan pengaruh strategi adaptasi terhadap efisiensi. Temuan menunjukkan bahwa sebagian besar petani menggunakan varietas berumur pendek dan menerapkan 2 jenis strategi adaptasi dalam satu musim tanam. Dengan meningkatkan jumlah strategi adaptasi, efisiensi teknis usahatani padi akan mengalami peningkatan. Hasil ini memiliki implikasi kebijakan yang penting untuk meningkatkan penerapan strategi adaptasi oleh petani. Pemerintah dan petani harus berkolaborasi untuk merumuskan kebijakan strategi adaptasi untuk menyediakan pilihan strategi adaptasi kepada petani.*

Kata kunci: *adaptasi, efisiensi teknis, pembangunan pertanian, perubahan iklim, usahatani padi*

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INTRODUCTION

Indonesia is the third-largest rice producer in the world, after China and India (IRRI, 2010). Its derivative product, rice, is an important commodity because it is the staple food of the Indonesian population. There is a belief that Indonesians have not eaten if they do not eat rice and will not be able to sleep if they have not eaten rice before (Bhanbhro et al. 2020). The Indonesian Central Statistics Agency reports that, from 2011 to 2019, there has been an increase in rice consumption of 1.36 million tons with an increasing trend of 0.307 million tons per year (BPS, 2019). However, rice is vulnerable to climate change because the cultivation process still depends on the climate. This commodity is very vulnerable to changes in climate indicators such as temperature and rainfall (IRRI, 2010).

Indonesia is located in a tropical region experiencing ongoing changes in climate indicators. In 2021, the temperature in Indonesia increased by 3.1% from 25.59ºC, and rainfall increased by 11.4% from 2780.28 mm compared to 1900 (World Bank Group, 2021). According to the scenario Representative Concentration Pathway 8.5 (RCP 8.5), annual rainfall, rainy days, monthly maximum temperature, and monthly minimum temperature are projected to increase by 74%, 60%, 14%, and 32%, respectively, in 2071-2100, compared to 1986-2005 (Putra et al. 2020). These findings are increasingly convincing that climate change in the future will reduce rice production in Indonesia. Based on previous findings, the increase in temperature during the vegetative phase of the planting stage accelerates photosynthesis and shortens the rice life cycle thereby reducing production by 12.5%. Meanwhile, rainfall harms rice plants during the canopy and flowering stages of their reproductive cycle, resulting in a decrease in the production of 31.35% (Abbas and Mayo, 2021; Vaghefi et al. 2016). Increased annual temperature variability and crop damage caused by rainfall harm agricultural efficiency (Mar et al. 2018).

Climate change's adverse effects on agriculture spur innovation to adapt to environmental changes. Farmers must adapt their cultivation practices to climate change to minimize losses due to reduced production (Priyanto et al. 2020). The ultimate goal is to ensure that food is available to the population at all times (Campbell et al. 2016). Generally, adaptation strategies implemented by rice farmers are increasing the use and effectiveness of irrigation, crop rotation, using dolomite/lime/ameliorant fertilizers, using short-lived varieties, and field wells (Priyanto et al. 2020). Agricultural productivity will increase as the implementation of adaptation strategies increases (Abid et al. 2016), then also increases the technical efficiency. Technical efficiency is one of the most important components of agricultural productivity because it has significant policy implications for the development of not only farming communities, but also the entire community (Shahbaz et al. 2022). But more attention should be paid to farmers in rural areas because they are more vulnerable to the adverse effects of climate change, so adaptation strategies should be implemented in rural areas to improve technical efficiency (Torres et al. 2019).

Stochastic Frontier Analysis (SFA) is a widely used analytical technique for determining the level of farming efficiency, which Meeusen and van Den Broeck (1977) then developed the Cobb-Douglas model. By calculating the ratio of observed output to output frontier, the analysis can determine the efficiency level (Adzawla and Alhassan, 2021). Compared to Data Envelopment Analysis (DEA), SFA is more capable of performing high-quality data analysis (Erkoc, 2012). Numerous previous studies have used this analysis to ascertain the level of agricultural efficiency, the effect of input factors on production, and the effect of farmers' socioeconomic factors on agricultural inefficiency. However, few studies examine variables associated with climate change adaptation. The novelty of this study is to ascertain the effect of climate change adaptation on technical inefficiency in rice farming on this basis. This study is critical to determining whether the application of climate change adaptation results in the optimal (efficient) conversion of rice farming inputs to outputs.

METHODS

Sleman Regency is the locus of this study, chosen purposefully, i.e., the non-random method based on the characteristics and qualities of the participants, in this case, location (Etikan et al. 2016). Geographically, the areas lie between longitudes 100°13'00" E and 100°33'00" E and latitudes 73°4'51" S and 7°47'03" S, with an elevation range of 100-2,500 m asl. In 2018, 18.5% of the total workforce was employed in agriculture, and lowland rice accounted for the largest share of land and production compared to other food crops (BPS Sleman, 2019). Additionally, based on data from 2004 to 2019, climate indicators such as rainfall, average wind speed, average humidity, minimum temperature, average temperature, and maximum temperature all show an increasing trend of 0.136 mm, 0.097 m/s, 0.351%, 0.02°C, 0.036°C, and 0.005°C, respectively (BMKG, 2020).

In this study, simple random sampling is used in conjunction with the proportion estimation method (Nazir, 2017). The sample is 112 as a population representation of 2,996 farmers, with a sampling error of 3.08%. Due to the fact that one farmer had a crop failure rate of 100%, the data analysis sampled 111 farmers. The study employed a closed interview technique. Farmers were questioned about their cultivation practices, specifically their adaptation strategy, production in a single growing season, input costs, and farmers' socioeconomic circumstances.

Stochastic Production Frontier Model (SPFM) with Frontier 4.1 software is used to estimate the technical efficiency of rice farming. Generally the SPFM model is as follows (Adzawla and Alhassan 2021):

$$Y_i = f(X_i, \beta) \exp(V_i - V_u) \quad i = 1,2,3,...n$$

where Y_i – the output of the i-th farmer; X_i – the input vector used by the i-th farmer to produce the output; β – vector of unknown parameters to estimate; V_i – variables that cause random variations in output that the farmer cannot control such as weather, pest and disease attacks, and measurement errors; and V_u – non-negative random variable indicating the level of production inefficiency.

We employ efficiency scores from a stochastic frontier analysis to investigate the impact of climate change adaptation and farmers' socioeconomic characteristics on efficiency scores. The level of technical efficiency of rice farmers is obtained from the following formula:

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{f(X_i, \beta) \exp(V_i - V_u)}{f(X_i, \beta) \exp V_i} = \exp(-V_u)$$

where TE_i – Technical Efficiency of rice production of the i-th farmer; Y_i – the observed output in equation 1; Y_i^* – unobserved frontier output.

The structure of rice production using the Cobb-Douglas Stochastic Frontier Production Function is as follows:

$$LnPROD = \alpha + \beta_1 lnLAND + \beta_2 lnSEED + \beta_3 lnUREA + \beta_4 lnNPK + \beta_5 lnDOLOMITE + \beta_6 lnCHEMICAL + \beta_7 lnLABOR + (V_i - v_u)$$

where PROD – rice production (Kg); LAND – land area (m^2); SEED – number of seeds (Kg); UREA – amount of urea fertilizer (Kg); NPK – amount of NPK fertilizer (Kg); DOLOMITE – amount of dolomite/lime fertilizer (Kg); CHEMICAL – chemical input (Rp); LABOR – number of workers (HOK/*Man-days*); β_0 – constant or intercept; β_1-β_7 – coefficient of the variable; v_i – error term caused by external factors; dan v_i – error term caused by internal factors (inefficiency).

By using STATA17 software, we apply tobit regression analysis because the efficiency score which has a value limit of 0 (lower bound) and 1 (upper bound), is also called censored data (Theodoridis et al. 2017). Censored data will be biased and produce inconsistent estimates if analyzed using ordinary least squares because it will violate the normality distribution assumption. Tobit regression using the maximum likelihood estimation approach can produce consistent predictions on data with non-normal distributions (Okello et al. 2019). The following functions illustrate the tobit regression model.

$$TE_i = \delta_0 + \delta 1ADAPT + \delta_2 AGE + \delta_3 EDU + \delta_4 FAMILY + \delta_5 GROUP + \delta_6 LANDOWN + \delta_7 LANDLEASE + \varepsilon$$

where TE_i – technical efficiency; ADAPT – climate change adaptation (number of adaptation strategies); AGE – farmer's age (years); EDU – farmer education (years); FAMILY – number of family members (person); GROUP – farmer group membership (dummy); LANDOWN – own land (dummy); LANDLEASE – leased land (dummy); δ_0 – constant or intercept; δ_1-δ_7 – coefficient of the independent variable; and ε – error term. Description and expected signs of the variables used is presented in Table 1.

Table 1. Description and expected signs of the variables used in this study

Variables	Description	Exp. sign
PROD	Rice production (Kg)	No sign
LAND	Rice cultivation area (Ha)	+
SEED	Number of seeds (Kg)	+
UREA	Amount of UREA fertilizer (Kg)	+
NPK	Amount of NPK fertilizer (Kg)	+
DOLOMITE	Amount of dolomite/ameliorant fertilizer (Kg)	+
CHEMICAL	Amount of chemical input consisting of pesticides and herbicides (Rp)	+
LABOR	Total manpower (Man-days)	+
ADAPT	Number of adaptation strategies implemented by crop rotation, use of short-lived varieties, use of lime/ameliorant, and use of field wells (1-4)	+
AGE	Farmer's age (Year)	+/-
EDU	The duration of farmers' education (Year)	+
FAMILY	Number of family dependents (People)	+
GROUP	Farmer group membership (1 if a member of farmer group, 0 if not)	+
LANDOWN	Land tenure status (1 if the land is self-owned, 0 if other)	+
LANDLEASE	Land tenure status (1 if the land is leased, 0 if other)	+/-
LANDPS (Basis)	Land profit-sharing status (1 if the land is profit-sharing, 0 if other)	No sign

RESULTS

Socioeconomic Characteristics of Farmers

The average rice production is 1,496.44 kg, whereas the lowest and highest productions are 150 kg and 7,000 kg, respectively. Based on previous research, the variables that increase production are land area (Kea et al. 2016; Sheng and Chancellor, 2019), seeds (Bäckman et al. 2011), urea, NPK, dolomite (Kea et al. 2016; Wang et al. 2018), chemical inputs (Wang et al. 2018), and labor (Wang et al. 2018). In this study, farmers cultivate rice on an average land of 0.26 Ha. The number of seeds used by farmers ranged from 1.25 kg to 36 kg with an average of 12.43 kg. The average use of Urea, NPK, and Dolomite fertilizers was 77.11, 64.82, and 52.67 kg, respectively. The chemical input (pesticides and herbicides) used is an average of Rp. 90,900. The total workforce consists of plowing, planting, fertilizing, pesticide application, weeding, and harvesting an average of 74.52 man-days.

Farmers' socio-economic factors are known to affect the level of inefficiency in rice farming, namely the implementation of climate change adaptation, age, education, family members, farming experience, membership in farmer groups, and land tenure. Previous research stated that farmers who apply adaptation strategies have higher efficiency than farmers without adaptation strategies, and the level of efficiency will be higher as the number of adaptations increases (Ho and Shimada, 2019; Ojo and Baiyegunhi, 2020; Roco et al. 2017). On average, farmers use two adaptation strategies per growing season. There is a debate about the effect of age on efficiency, where Haryanto et al. (2016) stated that age had a negative effect on technical efficiency because older farmers were reluctant to adopt new technology, while Dube et al. (2018) and Varina et al. (2020) stated that age had a positive effect.

Our study found that farmers were between 25 and 83 years old with an average age of 59.99 years. The average education of farmers is 9.12 or at the junior high school level. Higher farmer education will increase efficiency levels (Haryanto et al. 2016). Likewise the number of family members who are known to affect increasing the level of farming efficiency (Konja et al. 2019). The average number of farmer family members is 2.33 people. The majority of farmers belong to farmer groups and 45% of farmers cultivate on their land. According to previous research, farmers who are members of farmer groups have a higher level of efficiency than farmers who are not involved (Abdul-Rahaman and Abdulai, 2018), and farmers who own land are known to have higher technical efficiency (Dube et al. 2018; Varina et al. 2020). Socioeconomic characteristics of farmers is presented in Table 2.

Table 2. Descriptive statistics of variables

Variables	Mean	Std. dev.
PROD	1,496.44	1,330.19
LAND	0.26	0.21
SEED	12.43	8.08
UREA	77.11	85.23
NPK	64.82	63.54
DOLOMITE	52.67	126.75
CHEMICAL	90,900.00	98,706.68
LABOR	74.52	27.59
ADAPT	1.84	0.98
AGE	59.99	12.06
EDU	9.12	3.41
FAMILY	2.33	1.23
GROUP	0.75	0.44
LANDOWN	0.45	0.49
LANDLEASE	0.06	0.24
LANDPS	0.49	0.50

Climate Change Adaptation Strategy

The percentage of farmers who used each adaptation strategy was determined by analyzing the use of field wells, dolomite fertilizer application, short-lived rice varieties, and crop rotation (Figure 1). The findings indicate that the majority of farmers employ adaptation strategies such as crop rotation each year (63.96%). Crop rotation is carried out in a rice-rice-secondary crop pattern, with secondary crops such as chili and corn being the most commonly grown. While other farmers choose to plant rice three periods in one year because there is more water available in their location. Rice plants require adequate water, particularly when they reach the flowering stage. When there is a water shortage, infertility occurs, resulting in decreased productivity (Mahmood, 1995). Additionally, planting secondary crops in these locations will be ineffective because the lack of available water will impair the growth and development of horticultural plants. Secondary crops such as corn, cayenne pepper, and green beans require sunlight and little water. Therefore, excessive water will cause problems for horticultural crops, particularly as harvest season approaches (Jalaluddin et al. 2018). Excess water, which can be caused by excessive rainfall, increases the water content of seeds, resulting in a reduction in the quality of horticultural seed yields such as corn (Murni and Arief, 2008).

The most widely used adaptation strategy is the use of short-lived rice varieties. Farmers believe that planting short-lived varieties will produce results in the event of sudden extreme climatic phenomena. Additionally, they can rest the land they cultivate for 1-2 months to interrupt the life cycle of pests and plant diseases. Ciherang, IR-64, Mekongga, Inpari 42, Situ bagendit, Inpari 33, and Cigeulis are among the short-lived rice varieties planted by farmers. Therefore, it is critical to collaborate to develop high-yielding varieties of short-lived lowland rice, particularly in light of the threat posed by climate change and planting index efforts (Pramudyawardani et al. 2015).

A total of 33.33% of farmers use dolomite fertilizer adaptation strategies to control soil acidity and maintain soil fertility during periods of heavy rain. The purpose of applying lime fertilizer is to increase the nutrient content of the soil, improve soil elements, reduce the content of toxins such as Fe, Al, and Mn substances, and decrease the level of soil acidity (increasing soil pH), which typically increases during periods of heavy rainfall (Saputro et al. 2017).

Field wells are used by fewer farmers than the other three strategies because they combat the threat of drought. Making a new field well requires a significant investment but provides significant benefits, including the ability to provide water for an area of 0.4-0.8 Ha (Palanisami et al. 2019). In addition, farmers who use field wells have an average land area of 0.55 hectares, which means that farmers with large landholdings employ field wells.

According to Figure 2, 12.61% of farmers do not use climate change adaptation strategies, while 87.39% use at least one. The comparisons made in this study are comparable to those made in Fadina and Barjolle (2018), which found a ratio of 14.2% to 87.8%. Farmers' awareness of climate change and capital availability are two factors that influence the number of implemented adaptation strategies. Farmers who employ additional adaptation strategies have a greater understanding and capital. The cultivated land area is one of the most influential forms of capital. As a result, farmers with more land tend to employ the strategy more extensively (Priyanto et al. 2020).

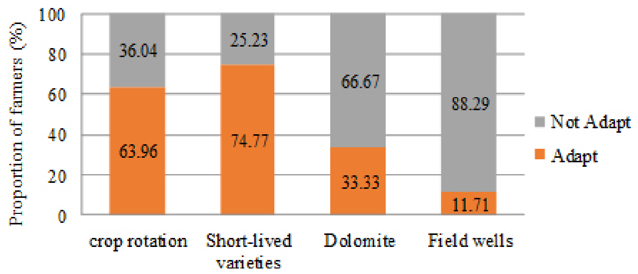

Figure 1. Number of farmers by type of adaptation strategy

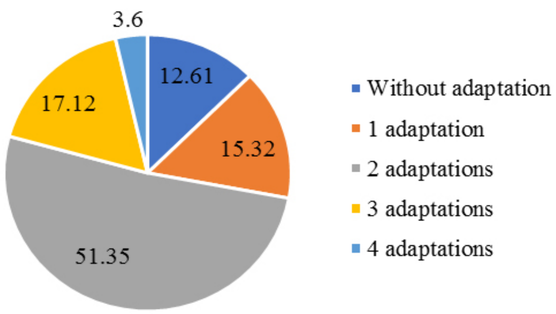

Figure 2. Number of farmers by number of adaptation strategies

Rice Production Function

As shown in Table 3, five of the seven variables analyzed significantly impact rice production: land area, seeds, dolomite fertilizer, chemical inputs, and labor. Additionally, the MLE log-likelihood value is greater than the OLS log-likelihood value, indicating that MLE estimation is superior to OLS estimation for analyzing factors influencing inefficiency.

At a significance level of 1%, increasing land area has a beneficial effect on increasing rice production at the maximum level of elasticity. These findings corroborate previous research (Kea et al. 2016). The land area is proportional to the capital raised by the farmer. Therefore, the increased land area requires farmers to invest more capital and technology to increase production efficiency (Sheng and Chancellor, 2019).

Seed is a critical component of increasing production. According to studies, increasing seed production by 1% results in an increase in rice production of 13.1%, or vice versa. As a result, increased seed use per hectare results in increased production (Bäckman et al. 2011). These findings indicate that seed production can still be increased to achieve optimal yields. However, if increased seed use results in decreased production, it must be halted. Then, each time, rice seed varieties that are more adaptable to local climate changes must be developed to make rice farming more effective and productive (Mar et al. 2018).

Dolomite fertilizer positively affects rice production at a 10% significance level, consistent with previous research indicating that fertilizer is critical for increasing yields (Ahmed et al. 2017). Fertilization is used to keep the soil's pH and nutrients stable. Previous research has demonstrated that soil pH and phosphorus levels decrease significantly during the rainy season, reaching even lower levels during the rainy season's peak. At the height of the rainy season, the content of N, P, Ca, Mg, and K decreases (Fatubarin and Olojugba 2014). A soil with a high acidity level can kill rice plants. Adding dolomite fertilizer to the soil can help maintain rice's growth phase and productivity (Wongleecharoen et al. 2020). Apart from combating soil acidification and increasing soil nutrient content, increasing dolomite fertilizer application can help reduce N20 emissions via soil pH (Shaaban et al. 2015). However, fertilizers must be used sparingly, as excessive use will increase pests and diseases, reducing production (Ahmed et al. 2017).

At a 5% significance level, chemical inputs such as pesticides and herbicides positively affect rice production. Increased pesticide use by 1% results in an increase in rice production of 0.6%, ceteris paribus. Pesticides contribute to farm productivity by preventing losses due to pests, weeds, insects, and plant diseases. On the other hand, farmers are hesitant to take on the risk of using pesticides to avoid losses (Wang et al. 2018). While pesticides can increase agricultural production, their use must be regulated to avoid residues that harm the environment, insects, and plants (Ahmed et al. 2017; Mar et al. 2018).

At a significance level of 10%, increased labor positively affects rice production, which is consistent with previous research (Wang et al. 2018). This beneficial effect demonstrates that manual labor is still capable of increasing production. According to field observations, almost all farming activities, including planting, fertilizing, pesticide application, and weeding, are performed manually. Only plowing and harvesting processes were mechanized, with 80.18% and 64.86% of farmers, respectively, using mechanization. Even then, it is operated by human labor. The desire to fully mechanize agriculture encountered obstacles due to farmers' difficulty operating agricultural machinery and limited capital resources. As a result, manual labor remains the primary source of income for small farmers (Mango et al. 2015). Furthermore, farming becomes inefficient if farmers continue to use mechanization on a small plot of land.

Factors affecting rice efficiency

The average technical efficiency of farmers in the study area is 0.713 or 71.3%. Farmers have an opportunity of 28.7% through their efforts so that farming becomes more efficient and productive (Table 4). Previous research found different results regarding the efficiency of rice farming, including research by Kea et al. (2016) by 78.4% and Ho and Shimada (2019) by 77.25%.

This study found that climate change adaptation strategies significantly positively affect rice farming efficiency (Table 5). This positive effect indicates that increasing the implementation of adaptation strategies will increase farm efficiency. It shows that in addition to reducing the negative impacts of climate change, adaptation strategies can also increase the efficiency of agricultural rice production (Ojo and Baiyegunhi, 2020). Previous research found that farmers who did not implement adaptation strategies had lower technical efficiency than farmers who implemented adaptation strategies (Ho and Shimada, 2019; Khanal et al. 2018; Roco et al. 2017). This result is reinforced by Table 4, where farmers implementing four adaptation strategies have the highest average production efficiency of 0.818. Meanwhile, farmers without implementing adaptation strategies have an average efficiency of 0.613. Implementing adaptation strategies can overcome production losses so that production inputs are converted into maximum output, which indicates more efficient farming (Twumasi and Jiang, 2021). Climate change adaptation is important to be implemented to achieve sustainable rice production amidst the threat of climate change. Adopting this practice allows farmers to withstand the stresses caused by climate change (Shahbaz et al. 2022).

Table 3. Cobb Douglas stochastic frontier estimation

Variable	Coefficient	Standard error	t-ratio	P-value
Constant	7.791***	0.428	18.190	0.000
LAND	0.843***	0.071	11.812	0.000
SEED	0.131**	0.058	2.273	0.025
UREA	0.021	0.014	1.482	0.141
NPK	0.001	0.005	0.139	0.890
DOLOMITE	0.007*	0.004	1.714	0.090
CHEMICAL	0.006**	0.003	2.445	0.016
LABOR	0.128*	0.068	1.879	0.063
Log likelihood OLS	0.170			
Log likelihood MLE	7.280			
LR test of the one-sided error	14.219			

Notes: ***, **, and * shows significance at 1%, 5%, 10% respectively

Table 4. Average technical efficiency by number of adaptation strategies

Adaptation	Freq.	Mean	Min	Max
0	14	0.613	0.424	0.842
1	17	0.657	0.546	0.796
2	57	0.726	0.513	0.896
3	19	0.772	0.601	0.948
4	4	0.818	0.630	0.919
Total	111	0.713	0.424	0.948

Table 5. Socio-economic factors affecting rice efficiency using tobit regression

Variable	Coefficient	Std. error	t-ratio	P-value
Constant	0.438***	0.069	6.38	0.000
ADAPT	0.060***	0.010	6.23	0.000
AGE	0.002**	0.001	2.19	0.031
EDU	-0.001	0.003	-0.43	0.667
FAMILY	0.010	0.008	1.14	0.255
GROUP	0.026	0.021	1.23	0.220
LANDOWN	0.053***	0.020	2.72	0.008
LANDLEASE	-0.018	0.038	-0.46	0.649
Wald chi2	44.590			
Prob>chi2	0.000			

Notes: ***, **, and * shows significance at 1%, 5%, 10% respectively

Age was found to have a positive effect on the technical efficiency of farmers' rice farming. This finding seems consistent with other studies which have found that older farmers increase farm efficiency. The reason is that older farmers have more experience than young farmers in rice farming. More experience of farmers is usually synonymous with wider cultivation areas, then having the privilege to take part in training activities initiated by the local government in improving farming efficiency (Nguyen et al. 2018; Varina et al. 2020). In addition, because they spend longer in farming, they gain greater resources such as labor, cattle, and agricultural equipment which are used to increase production and efficiency (Dube et al. 2018; Nandy and Singh, 2020). We also found that farmers with their own cultivation area had higher levels of farming efficiency than profit-sharing. This finding makes sense because they are free to innovate on their own land by using the latest technology to gain high productivity and income. Meanwhile, farmers with leased land or profit-sharing tend to be hindered by the rules and decisions of the landlord. This explanation is reinforced by the findings Koirala et al. (2016) that farmers' production and efficiency on profit-sharing and leased land is lower because they do not invest in cultivated land, and the absence of incentives from farming makes them unmotivated to produce higher production. In addition, farmers with their own land tend to prioritize the efficiency of their land by considering various aspects of farming (Dube et al. 2018; Varina et al. 2020).

Managerial Implication

Our findings show important points regarding farm inputs that increase rice production, namely land area, seeds, dolomite fertilizer, chemical inputs, and labor inputs. Farmers need to increase the use of these inputs to obtain higher production. The technical efficiency score of 71.3% indicates that there is still a 28.7% level that must fill so that farming becomes efficient. Climate change adaptation is one way to improve it. We find that more climate change adaptation strategies will increase the level of technical efficiency of rice farming. This proves that apart from reducing the negative impacts of climate change, adaptation strategies are able to increase the technical efficiency of rice farming.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This article tries to fill the gap in previous research by exploring the effect of implementing climate change adaptation on the technical efficiency of rice farming using stochastic frontier analysis and tobit regression. We explore whether more adaptation to climate change will increase the technical efficiency of farming. We found that more than half of the farmers adopted the adaptation strategy of crop rotation and short-lived varieties. Meanwhile, less than half of the farmers implement dolomite fertilizer and field wells. Based on the number of adaptation strategies, most farmers apply two adaptation strategies, while four adaptation strategies are at least. There are still farmers who do not implement adaptation strategies due to their lack of understanding about climate change and limited capital, namely land. Our main finding is the technical efficiency of 71.3%, indicating that there is a 28.7% chance of maximizing the technical efficiency of rice farming. The effort that must be made by farmers is to implement climate change adaptation strategies, where we find technical efficiency will increase as the number of adaptation strategies increases.

Recommendations

These findings have important policy implications for governments and farmers. They should work together to formulate climate change adaptation policies to avoid a decline in rice production. Where possible, climate change adaptation increases technical efficiency in the face of climate change threats. The government formulates the choice of adaptation strategy, and farmers should be involved in the formulation because they have better knowledge of regional climatic conditions and local adaptations that are effective in reducing the negative impacts of climate change. Investment in climate change information facilities needs to be increased to provide information related to climate change and choose the cheapest climate change adaptation. For example, by providing an application that contains material on climate change to increase farmers' knowledge and information about climate change adaptation along with the price. Further studies are needed to assess the level of technical efficiency of any climate change adaptation. Thus, farmers optimize adaptation strategies that provide greater benefits for their farms.

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