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Profit Efficiency, Weather Risk and Climate Adaptation Practices of Rice Farmers in Myanmar

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Abstract

In recent years most developing countries, including Myanmar, have been seriously affected by the negative effect of climate variability—such as erratic rainfall, increased temperatures, longer dry spells, flooding and saltwater intrusion—during the crop growing season. Furthermore, most farmers lack knowledge of climate variability and how to cope with the negative effect of climate change. This study aimed to evaluate the profitability and profit efficiency of rice farmers in the Ayeyarwady Delta, Myanmar, during 2019 monsoon growing season, taking into consideration the effect of weather shock and farmers' agricultural adaptation practices to climate variability. The Cobb-Douglas functional form was applied, with maximum likelihood techniques, to estimate rice growing productivity and the influencing factors of profit inefficiency among individual rice farmers. The average profit efficiency level of the yield loss group was approximately 0.39, while that of the no yield loss group was 0.66, indicating a relatively large gap between the two groups (27% wider distribution). Observation of the climate adaptation performances of rice farmers indicated that rice production incorporating climate adaptation practices (CAP) led to a significantly better average profit efficiency score (66%) than rice production omitting CAP. This study clearly revealed that the effect of weather variability on individual rice farmers leads to large variations in net profit and profit efficiency for monsoon rice production in the study area. Climate-smart agricultural practices should be developed through agricultural extension services, and using farmer-to-farmer extension services, to share information and technologies among smallholder rice farmers.

Keywords: Weather-related hazards, Climate adaptation practices, Cobb-Douglass functional form, Profit efficiency, Rice farming, Ayeyarwady Delta

1. Introduction

1.1 Background Information

The agricultural sector is the mainstay of the economy of Myanmar. In 2018-2019 it contributed 22.4% of gross domestic product (GDP) (including crops, livestock and fishery sub-sectors) and 61.2% of overall employment (MoALI, 2019a). Rice is the predominant agricultural crop, not only in terms of food security, but also in the nation's economic development. In 2018-2019, rice production was approximately 28 million MT and the country exported 1.8 million MT (MoALI, 2019b), a decrease of nearly 61% (1.11 million MT) of rice exports compared with the export volume in 2017-2018. The country's average rice yield was 3.8 MT ha^{-1}, low compared with neighboring countries such as Vietnam and Indonesia, which had yields of approximately 5.84 and 5.11 MT ha^{-1}, respectively, in 2019 (FAO, 2020). Ayeyarwady Delta is the main rice bowl of the country, comprising approximately 30% of total production. There are two seasons for rice production in Myanmar, monsoon and summer. The total sown area of monsoon rice and summer rice in 2018-2019 was 6.10 million hectares and 1.12 million hectares, respectively (MoALI, 2019a).

1.2 Problem Statement

Fluctuations in rainfall and temperature seriously affect the smallholder rice farmers who mainly depend on rainfed agriculture. Regarding the past 10 year's crop production data (2009-2019), the rice production has been gradually decreasing owing to some production challenges and constraints, especially climate variability during the crop growing season (erratic rainfall, increased temperatures, longer dry spells, flooding and saltwater intrusion); lack of knowledge of climate change; and absence of farmers' adaptive capacity. In 2018, more than 226,000 ha of farmland across the country was destroyed owing to heavy rain in the early part of the rainy season (FAO, 2019). The delta area is also extremely vulnerable to the effects of climate change. As agricultural production is rainfall dependent, late or early onset of the monsoon season, erratic rainfall, longer dry spells, heavy rains, stronger typhoons and flooding are major challenges and constraints to rice farmers in this area. Moreover, damage to embankments, sluice gates and drainage systems—which protected rice farms from salt water intrusion resulting from Cyclone Nargis in 2008—delayed the rehabilitation process, and saltwater intrusion occurred even in the monsoon season (MoALI, 2015). The average production cost of monsoon paddy in this area is higher than in the rest of the country, owing to labor scarcity and yield losses resulting from climate change and saltwater intrusion (Driel & Nauta, 2013). In 2019 monsoon rice-growing season, although 76% (117) of the sample farmers faced erratic weather shock, 69 sample rice farmers suffered yield losses. The types of weather shocks and stages of monsoon rice production in 2018-2019 that were severely affected are shown in Figures 1 and 2.

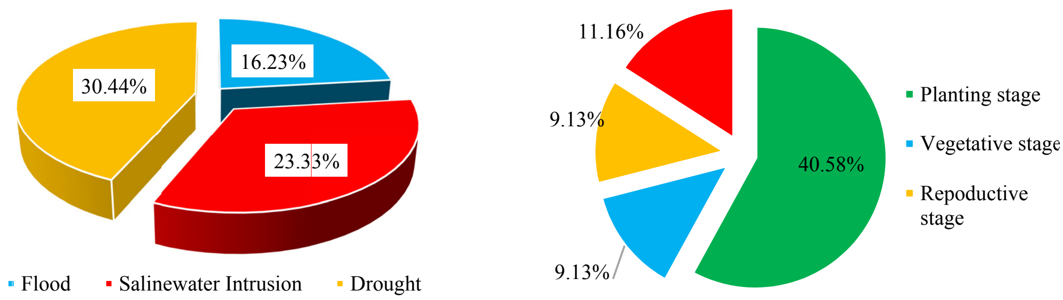

Figure 1 and 2. Types of weather risk and the extremely affected stages of monsoon rice production in 2018-2019 (no. of observations = 69)

Source: Field survey, 2020.

To mitigate the current climate hazards, Myanmar's Climate Smart Agriculture Strategy was introduced in 2015 by the Ministry of Agriculture, Livestock and Irrigation (MoALI) and encouraged the implementation of climate adaptation practices (CAP) in farming activities. The country is in the early phase of implementation adaptation options, and research into the identification and exploration of data, policy development and education, and training is still needed (Ansems et al., 2017). In the study area, 58% (90) of rice farmers used CAP to mitigate unpredictable weather risk during monsoon growing season. Currently, CAP such as crop calendar adjustment; use of varieties that are resilient to floods, salt, deep water, waterlogging and submerging; changes in cropping patterns, increased use of organic fertilizers/compost; changes from direct seeding to transplanting; applied the farm machinery and applied desalinization and gypsum, have been used. Figure 3 describes the current climate adaptation practices of sample rice farmer in Ayeyarwady Delta. However, most farmers lack knowledge of how to cope with the negative effects of climate change with these practices, and also have limited knowledge of climate variability. Moreover, there has been limited studies that the assessment of farmers' agricultural adaptation practices on profitability of rice production in Myanmar.

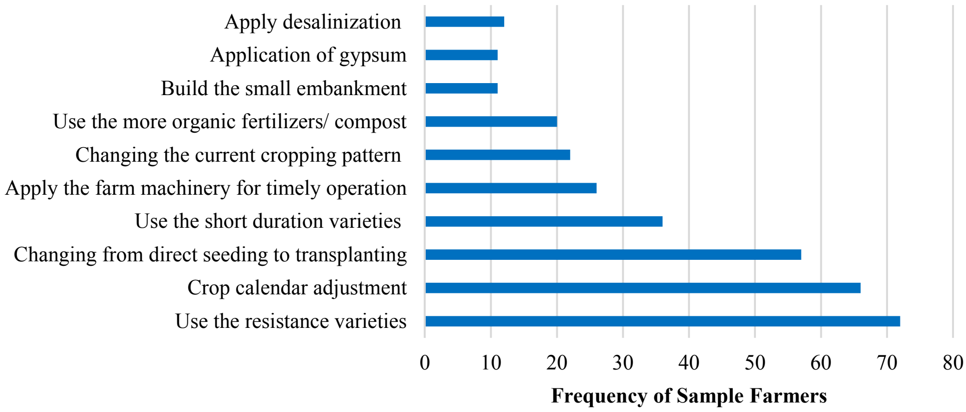

Figure 3. Farmers' climate adaptation practice to erratic weather in Ayeyarwady Delta (no. of observations = 90)

Source: Field survey, 2020.

1.3 Literature Review

Studies of agricultural efficiency are important to support economists and policy makers in developing agriculture-based economies, and so is the adoption of better technologies (Chowdhury, 2013). A high level of agricultural efficiency on the part of poor farmers can improve their farm income and ensure supplies to a competitive market (Rahman, 2003). Hoang and Yabe (2012) studied the effect of environmental factors on the profit efficiency of rice production in Vietnam's Red River Delta using the translog profit function approach. They reported that environmental factors such as water pollution were serious problems and negatively affected profit efficiency. Djomo et al. (2021) applied the Cobb-Douglas stochastic frontier model to determine the perceived effects of climate change on profit efficiency among small-scale chili pepper marketers in Benue State, Nigeria. Their findings revealed that rainfall variability, temperature variability and drought significantly affect their profit efficiency. Sein Mar (2018) studied an evaluation of the effect of erratic rainfall on the profit efficiency of pulse farmers in Myanmar. The study found that the irregular rain incidence during early vegetative growth stage of crop cultivation led to a failure to achieve the potential net profits in pulse production, and a lower level of profit efficiency. Many studies have focused on the technical and economic efficiency of rice production in Myanmar. Tun and Kang (2015); Linn and Maenhout (2019) studied the efficiency of rice production in Myanmar by using stochastic frontier model and data envelopment analysis, respectively. However, the analysis of profit efficiency in the context of the effect of weather hazards and the importance of agricultural adaptation practices on climate variability has been limited to empirical estimation.

1.4 Research Objectives and Hypotheses

The present study attempted to evaluate the profitability and profit efficiency of rice farmers in the Ayeyarwady Delta, Myanmar, during 2019 monsoon growing season, taking into consideration the effect of weather shock and farmers' agricultural adaptation practices to climate variability. Four statistical hypotheses were tested:

Hypothesis 1: The efficient use of scarce resources with the best environment for rice production (rainfall, temperature, favorable land and best agricultural practices) clearly affected profit maximization through increased productivity and receipt of maximum price of rice.

Hypothesis 2: The education levels of farmers, access to credit and risk attitude to their farming activities significantly influenced their profit efficiency levels.

Hypothesis 3: The adverse effects of erratic weather at the critical growth stage resulted in less actual profit, incurred high profit-loss and a lower efficiency level.

Hypothesis 4: Upscaling the use of local climate adaptation strategies led to better rice production performance in terms of earning a high actual profit and operating at a higher level of profit efficiency.

2. Research Methodology

2.1 Research Area and Data Information

The Ayeyarwady Delta in Myanmar was chosen for this study as it produces almost 30% of the country's total rice production. Pathein and Myaung Mya Districts were selected from that area because of their large shares of monsoon rice production during the 2018-2019 crop growing season: 3.1 million MT and 0.9 million MT, respectively (DOA, 2019). Most of the cultivated area in this region is favorable for rice production and has a monsoonal climate. There is limited access to irrigation systems for rice production in this area, and most farmers cultivate monsoon rice that is reliant on rainfall. Rainfall data for the past 10 years (2009-2019) indicated that the average annual rainfall in Pathein District and Myaung Mya District was 2583 mm and 2910 mm, respectively, while the maximum temperatures were approximately 38.2 °C and 29.5 °C, respectively (DOA, 2019).

2.1.1 Sampling Procedures and Sample Size

The primary data were collected in June 2020 using a questionnaire survey delivered through an in-depth interview using a multistage sampling technique. First, three townships from Pathein District (Pathein, Kangyidaunt and Ngapudaw) and two townships from Myaung May District (Myaung Mya and Einme) were selected, based on their prime areas for rice cultivation and high rainfall and temperature fluctuations. Next, villages were randomly selected by choosing four or five from each township. In total, 160 rice farm households from these villages were selected using a simple random sampling technique; 154 samples were valid for data analysis after missing data had been removed. This study focused on monsoon rice production, however, because the majority of farmers relied more heavily on this. The survey covered the monsoon rice production period from May 2019 to October 2019, which was the monsoon season. To capture the necessary information, a pre-test survey was conducted before the main survey.

2.1.2 Sample Characteristics

Summarized statistics of sample rice farmers in Ayeyarwady Delta are shown in Table 1. The results showed that the average *rice yield* was about 2753.24 kg ha^{-1} with a range of 1287.65 kg ha^{-1} to 4120.49 kg ha^{-1}. The average *price of rice* was approximately 325 MMK kg^{-1} with a minimum of 230 MMK kg^{-1} and a maximum of 470 MMK kg^{-1}. The results showed a wide variation in rice yield and price, indicating that the effect of weather shocks was a significant problem for rice farmers as they sought to obtain maximum yield and a higher price. The mean values of *seed rate* and *seed price* were about 103.85 kg ha^{-1} and 548.03 MMK ha^{-1}. The average quantity of *labor used*, comprising hired and family labor, was about 71.34 person-day ha^{-1} with a range of 24.69 person-day ha^{-1} to 130.86 person-day ha^{-1}. The mean values of *labor wage* and *machine power price* were approximately 4,827 MMK person-day^{-1} and 19782 MMK machine-day^{-1}. The average rice *cultivation areas* of sample farmers was 3.86 ha with a range of 0.41 ha to 29.57 ha. There were two types of land for rice production in the study area: favorable lowland and unfavorable rainfed systems. About 68% of sample farmland was favorable lowland, most suitable for rice production. In the study area, 45% of sample rice farmers faced yield losses owing to severe weather shock, and especially to drought, flooding and salinity during the 2018-2019 monsoon rice-growing season. To mitigate climate variability, some farmers already used local CAP although the adaptation options were limited. About 58% of rice farmers used agricultural adaptation strategies. The average index of farmers' risk attitude was 31.27, showing that most respondents did not want to take any risk in their farming activities, including investment in new technology and new opportunities.

Table 1. Summary statistics of the variables used for the stochastic profit function and profit inefficiency model (no. of observations = 154)

Variable	Unit	Mean	STD	Min	Max
Output, input and prices					
Rice Yield	Kilograms per hectare	2753.24	481.67	1287.65	4120.49
Rice price	’000 MMK per kilograms [a]	0.33	0.06	0.23	0.47
Seed price	’000 MMK per kilograms [a]	0.55	0.14	0.38	0.96
Labor wage	’000 MMK per person-day [a]	4.83	0.36	3.30	6.44
Machine power price	’000 MMK per machine-day [a]	19.78	11.33	2.00	50.00
Seed rate	Kilograms per hectare	103.85	29.51	25.75	180.27
Labor Rate	Person-day per hectare	71.34	27.73	24.69	130.86
Rice cultivated area	Hectare	3.86	3.33	0.41	29.57
Environmental and Farm-specific variables					
Land type	Dummy variable (1 = Favorable lowland, 0 = Otherwise)	0.68	0.47	0.00	1.00
Impact of weather shock	Dummy variable (1 = Yield loss, 0 = No yield loss)[b]	0.45	0.50	0.00	1.00
Climate adaptation practices (CAP)	Dummy variable (1 = Used CAP, 0 = No used CAP)[c]	0.58	0.49	0.00	1.00
Experience	Years	33.54	11.99	5.00	60.00
Education	Years	7.03	3.21	2.00	14.00
Access to credit	Dummy variable (1 = Credit access more than one source, 0= Otherwise)[d]	0.27	0.44	0.00	1.00
Non-farm income	Dummy variable (1 = Yes, 0 = No)	0.36	0.48	0.00	1.00
Farmer’s risk attitude	Measured [e]	31.27	3.14	24.00	40.00
Location	1 = Pathein District, 0 = Myaung Mya District	0.56	0.50	0.00	1.00

Note. [a] Exchange rate: US$1 = 1,778 MMK (source: Central Bank of Myanmar, December 2021)

[b] Based on the farmers’ experience of crop losses due to erratic weather conditions, particularly, drought, flooding and salinity during the 2018-2019 monsoon rice-growing season.

c Based on the farmers’ agricultural adaptation practices to mitigate unpredictable weather events during the 2018-2019 monsoon rice-growing season.

[d] In the study area, 27% of rice farmers got credit access more than one source, including Myanmar Agricultural Development Bank (MADB), township/village cooperative and microfinance institution.

[e] Farmer’s risk attitudes were measured as the sum of 10 five-point scaled indicators representative of farmers’ risk-taking in improving their rice production. The assessment of farmer’s risk attitude were included taking new technology and new opportunity for improving rice production, market fluctuation, perception of weather shocks, production constraints and management.

2.2 Analytical Framework

Three components of efficiency: technical; price or allocative efficiency; and economic efficiency are usually analyzed as the traditional concept of efficiency (Farell, 1957). Technical efficiency is the concept of input-output relationship. A farm is said to be technically efficient by achieving the maximum feasible output level, given the same usage of input levels (Ali & Byerlee, 1991). Allocative efficiency is defined as the extent to which farmers make efficient decisions using inputs up to the level at which their marginal contribution to production value is equal to factor costs (Adesina & Djato, 1996). A farm is said to be scale efficient in a profit maximizing framework by producing an optimal output level when the price of the product equates to its marginal cost (Kumbhakar et al., 1989). The combination of all these components into one system has been developed using a profit function framework to achieve more efficient estimations (Wang et al., 1996).

In the efficiency analyses, the parametric stochastic frontier analysis (SFA) and non-parametric data envelopment analysis (DEA) are the most commonly used. The SFA is a stochastic method and allows the individual farmers to be distant from the frontier and for randomness (Aigner et al., 1977). The advantage of SFA over DEA is that it takes into account measurement errors and other noise in the data. It followed the Battese and Coelli (1995) model by formulating a profit function assumed to behave in the manner consistent with the stochastic frontier model. The stochastic frontier profit function is specified in Equation (1).

$$\pi_i = \mathrm{f}(P_{ij}, X_i, Z_i)\exp(\xi_i) \quad (1)$$

where, π_i is normalized profit of the i^{th} farm defined as gross revenue less variable cost, divided by farm-specific price of output; P_{ij} is the vector of variable input prices faced by the i^{th} farm divided by price of output; X_i is the vector of variable inputs used of the i^{th} farm; Z_i is the vector of fixed factor of the i^{th} farm; and ξ_i is an error term. The error term ξ_i is assumed to be decomposable for frontier profit function, presented as in Equation (1a):

$$\xi_i = v_i - u_i \quad (1a)$$

where, v_i is assumed to be independent and identically distributed random errors, having normal N (0, σ_v^2) distribution, independent of the u_i. The u_i is non-negative random variables associated with inefficiency in production and assumed to be independently distributed as truncations at zero of the normal distribution with a mean $\mu_i = \delta_0 + \sum_{d=1}^{D} \delta_d W_{di}$ and variance σ_u^2, where, W_{di} are the variables representing socioeconomic characteristics of the i^{th} farm to explain inefficiency and δ_0, δ_d are unknown parameters to be estimated. If u_i = 0, there is no profit inefficiency and $u_i > 0$ implies that the farm forgoes profit because of inefficiency (Ali & Flinn, 1989).

The profit efficiency of i^{th} farm is shown (Equation 2) as:

$$PE_i = \mathrm{E}\left[\exp\{-u_i\}\middle|\xi_i\right] = \mathrm{E}\left[\exp\{-\delta_0 - \textstyle\sum_{d=1}^{D} \delta_d W_{di}\}\middle|\ \xi_i\right] \quad (2)$$

where, E is the expectation operator, which is achieved by obtaining the expressions for the conditional expectation u_i upon the observed value of ξ_i. The stochastic profit frontier and the inefficiency effects function are estimated simultaneously using the maximum likelihood estimation method.

2.3 The Empirical Model

The Cobb-Douglas (C-D) and translog models are popular and widely used to estimate the profit function despite their own weaknesses (Kaliranjan & Obwona, 1994). The present study is followed by Oladeebo and Oluwaranti (2012) and Djomo et al. (2021) and applied the Cobb-Douglas functional form with maximum likelihood techniques to estimate the productivity of monsoon rice cultivation in the Ayeyarwady Delta, Myanmar, during 2019 crop growing season and the influencing factors of profit inefficiency among individual rice farmers. The stochastic profit frontier model is defined in Equation (3a).

$$\ln\pi_i = \beta_0 + \textstyle\sum_{j=1}^{3} \beta_j lnP_{ij} + \sum_{j=4}^{5} \beta_j \ln X_{ij} + \beta_6 \ln Z_{i6} + V_i - U_i \quad (3a)$$

where, π_i is the normalized net profit conducted for the i^{th} farm defined as gross revenue less variable cost of an individual farm for its monsoon rice production per hectare in the study area, divided by farm-specific price of rice (P_y); P_{ij} is the price of the j^{th} variable inputs contributing to profit efficiency normalized by farm-specific price of rice (P_y); where, P_{i1} is the price of seed, P_{i2} is the price of human labor wage and P_{i3} is the price of machine power on the i^{th} farm; and X_{ij} is the quantity of j^{th} variable inputs, including seed rate (kg) and labor rate (person-day). Z_{i6} is fixed input contributing to profit efficiency, representing the area under rice cultivation (ha/farm household); β_0, β_1, β_2, β_3, … β_6 are parameters to be estimated; V_i is a random variable assumed to independently and identically distributed N (0, σ_v^2) and independent of U_i, a non-negative random variable that is assumed to take account of the profit efficiency of monsoon rice production.

The profit inefficiency model of rice production is formulated (Equation 3b) as:

$$U_i = \delta_0 + \textstyle\sum_{d=1}^{9} \delta_d W_{di} + \xi_i \quad (3b)$$

where, W_{di} is represents the farm-specific characteristics of the i^{th} farm, and d = 1, 2, 3,…, 9. A set of farm-specific characteristics combines environmental factors such as (1) land type; (2) effect of weather shocks (dummy variable in which farmers experienced yield losses due to weather variability during 2019 monsoon rice-growing season); (3) CAP (dummy variable, representing use of agricultural practices to adapt to current weather variability) and the socioeconomic characteristics of sample rice farmers; (4) experience of rice cultivation (Years); (5) education level of sample rice farmers (Years); (6) access to credit (dummy variable); (7) non-farm income share (dummy variable); (8) farmers' risk attitudes (measured as the sum of 10 five-point scaled indicators); and (9) location (dummy variable).

3. Results

3.1 Economic Analysis of Monsoon rice Production Among the Farmer Groups

With respect to the effect of weather shock during 2019 monsoon rice-growing season and the effect of local CAP on rice production, this study included an economic analysis by separating groups of sample rice farmers (Table 2). Yield performance indicated wide gaps between the farmer groups. With respect to the effect of weather shock, the results clearly revealed that the farmers who did not experience yield reduction due to the erratic weather ('no yield loss' group) had an improved profit (323,285 MMK ha^{-1}) with higher yield performance (more than 20%) compared with farmers who faced yield loss due to the severe weather shock during the monsoon rice-growing season ('yield loss' group). It was found that farmers who operated rice farming with CAP ('with CAP') achieved a greater profit (321,578 MMK ha^{-1}) than those who did not use CAP ('without CAP'), as well as an improvement in rice yield (more than 27%).

Table 2. Economic analysis of the effect of weather shock and climate adaptation practices in 2019 monsoon rice production

	Indicators	Impact of weather shock		Climate adaptation practices (CAP)		Pooled data (N = 154)
		Yield loss group (N = 69)	No yield loss group (N = 85)	Without CAP (N = 64)	With CAP (N = 90)	
1	Yield (kg)	2479.0	2975.8	2366.1	3028.6	2753.2
2	Selling price (kg^{-1})	325.7	325.1	324.8	325.8	325.4
3	Revenue (1) × (2)	807,410.3	967,432.6	768,509.3	986,717.9	895,891.3
4	Total material cost	147,290.6	177,000.1	136,572.6	182,971.2	163,688.6
5	Total variable cost	637,670.4	644,147.2	607,642.6	665,140.4	641,245.1
6	**Benefit (3) – (5)**	169,739.9	323,285.4	160,866.7	321,577.5	254,646.2
7	**Benefit-cost ratio (BCR)**	1.27	1.50	1.26	1.48	1.40

Note. The economic analysis was calculated for 1 ha of monsoon rice production in Myanmar kyat (MMK) during 2019 monsoon growing season in the study area.

Exchange rate: US$1 = 1,778 MMK (Source: Central Bank of Myanmar, December 2021).

Source: Own Survey (2020).

3.2 Stochastic Frontier Profit Function for Monsoon Rice Production

The maximum likelihood estimates (MLE) of the parameters of the Cobb-Douglas frontier profit model are presented in Table 3; STATA version 17 was used. The coefficients of labor wage, and the price of machine power and the labor rate, had a significantly negative effect on the profitability of rice production at 1% and 5% levels, as expected. The results indicated that the higher labor wage, and the price of machine power and the labor rate will reduce the net profit from rice production. The coefficient value of seed rate was significantly positive at the 1% level, whereas the coefficient value of the price of seed also had a positive but not significant. These results indicated that increased use of higher quality seed leads to more profitable rice farming.

The effect of environmental and farm-specific factors on the profit inefficiency of sample rice farming is shown in the lower part of Table 3. The education of household head and access to credit were significantly negative at 1% level, implying that highly educated farmers who were able to access more credit were able to reduce the inefficiency of rice production. The effect of rice farmers having a non-farm income share was significantly positive at the 5% level, indicating that a household with a non-farm income share was less efficient in terms of profit in rice production. As expected, the effect of weather shock was significantly positive at the 1% level. The result clearly revealed that the unpredictable weather events led to a decrease in profitability of rice production in the study area. The environmental variable representing the land type and the variable for climate adaptation performance were statistically significant at 1% and 10% levels of significance, respectively, in a negative sign. These results highlighted that the farmers who used the local CAP and those farming in the favorable lowland area achieved better profit efficiency performance. The farmers' risk attitudes to their faming activities were negative and there was a significant effect on profit inefficiency at the 1% level, indicating that farmers who wanted to take some risks with new opportunities or technologies in rice production would be able to increase the profit efficiency level. The dummy variable for location was positive and significant at the 10% level, indicating that farmers from Pathein District were less efficient in the profitability of their rice production than those from Myaung Mya District. A set of hypotheses on the inefficiency specifications was tested using a likelihood-ratio (LR) test statistic. The likelihood-ratio (LR) test statistic can be defined as, $\lambda = -2\{\log[\text{likelihood}(H_0)] - \log[\text{likelihood}(H_1)]\}$, approximately χ^2_v distribution with v equal to the number of constraints. The tests involved the γ parameter; and the critical value of the χ^2 was taken from Kodde and Palm (1986). The hypothesis testing that the profit inefficiency effect did not exist in the model ($\gamma = 0$) was strongly rejected at the 5% level of significance (LR statistic 36.15 > $\chi^2_{1,0.95}$ = 3.84), indicating that the profit inefficiency level was significant and also influenced the variability of profit of rice farms in the study area. In addition, estimated values of the γ and σ^2 in Table 3 were also significant, reporting the presence of inefficiency. The key parameter γ, which was the share of the one-sided error component in the total variance, was between 0 and 1; if γ is not significantly different from 0, there is no variance in the inefficiency effects (Battese and Coelli, 1995). The estimated value of γ was close to 1 (94%), representing a high level of inefficiency effects in the sample rice farming (Table 3). The null hypothesis that the environmental and managerial factors of rice farmers were jointly zero was also rejected at the 5% level of significance (LR statistic 50.23 > $\chi^2_{9,0.95}$ = 16.92). This implied that the effects of environmental and managerial factors in the profit inefficiency model were statistically significant in representing the profit inefficiencies among modern rice farmers. The results of these hypotheses highlight that the majority of sample rice farmers were operating below the optimal profit efficiency threshold owing to the presence of allocative, technical and scale inefficiencies.

Table 3. Maximum likelihood estimates of the stochastic frontier profit function

Variables	Parameters	Coefficients		Robust Std. Error	t-ratio
Frontier profit function					
Constant	β_0	12.5465	***	1.568	8.00
Price of seed	β_1	0.0003		0.117	0.00
Labor wage	β_2	-1.2880	***	0.257	-5.01
Price of machine power	β_3	-0.1783	**	0.069	-2.57
Seed rate	β_4	0.4276	***	0.137	3.12
Labor rate	β_5	-0.7500	***	0.173	-4.34
Rice cultivated area	β_6	-0.0574		0.045	-1.28
Variance Parameter					
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	σ^2	0.4250	***	0.008	55.60
$\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$	γ	0.9416	***	0.601	1.57
Log-Likelihood		-88.1510			
Profit inefficiency effect function					
Constant	δ_0	4.0300	***	0.979	4.12
Education of farmer	δ_1	-0.0857	***	0.030	-2.86
Experience of the farmer	δ_2	-0.0005		0.008	-0.05
Access to credit	δ_3	-0.5053	***	0.192	-2.63
Non-farm income	δ_4	0.4393	**	0.170	2.58
Farmers' risk attitude	δ_5	-0.0973	***	0.033	-2.94
Land type	δ_6	-0.4929	***	0.184	-2.68
Impact of weather shock	δ_7	0.6538	***	0.226	2.89
Climate adaptation practices	δ_8	-0.4424	*	0.234	-1.89
Location	δ_9	0.3964	*	0.208	1.90

Note. ***, ** and * indicate significance level at 1% ($p < 0.01$), 5% ($p < 0.05$) and 10% ($p < 0.10$) respectively.

3.3 Distribution of Profit Efficiency for Monsoon Rice Production

The frequency distribution of the estimated profit efficiency scores of sample rice farmers is provided in Table 4. The mean profit efficiency score was 54%, with a wide range spanning from 5% to 95%. This result indicated that 46% of profit can be earned by improving the technical, allocative and scale efficiency of sample rice farmers. The observation of a wide variation in profit efficiency is in line with the previous profit efficiency studies of rice production. Rahman (2003) reported a mean profit efficiency level of Bangladeshi rice farmers of 0.77 (range 6%-83%). Sumelius et al. (2011) also revealed a mean profit efficiency of Bangladeshi rice farmers who did not participate in microfinance of 0.52 (range 6%-89%). The result illustrated that 41.56% of sample rice farmers can operate rice production at the lowest level (range 10%-50%).

This study described the profit efficiency levels of rice farmers by separating groups according to erratic weather effects and use of local climate adaptation strategies (Figures 4 and 5). The average profit efficiency level of the yield loss group was approximately 0.39, while the average profit efficiency score of the no yield loss group was

0.66, indicating a relatively large gap in the efficiency score between the two groups (27% wider distribution). Moreover, 65% of farmers in the yield loss group ran their businesses below the 50% profit efficiency level, whereas 22% of no yield loss farm households were operating at that level (Figure 4). This result appeared to be evidence that the erratic weather conditions were the major constraints on improving the profitability of rice production in the study area. Observation of the climate adaptable performances of rice farmers suggested that rice production using CAP had a significantly better average profit efficiency score (66%) than the rice production that did not use CAP. Figure 5 shows that 53% of sample rice farmers who tried to adjust their farming activities with CAP were able to achieve a profit efficiency level above 70%, while only 8% of rice farmers who did not operate with CAP obtained that level.

Table 4. Profit efficiency scores of modern rice farmers

Efficiency score	No. of farmers	Percent
≤ 10%	7	4.55
> 10 - ≤ 20%	16	10.39
> 20 - ≤ 30%	15	9.74
> 30 - ≤ 40%	15	9.74
> 40 - ≤ 50%	11	7.14
> 50 - ≤ 60%	16	10.39
> 60 - ≤ 70%	21	13.64
> 70 - ≤ 80%	23	14.94
> 80 - ≤ 90%	20	12.99
> 90 - ≤ 100%	10	6.49
Total	154	100.00
Mean		53.64
Minimum		5.39
Maximum		94.97
Standard deviation		26.56

Source: Own Survey (2020).

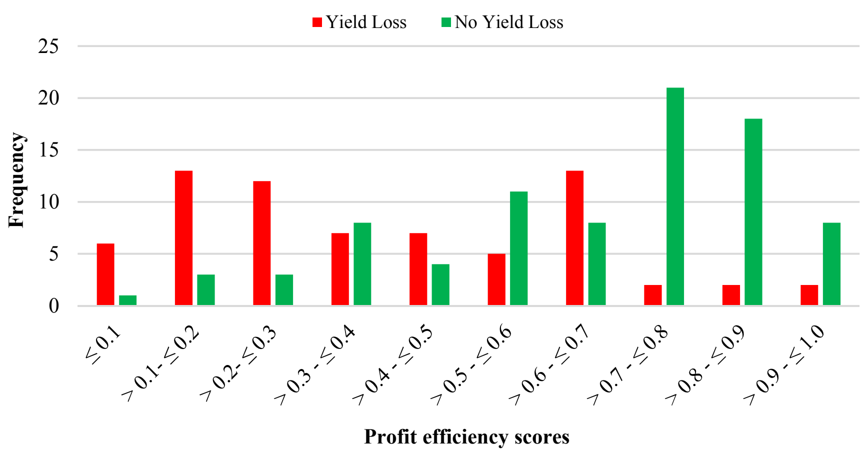

Figure 4. Frequency distribution of profit efficiency of rice farmers by effect of weather shock

Source: Own Survey (2020).

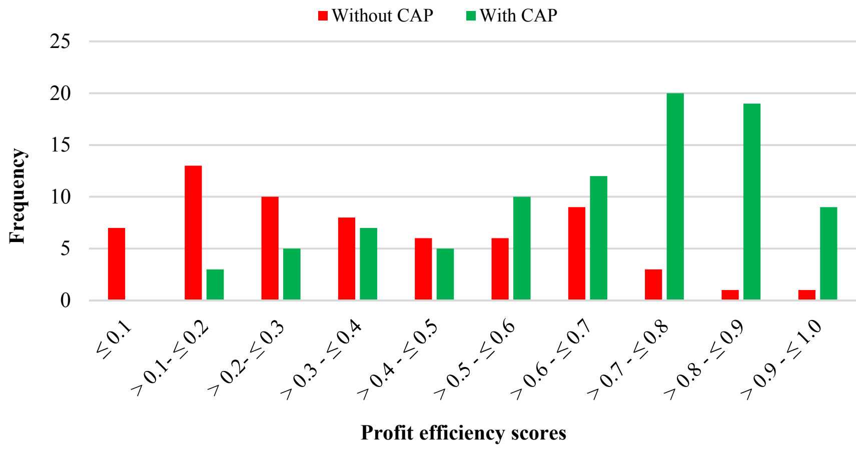

Figure 5. Frequency distribution of profit efficiency of rice farmers by climate adaptation practices (CAP)

Source: Own Survey (2020).

3.4 Comparison of profitability and profit efficiency between individual rice farming groups

Statistical hypotheses testing used one-way ANOVA and the Robust (Welch) test using IBM SPSS statistics 28 to compare profitability and profit efficiency levels between individual rice farmer groups. A normality test was first carried out to explore whether a variable was normally distributed. After that, the homogeneity of variances in each group was tested using Levene's test that is used to examine whether two or more groups have equal variances. If equal variance is assumed ($p > 0.05$), ANOVA can be used to analyze whether the means of variables are different or not. Otherwise, equal variance is not assumed, and the Robust (Welch) test can be used (Welch, 1951).

This analyzed three variables: the average actual profit, average estimated profit-loss and average profit efficiency score of an individual farm household. A average actual profit is the net farm income per hectare, calculated as gross revenue per hectare less total variable cost per hectare of rice production. Estimated profit-loss is the estimate of loss from the maximum profit per hectare, calculated by dividing the actual profit per hectare of individual rice farmers by their profit efficiency score. Profit efficiency is defined as the ability of a farm household to achieve the highest possible profit and implies that the average farm producing rice could increase profit by improving their technical, allocative and scale efficiency.

Tables 5 and 6 show the results of the hypothesis testing on the comparison of mean actual profit, estimated profit-loss and profit efficiency score between the specific groups of sample rice farmers. The null hypothesis—that the average actual profit, estimated profit-loss and profit efficiency of rice farming between the yield loss group and the no yield loss group were not significantly different—was strongly rejected (Table 5). The result implied that the effect of weather shock clearly revealed the adverse effect on profitability, leading to higher profit-loss as well as a lower efficiency level among the farmers who faced yield loss. As expected from the climate adaptation performance, the null hypothesis—that the average profitability and profit efficiency of rice farming between the farmers who used CAP and those who did not are not statistically significant—is confidently rejected (Table 6). This result highlighted that the farmers who used CAP performed significantly better in terms of their actual profit, and they incurred less profit-loss and had a higher level of operating efficiency.

Table 5. Hypothesis testing of the effect of weather shock on the mean profit-loss and profit efficiency between yield loss and no yield loss groups

Variable		No. of farmer	Average actual profit per ha ('000)	Average estimated profit-loss per ha ('000)[a]	Average profit efficiency
Impact of weather shock	Yield loss group	69	172.85	233.42	0.39
	No yield loss group	85	319.40	138.84	0.66
Homogeneity of variance			4.395 (0.038)	0.736 (0.392)	0.964 (0.328)
ANOVA			25.378 (0.001*)	38.435 (0.001*)	50.351 (0.001*)
Robust			26.958 (0.001*)	37.570 (0.001*)	49.724 (0.001*)
Hypothesis **H_0: $U_1 = U_2$** (no significant differences of average profit between 2 groups of farmer)			Reject	Reject	Reject

Note. [a] Estimate of profit-loss is calculated from the maximum profit obtainable at given prices and fixed factor endowments.

Figures in the parentheses represent p-value; * indicates significance at the 5% ($p < 0.05$) level.

Source: Own survey (2020).

Table 6. Hypothesis testing of the use of climate adaptation practices (CAP) on the mean profit-loss and profit efficiency of groups without CAP and those with CAP

Variable		No. of farmer	Average actual profit per ha ('000)	Average estimated profit-loss per ha ('000)	Average profit efficiency
Climate adaptation practices (CAP)	Without CAP	64	162.81	241.26	0.36
	With CAP	90	318.36	138.52	0.66
Homogeneity of variance			4.414 (0.037)	0.133 (0.716)	0.508 (0.477)
ANOVA			28.607 (0.001*)	46.419 (0.001*)	67.808 (0.001*)
Robust			31.556 (0.001*)	45.763 (0.001*)	67.172 (0.001*)
Hypothesis **H_0: $U_1 = U_2$** (no significant differences of average profit between 2 groups of farmer)			Reject	Reject	Reject

Note. Figures in the parentheses represent p-value; * indicates significance at the 5% ($p < 0.05$) level.

Source: Own Survey (2020).

4. Discussion

This study focused on determining the effect of weather shock on profitability and profit efficiency of monsoon rice production, as well as the effectiveness of agricultural practices to adapt to climate variation in the Ayeyarwaddy Delta, Myanmar. The farmers who did not experience yield loss had a higher net benefit than yield loss farmers because of the severe weather shock in the monsoon growing season. This result corroborates an earlier study that found that the net benefit of pulses production in a group experiencing yield loss owing to rain incidence was less than in a no yield loss group (Sein Mar, 2018). The net benefit of using CAP resulted in the highest average yield in the study area. Hein et al. (2019) and Ali et al. (2021) also noted that farmers' adaptation practices reduced the adverse effects of climate change and improved rice productivity. Among the cost of production inputs, labor costs, consisting of family and hired labor, comprised the largest share of the total cost (54%), suggesting that the efficient use of skilled labor could improve the profit share. Similar results in cost and benefit analysis of rice was reported by Linn and Maenhout (2019).

All estimated coefficients of input prices and input rate in the profit frontier function were statistically significant, except for the price of seed and the cultivated area as a fixed factor. Furthermore, the profit function results indicated that the labor wage and labor rate were negatively related to the profitability of rice production. This is consistent with earlier studies, which reported that the extensive use of and increased wages for labor could reduce the net profit of rice production (Rahman, 2003; Okoruwa et al., 2009). The positive sign and significant of seed rate is reported that the increased use of high-quality seeds (*e.g.*, certified seeds), as well as the climate resilience, will improve the profitability of rice production. This finding conforms to study on rice production by Linn and Maenhout (2019). The variables representing education, credit access, land type, farmers' risk attitude and CAP were negatively related to the profit inefficiency of rice production, as expected. These findings corroborated earlier efficiency and rice production study (Tu et al., 2018). The effect of weather shock is highlighted: farmers who faced yield loss due to weather shock operated at a significantly lower level of profit efficiency. Djomo et al. (2021) also noted that excessive rainfall and drought can be decrease the profit efficiency of producers and marketers of chili pepper. Moreover, households with a non-farm income share also operated at a lower level of profit efficiency, indicating that the farmers had paid less attention to crop productivity than did the full-time farmers. This finding was also reported by Rahman (2003).

A wide range of profit efficiency levels is clearly revealed in the Ayeyarwady Delta, based on farm-specific profit efficiency scores. These results emphasized the different levels of technical, allocative and scale inefficiency of individual rice farmers in the study area. The large variation in profit inefficiency implies that sample rice farmers faced different effects of severe weather shock and also used different managerial practices, including the use of CAP. The farmers who faced yield loss due to weather shock during the monsoon crop season earned significantly less actual profit, incurred high profit-loss and operated at lower levels of efficiency. The findings clearly revealed that the farmers who used the CAP achieved significantly higher profitability, as well as the improving the efficiency of rice production. These results conform to the study on the effect of environmental factors on profit efficiency conducted by Hoang and Yabe (2012). Overall, this study found that the erratic weather events during the monsoon rice-growing season were the major constraints to improving the productivity and profitability of sample rice farmers in the Ayeyarwady Delta. Local climate adaptation strategies should be developed to mitigate unpredictable weather variability.

5. Conclusions and Policy Implications

This study determined the evaluation of weather-related hazards on rice profitability and profit efficiency of monsoon rice production in the Ayeyarwady Delta, taking into account farmers' experience of crop damages due to erratic weather events in the monsoon rice-growing season. It also explored contemporary agricultural practices, and particularly the farmers' use of CAP to address crop yield losses and farm income, and their effectiveness on the profitability and profit efficiency of rice production. The results will be valuable for policymakers and stakeholders in providing a better understanding of the adverse effects of unpredictable weather events, and of how farmers can adjust their agricultural practices to mitigate climatic variability. This study attempted to expand the existing, limited empirical studies by emphasizing the effect of weather risk on the profitability and profit efficiency of rice production by the Cobb-Douglas profit frontier model.

The economics analyses clearly revealed that the net profit of individual rice farmers who faced crop damage due to severe weather shock was significantly lower than those in the no yield loss group. The same results indicated that farmers who adopted local CAP were able to earn greater profits than those who did not use CAP. The findings of this study showed that the greater use of labor and increases in labor wage rates significantly decreased rice production profits. Effective and efficient use of skilled labors was, therefore, vitally important in improving profitability and the profit efficiency of modern rice farmers in the study area. The substitution of machinery services for scarce labor should be developed for farm processing, and especially for land preparation, harvesting and threshing. Moreover, the government should place greater emphasis on accessing high-quality or certified seed, and also promote the use of climate-resilient varieties for flood and drought-prone areas.

With respect to the estimated results of factors affecting profit inefficiency models, highly educated and entrepreneurial farmers can achieve enhanced benefits from rice production by adopting new technologies and innovation, and efficient farming practices can easily be learnt from public and private organizations. These findings suggest that policymakers and stakeholders should promote rural education through effective extension programs, thus enhancing the perception of new opportunities and technologies for farm businesses. The positive influence of a favorable lowland area for rice production can clearly be seen in this study. For this reason, government should support the use of suitable rice varieties and technologies for application in unfavorable rice production areas. The relationship between credit access and profit efficiency indicates that improving access to credit access will increase profit efficiency. Streamlining agricultural microfinance programs for the benefit of small-scale farmers will be required to improve farm processing.

Overall, the findings of this study revealed that the effect of weather risk on individuals engaged in rice farming was a large variation in net profit and profit efficiency for monsoon rice production. This result implies that reducing the negative effects of weather shocks may encourage farmers to adopt new technologies, or any opportunity, for improving their farm incomes. The use of climate adaptation strategies may not only increase productivity, but also raise the profitability of rice production. Farmers' understanding of weather variability and upscaling the use of local climate adaptation strategies should be strengthened to mitigate crop damage from climate change and ensure the improvement of a net benefit from rice farming. Climate-smart agricultural practices should be developed through agricultural extension services, and also through farmer-to-farmer extension services, to share the information and technologies among smallholder rice farmers. The findings of this study can contribute to the planning and application of policies for more effective and appropriate climate adaptation strategies, leading to development of the rice production sector. This study is focused only on the monsoon rice production in the Ayeyarwady Delta region, which might not be representative of Myanmar's rice production efficiency overall. Future studies can determine other rice production areas in Myanmar with a larger sample size.

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References

Adesina, A. A., & Djato, K. K. (1996). Farm size, relative efficiency and agrarian policy in Cote d'Ivoire: profit function analysis of rice farms. *Agricultural Economics, 14*, 93-102. https://doi.org/10.1111/j.1574-0862.1996.tb00406.x

Aigner, D., Lovell, C. A. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *J. Econom., 6*, 21-37. https://doi.org/10.1016/0304-4076(77)90052-5

Ali, M., & Byerlee, D. (1991). Economic efficiency of small farmers in a changing world : a survey of recent evidence. *J. Int. Dev., 3*, 1-27. https://doi.org/10.1002/jid.4010030102

Ali, M., & Flinn, J. C. (1989). Profit Efficiency among Basmati Rice Producers in Pakistan Punjab. *Am. J. Agric. Econ., 71*(2), 303-310. https://doi.org/10.2307/1241587

Ali, S., Ghosh, B. C., Osmani, A. G., Hossain, E., & Fogarassy, C. (2021). Farmers' Climate Change Adaptation Strategies for Reducing the Risk of Rice Production: Evidence from Rajshahi District in Bangladesh. *Agronomy, 11*, 600. https://doi.org/10.3390/agronomy11030600

Ansems, H. L. G., Boonstra, H., Gartner, A., & Sari, F. P. (2017). Adaptation experiences in Deltas around the World. *Report for the Wageningen University and Research Cours*e*: WSG-60812-Design of Climate Change Mitigation and Adaptation Strategies*. Wageningen, Gelderland, the Netherlands.

Battese, G. E., & Coelli, T. J. (1995). A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data. *Empirical Economics, 20*, 325-332. https://doi.org/10.1007/BF01205442

Chowdhury, N. T. (2013). The Relative Efficiency of Hired and Family Labour in Bangladesh Agriculture. *J. Int. Dev., 28*(7), 1075-1091. https://doi.org/10.1002/jid.2919

Djomo, C. R. F., Ukpe, H. U. U., Ngo, N. V., Mohamadou, S., Adedze, M., & Pemunta, N. V. (2021). Perceived effects of climate change on profit efficiency among small scale chili pepper marketers in Benue State, Nigeria, *GeoJournal, 86*, 1849-1862. https://doi.org/10.1007/s10708-020-10163-x

DOA (Department of Agriculture). (2019). *Data Sources from Regional Offices*. Department of Agriculture, Pathein; Ministry of Agriculture, Livestock and Irrigation, Ayeyarwady Delta, Myanmar.

Driel, W. F. V., & Nauta, T. A. (2013). *Vulnerability and Resilience Assessment of the Ayeyarwady Delta in Myanmar, scoping phase* (p. 148). Bay of Bengal Large Marine Ecosystem (BOBLME) Project, Global Water Partnership (GWP) and Delta Alliance, Delta-Wageningen, the Netherlands.

FAO. (2019). *Handbook on climate smart agriculture in Myanmar* (p. 192). Ministry of Agriculture, Livestock and Irrigation, Naypyidaw, Myanmar. https://doi.org/10.4324/9781315743677-19

FAO. (2020). *FAOSTAT data*. Retrieved April 26, 2018, from http://www.fao.org/faostat/en/#data

Farell, M. J. (1957). The measurement of Productive Efficiency. *Journal of the Royal Statistical Society. A. General, 120*(3), 253-281. https://doi.org/10.2307/2343100

Hein, Y., Vijitsrikamol, K., Attavanich, W., & Janekarnkij, P. (2019). Economic assessment of climate adaptation options in Myanmar rice-based farming system, *Journal of Agricultural Science, 11*(5), 35-48.

https://doi.org/10.5539/jas.v11n5p35

Hoang, L. V., & Yabe, M. (2012). Impact of environmental factors on profit efficiency of rice production: A study in Vietnam's Red River Delta. *World Academy of Science, Engineering and Technology International Journal of Agricultural and Biosystems Engineering, 6*, 330337.

Kalirajan, K. P., & Obwona, M. B. (1994). A measurement of firm-specific and input-specific technical and allocative efficiencies. *Applied Economics, 26*, 393-398. https://doi.org/10.1080/00036849400000085

Kodde, D., & Palm, F. (1986). Wald Criteria for Jointly Testing Inequality Restrictions, *Econometrica, 54*, 1243-1248. https://doi.org/10.2307/1912331

Kumbhakar, S. C., Biswas, & B., Bailey, D. V. (1989). A study of economic efficiency of Utah dairy farmers: a systems approach. *Review of Economics and Statistics, 71*, 595-604. https://doi.org/10.2307/1928101

Linn, T., & Maenhout, B. (2019). Measuring the efficiency of rice production in Myanmar using data envelopment analysis. *Asian Journal of Agriculture and Development*, 2-16. https://doi.org/10.37801/ajad2019.16.2.1

MoALI (Ministry of Agriculture, Livestock and Irrigation). (2015). *Myanmar Rice Sector Development Strategy* (p. 112). Ministry of Agriculture, Livestock and Irrigation (MoALI), Naypyidaw, Myanmar.

MoALI (Ministry of Agriculture, Livestock and Irrigation). (2019a). *Myanmar Agriculture at a Brief*. Department of Planning, Ministry of Agriculture, Livestock and Irrigation (MoALI), Naypyidaw, Myanmar, 2019.

MoALI (Ministry of Agriculture, Livestock and Irrigation). (2019b). *Myanmar Agriculture at a Glance*. Department of Planning, Ministry of Agriculture, Livestock and Irrigation (MoALI), Naypyidaw, Myanmar.

Okoruwa, V. O., Akindeinde, A. O., & Salimonu, K. K. (2009). Relative Economic Efficiency of Farms in Rice Production: A Profit Function Approach in North Central Nigeria, *Tropical and Subtropical Agroecosystems, 10*, 279-286.

Oladeebo, J. O., & Oluwaranti, A. S. (2012). Profit efficiency among cassava producers: Empirical evidence from South western Nigeria. *Journal of Agricultural Economics and Development, 1*(2), 46-52.

Rahman, S. (2003). Profit Efficiency among Bangladeshi Rice farmers. *Food Policy, 28*, 487-503. https://doi.org/10.1016/j.foodpol.2003.10.001

Sein Mar. (2018). *Evaluation of erratic rainfall effect on profit efficiency of pulses farmers in lower Myanmar* (PhD thesis, Kyushu University, Fukuoka, Japan).

Sumelius, J., Islam, K. M. Z. I., & Sipilainen, T. (2011). Access to Microfinance: Does it Matter of Profit Efficiency among Small Scale Rice Farmers in Bangladesh? *Middle-East Journal of Scientific Research, 9*(3), 311-323.

Tu, V. H., Can, N. D., Takahashi, Y., Kopp, S. W., & Yabe, M. (2018). Technical and Environmental Efficiency of Eco-friendly Rice Production in the Upstream Region of the Vietnamese Mekong Delta. *Environ Dev Sustain, 21*, 2401-2424. https://doi.org/10.1007/s10668-018-0140-0

Tun, Y. Y., & Kang, H.-J. (2015). An analysis on the factors affecting rice production efficiency in Myanmar. *Journal of East Asian Economic Integration, 19*(2), 167-188. https://doi.org/10.11644/KIEP.JEAI.2015.19.2.295

Wang, J., Cramer, G. L., & Wailes, E. J. (1996). Production efficiency of Chinese agriculture: Evidence from rural household survey data. *Agricultural Economics, 15*, 17-28. https://doi.org/10.1111/j.1574-0862.1996.tb00417.x

Welch, B. (1951). On the comparison of Several Mean Values: An Alternative Approach. *Biometrika, 38*, 330-336. https://doi.org/10.1093/biomet/38.3-4.330

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