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Impact of Erratic Rainfall from Climate Change on Pulse Production Efficiency in Lower Myanmar

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Abstract: Erratic rainfall has a detrimental impact on crop productivity but rainfall during the specific growth stage is rarely used in efficiency analysis. This study focuses on this untapped point and examines the influence of rainfall specifically encountered during the sowing stage and early vegetative growth stage and the flowering stage of pulses on productivity and efficiency in Lower Myanmar using data from 182 sample farmers. The results of a stochastic frontier production function reveal that rainfall incidence during the flowering season of pulses has a negatively significant effect on yield while replanting crops after serious damage by rain increases productivity. Controlled rainfall variables, seed rate, human labor and land preparation cost are important parameters influencing pulses yield. In the efficiency model, levels of yield loss have a negative impact while being a male household head, access to government credit, access to training, locating farms in the Bago Region and possessing a large area of pulses have a positively significant effect on technical efficiency. Policy recommendations include the establishment of a safety network, such as crop insurance to protect farmers from losses due to unpredictable weather conditions, promoting training programs on cultural practices adapted to climate change, wide coverage of extension activities, giving priority to small-scale farmers and female farmer participation in training and extension activities and increasing the rate of credit availability to farmers.

Keywords: pulse production; Lower Myanmar; stochastic production frontier function; technical efficiency; climate change

1. Introduction

Agriculture can be viewed in three dimensions of environment, behavior and policy [1]; it is a risky business, as environmental factors interact in complex ways with farmer behavior [2]. This factor is especially relevant in developing countries, where farm infrastructure, like irrigation and drainage facilities and policy environments for farming activities, such as agricultural subsidy and farmer protection laws and regulations have not yet been well developed. Rahman and Hasan [3] affirmed that farmer production performance is greatly influenced not only by the availability of physical resources and farming technologies but also by environmental conditions that affect production. Along with the potential increase in global temperature, rainfall has already become increasingly variable and unpredictable and has demonstrated uneven distribution [4–7], causing extreme events such as floods and droughts. Previous studies by Easterling et al. [8] and Gitay et al. [9] have revealed that such erratic precipitation will significantly impact crop yields.

Extreme weather events during growing and harvesting seasons can cause serious damage to agriculture and can influence farmers' production decisions in terms of the allocation of farm inputs, resulting in lower output and higher inefficiency [10]. Therefore, concerned with short-term climate, the adoption of efficiency analysis can measure and help examine the variations in the physical and financial performance of farmers operating under the same environmental and economic constraints [11]. Most of the input-output relationship studies did not incorporate variability in climate conditions [12–14]. Furthermore, previous predictions of production efficiency have often been derived from an economic production function without consideration of changes in crop science and climate conditions, which leads to undesirable estimation results [12,15].

Introducing pulse crops that simultaneously adapt to climate change and contribute to mitigating its effects can be key to increasing resilience to climate change in farming [16]. Pulses themselves are, however, very sensitive to torrential rain, especially in the early vegetative stage and at flowering and a high quantity of rainfall can cause disease infestation in crops [17].

To our knowledge, there is no research emphasizing rainfall effects during the flowering stage, which is vital for pulse crops to assess their potential impact on technical efficiency.

Among the crops mostly grown in Myanmar, pulses are the second most important crop after rice and have the highest potential for export and foreign income. From 2014–2015, the export of pulses generated about $1205 million USD, which is about 48% of the total crop export and 41% of the agricultural product export value [18]. Although pulses are very promising crops for export, pulse farmers are facing various problems and constraints, such as uncertain and sudden changes in weather conditions during the crop season, which subsequently cause serious pests and disease infestation, low-quality seed for cultivation, unstable domestic and export markets and sudden price fluctuations. At present, pulse yields targeted by the Ministry of Agriculture, Livestock and Irrigation (MoALI) are 1.6–2.5 tons per hectare, dependent on the kinds of pulse varieties, whereas the average actual yield, which farmers obtain at the farm level, is about 1.3 tons per hectare [19]. Therefore, a yield gap exists between actual and targeted yields; thus, considerable improvements are needed in the productivity of pulse farming to achieve target yields. There are two ways to increase pulse yield to achieve targets among all farmers: one is to introduce new technologies, which are costly and another is to improve the technical efficiency of farmers, considering their input use in response to climate change during the crop growing season, especially under erratic rain occurrences.

Pulses are grown all over the country in Myanmar but depending on location, the cultivated varieties of pulses are different. In Lower Myanmar, green gram, black gram and cowpea are the major widely grown pulses. Figure 1 depicts the generalized cropping calendar of pulses in Lower Myanmar. Generally, the pulses begin to grow in early November and begin to be harvested at the beginning of February. If the rain is heavy, however, during the seedling stage or early vegetative stage, some farmers have to replant an entire plot again, or some have to do patch replanting, causing late sowing, which might lead to poor performance in crop growth. The farmers also encountered erratic rain, where it refers to unpredictable and out-of-season rain, during the crop growing season, especially rain at flowering, which can damage and shed pulse flowers and fail to pollination and, thus, it will directly affect the fruit setting and consequently lead to yield losses. Crop sensitivity to different stresses varies greatly, depending on the different growth stages of the crop such as the vegetative, reproductive, flowering and maturity stages [20]. Moreover, Sardana et al. [21] observed that cloudy weather or rain at flowering and fruiting resulted in poor pod setting and seed filling and may lead to increased damage from pod borers.

Despite its importance and potential to export not only for farmer income but also for the national economy, there has been no obvious study of the technical efficiency of pulse farmers until now although many scholars have focused on estimating the technical efficiency of many crops such as rice [22,23], cotton [24], sesame [25] and mango [26] in Myanmar.

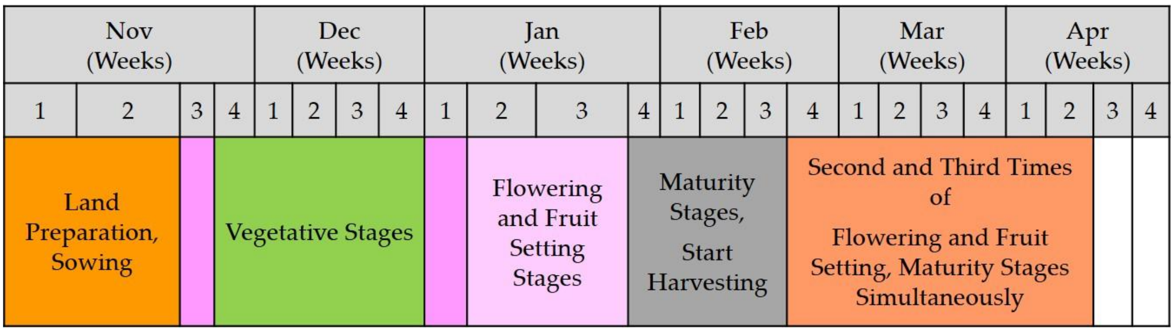

Figure 1. Generalized cropping calendar of pulses in Lower Myanmar.

In a production efficiency study, failing to take into account environmental production conditions such as rainfall, pest infestation and plant disease in the production function induces significantly inflated and biased estimates of the parameters in the production function and overestimates the technical inefficiency [3,20,27–29]. So far, to our knowledge, only the seminal works of Sherlund et al. [20], Hasan et al. [29] and Ogada et al. [30] considered environmental production conditions including the rainfall index and overall rainfall magnitude received during the entire growing season in an analysis of technical efficiency. However, this study focused only on specific rainfall during the flowering time and the additional cost of replanting as a proxy of environmental production conditions.

Considering the dependence of crop yields on climatic conditions and the frequent incidence of erratic rainfall during the crop growing season of pulses, there is a vital need to assess the potential effects of rainfall during the crop growing season to ensure the economic viability of pulse farmers and to find a suitable policy approach that can reduce the potential impacts of climate change on crop productivity.

The main aim of this research was to explore some policy recommendations for the improvement of the pulse industry in Myanmar based on evaluating the present production performance of pulse farmers. The detailed objectives were to estimate the technical efficiency of pulse farmers during rain occurrences during the flowering of pulses and to analyze the influencing factors with and without rainfall as a climate variability proxy.

Therefore, the quantity of rainfall (mm) received during flowering among pulses was incorporated into the production function to empirically investigate the effect of rain incidence during the flowering stage of pulses on crop yields. This point is the main and original idea of this research. We expected a negative relationship between rainfall incidence during the flowering time and pulse yield.

Accordingly, this study will focus on answering the following research questions: (1) Does the impact of rain during the flowering season of pulses have a positive or negative influence on productivity? (2) Are pulse farmers using their inputs efficiently? (3) What factors are affecting the technical efficiency of the pulse production?

This paper will be organized as follows. The next section describes the analytical framework, study areas and data, followed by the empirical model. The proceeding sections present the descriptive summary, empirical results and discussion and the final section provides conclusions, policy recommendation and implications.

2. Research Methodology

2.1. Analytical Framework

In this study, the stochastic production frontier approach, introduced by Aigner et al. [31] and Meeusen and van Den Broeck [32], was applied. In addition to the physical inputs used in production, the quantity of rainfall (mm) that occurred during the flowering time of pulses and additional costs incurred from replanting pulses (hereinafter, referred to as 'replanting cost') if the farmers encountered heavy rain that caused total pulse damage during sowing and in the early stage of vegetative growth were included in the model to examine farmer production performance under climate variability. The analytical framework and incorporation of two extra variables, rainfall and replanting costs, in this analysis was based on descriptions of Rahman and Hasan [3] and Sherlund et al. [20]. The stochastic production frontier for the ith farmer is written as follows:

$$Y_i = f(X_i,\ R_i) - u_i + v_i, \tag{1}$$

where Y_i is the output, X_i is the vector of physical inputs, R_i is the vector of rainfall variable and the variable for the replanting cost and v_i is assumed to be an independently and identically distributed $N(0,\sigma^2{}_v)$ two-sided random error, independent of the u_i, which is a non-negative random variable ($u_i \geq 0$) that accounts for technical inefficiency in production and is assumed to be independently distributed as truncations at zero in the normal distribution with a mean $-Z_i\delta$ and variance $\sigma_u{}^2$ ($\mid N(-Z_i\delta, \sigma^2{}_u \mid$). In most studies in the literature, it is typically estimated by:

$$Y_i = g(X_i,\ R_i^*) - u_i^* + v_i^*, \tag{2}$$

where $R_i^* \subseteq R_i$, which ignores R_i variables, resulting in biased estimates of the parameters of the production function, overstatement of technical inefficiency, as well as biased correlates of inefficiency [3,20].

Wang [33] provided some theoretical insights into the bias problem in estimating the stochastic frontier function and farm-specific technical efficiency separately using a two-step approach. In the estimation of the technological parameters of the production function, the ignorance of the dependence of inefficiency on its sources can produce biased estimates of these parameters if the explanatory variables in the production function and those in the technical efficiency model were correlated.

To avoid this kind of correlation, the single stage approach proposed by Battese and Coelli [34] was utilized to determine the influencing factors of production efficiency in which the technical efficiency of the farms is associated with farmer socio-economic conditions and managerial skills and with the demographic characteristics of the farms. Following Battese and Coelli [34], the technical efficiency of the stochastic frontier production function of the ith farm is defined as follows:

$$TE_i = E[\exp(-u_i) \mid \xi_i] = E[\exp(-\delta_0 - \sum Z_i\delta|\xi_i)], \tag{3}$$

where $\xi_i = v_i - u_i$ and E is the expectation operator. This is achieved by obtaining the expressions for the conditional expectation u_i for the observed value of ξ_i.

In this analysis, the technical efficiency model was extended by incorporating dummy variables indicating the levels of yield loss due to rain incidence. A description of these variables is provided in Table 1. Thus, the simplified specification of technical efficiency effect model including these dummies is described as follows:

$$u_i = Z_i\delta + D_i\tau + \zeta_i \geq 0, \tag{4}$$

where δ and τ are vectors of the parameters to be estimated, Z_i are the farm-specific demographics, managerial and household characteristics, D_i is the dummy variable indicating the levels of yield loss due to the rain incidence and the error ζ_i is a random variable distributed with zero mean and variance, σ^2. Since $u_i \geq 0$, $\zeta_i \geq -Z_i\delta$ so that the distribution of ζ_i is assumed as a truncation from below at the variable truncation point, $-Z_i\delta$.

The maximum likelihood method is used to estimate the unknown parameters, with the stochastic frontier and inefficiency effect functions estimated simultaneously. The likelihood function is expressed in terms of the variance parameters $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2/\sigma^2$ [34].

Table 1. Descriptive statistics of output and the independent variables used in the models. Sample size = 182.

Variables	Unit	Mean	Standard Deviation	Minimum	Maximum
Yield	Tons per hectare	1.19	0.34	0.32	2.19
Rainfall at flowering time	Millimeters	14.64	11.81	0.00	30.99
Replanting cost [a]	'000 Kyats * per hectare	21.30	66.75	0.00	453.96
Seed rate	Kilograms per hectare	78.64	17.40	41.56	145.27
Fertilizer	Kilograms per hectare	61.24	57.59	0.00	258.93
Chemicals	Kilograms per hectare	9.98	6.39	0.30	32.95
Human Labor	Man-days per hectare	88.35	34.11	29.65	221.15
Land preparation cost [b]	'000 Kyats * per hectare	128.04	40.86	43.00	296.52
100% yield loss by rain [c]	1 = Yes, 0 = No	0.08	0.28	0.00	1.00
75% yield loss by rain [c]	1 = Yes, 0 = No	0.08	0.27	0.00	1.00
50% yield loss by rain [c]	1 = Yes, 0 = No	0.10	0.31	0.00	1.00
25% yield loss by rain [c]	1 = Yes, 0 = No	0.14	0.35	0.00	1.00
No loss by rain	1 = Yes, 0 = No	0.60	0.49	0.00	1.00
Gender of household head	Male = 1, Female = 0	0.96	0.19	0.00	1.00
Age of household head	Years	50.92	11.54	23.00	82.00
Experience of household head	Years	21.84	9.78	2.00	50.00
Education of household head	Years	7.30	3.73	3.00	16.00
Credit Access	1 = Yes, 0 = No	0.88	0.33	0.00	1.00
Participation in farmer organization	1 = Yes, 0 = No	0.05	0.23	0.00	1.00
Training Access	1 = Yes, 0 = No	0.32	0.47	0.00	1.00
Location	1 = Bago, 0 = Yangon	0.54	0.50	0.00	1.00
Pulses Area	Hectare	7.26	7.00	0.40	52.61

[a] Replanting *cost* is a cost incurred from replanting the pulses after complete damage of the pulses by rain in the early vegetative stage. About 10.4% of farmers replanted their crops during the 2015–2016 growing season. [b] Only 29 farmers used animal power for land preparation, whereas the other farmers used machinery services. Animal power is counted in workdays. However, in machinery service, farmers used different kinds of tractors with different engine powers, which makes it difficult to get a precise average working hour for one hectare of land across the survey area. Moreover, machinery services were generally paid for on a per hectare basis but not on a working hour basis. Therefore, we used the cost (Kyats/hectare) of combining animal and machinery service costs. [c] Figures based on farmer response about the level of yield loss due to rain. About 40% of farmers faced a different level of losses, as shown in the above table during the 2015–2016 pulse-growing season. A *100% yield loss from rain* indicates that farmers lost about 100% of the first flowers and, thus, completely lost the output of the first harvest. A *75% yield loss from rain* represents a loss of about 75% of the flowers, which highly reduced the output of the first harvest. A *50% yield loss from rain* indicates a loss of about 50% of the flowers and in the output of the first harvest. A *25% yield loss from rain* represents a loss of only about 25% of the flowers, as well as the output of the first harvest after rain incidence. * 1 US$ = 1362 Kyats (as of 29 December 2017). Source: Field survey data, 2016.

2.2. Study Area and Data Information

The study area was in the Bago and Yangon Regions, which are located in Lower Myanmar. Of the approximately 4,655,981 hectares of total pulse area in Myanmar, the two regions contributed to 1,010,894 hectares (21.7%) [35]. The average annual rainfall is about 3366 millimeter (mm) in Bago Region and 2947 mm in Yangon Region with the average maximum temperatures of about 32.6 degree Celsius and 33.4 degree Celsius, respectively [18]. Bago Region covers about 39,404 square kilometer (km^2) comprising 4 districts and 28 townships while Yangon Region has an area of 10,171 km^2 consisting of 4 districts and 45 townships [36].

A multistage sampling technique was applied to conduct the survey. The first stage included a purposive selection of the two townships from each region. Daik-U and Waw townships from Bago Region and Khayan and Thongwa townships from Yangon Region were chosen because of their prime pulse growing areas among the townships in the two regions. In the second stage, two villages from each township were chosen based on the above categories for conducting primary data collection from farm households. A simple random sampling technique was used to select 182 farmers to interview. All of the information collected from pulse farmers was based on pulse production activities operated in the growing season from November 2015 to March 2016, as in the study area pulses, which are grown only in the winter season.

The survey was conducted from July–August 2016 using structured questionnaires and face-to-face interviews. A pre-test was conducted to refine the questionnaires before the main survey. The final questionnaires consisted of extracting information regarding outputs of each pulse crops and inputs used, such as foliar and granule fertilizers, pesticides, herbicides, seed rate, labor, land preparation cost and pulse sown area. In addition, the farmers' managerial characteristics, such as age, gender, education, experience, institutional factors, like access to credit and training, participation in farmer organization, weather-related variables, such as monthly rainfall and replanting cost and farmers' perception on the damage and yield loss of the crop due to the rain incidence during sowing stage and early vegetative stage and flowering stage were also collected (for more detail, please see the supplementary questionnaire file). During the survey, collected data was inputted into an Excel file and were checked immediately on a daily basis and if some irrelevant or uncertain points were found, the respondents were asked these points again via phone or in person at once or at the next day. In this way, all the collected data were made useful. The units of all dependent and independent variables that appeared in the analysis were weighted to be a reasonable estimation, as almost all of the sample farmers in this study cultivated different kinds of pulse varieties, such as green gram, black gram, and/or cowpea on their farms.

Rainfall data were collected from respective survey areas of the township office of the Department of Agriculture (DOA), where the rainfall data were collected on a daily basis at the township level.

2.3. The Empirical Model

In this study, the data obtained from 182 farmers were analyzed using a stochastic production function (SPF), applying a Cobb-Douglas production frontier function with maximum likelihood techniques, which examined the factors influencing the productivity of the pulse production that had a direct impact on farmer income and profits from pulse production. In addition to observing the consequences of rainfall incidence during the flowering time of pulses, the frontier was estimated 'with' and 'without' rainfall and replanting cost variables. Thus, the traditional specification of the production frontier, which omits the two weather impact variables, is given as follows:

$$lnY_i = \alpha'_0 + \sum_{j=1}^{5} \alpha'_j \, lnX_{ij} + \nu'_i - u'_i \tag{5}$$

and:

$$u'_i = \delta'_0 + \sum_{d=1}^{9} \delta'_d \, Z_{id} + \zeta'_i \tag{6}$$

where *ln* is a natural logarithm; Y_i is the weighted amount of pulse *yield* for the *i*th farm measured in tons per hectare; X_i is the *j*th input, such as the *seed rate* (kg), *fertilizer* (kg), *chemicals* (kg) applied to control weeds, pests and diseases, *human labor* (man-day) and *land preparation cost* (Ks) expensed by the *i*th farmer (all of the inputs used were weighted values on a per hectare basis); v_i is the two-sided normally-distributed random error; and u_i is the one-sided half normal error. Z_{id} is the variable representing the farm-specific managerial and demographic and household characteristics to explain the inefficiency of the farm, ζ_i is the truncated random variable and α_0, α_j, δ_0 and δ_d are the parameters to be estimated. The symbol " $'$ "denotes the model without *rainfall* and *replanting cost* variables.

Similarly, the full model specification including the variables representing *rainfall* and *replanting cost* incurred due to rain incidence in the production function is written as follows:

$$lnY_i = \alpha_0 + \sum_{j=1}^{5} \alpha_j \, lnX_{ij} + \sum_{m=1}^{2} \beta_m lnR_{im} + \nu_i - u_i \tag{7}$$

and:

$$u_i = \delta_0 + \sum_{l=1}^{4} \tau_l \, D_{il} + \sum_{d=1}^{9} \delta_d \, Z_{id} + \zeta_i \tag{8}$$

where R_{im} is the variable representing the amount of *rainfall* incidence during flowering time in each township in millimeters (mm) and the *replanting cost* incurred for growing pulses again after full damage by rain in Kyats, D_{il} depicts the dummy variables for the different levels of yield losses (*100%*, *75%*, *50%*, *25% loss compared to no loss*), which were opined by the sample farmers based on the impact of rain incidence during flowering. β_m and τ_l are parameters to be estimated. All other variables are the same as previously defined. In the stochastic frontier model, a total of five input variables and two variables related to rain impact are used and a total of nine farm-specific, demographic and household socio-economic characteristics and four dummy variables representing different levels of yield loss were incorporated into the technical inefficiency effect model. We illustrate these variables in the descriptive summary, namely, in the following results section.

3. Descriptive Summary of Production Inputs and Rain Incidence

Table 1 depicts the definition, units of measurement and summary statistics of all the dependent and independent variables in the models.

During 2015–2016 winter crop-growing season, the rain incidence occurred in November during sowing time and the early vegetative stage and in January during flowering. In practice, Daik-U Township in the Bago Region did not record a rainfall magnitude during the flowering season in January 2016, meaning that there was no rain incidence, while the other three townships did. The actual rainfall of each township in the flowering season was 30.99 mm in Wal Township, 9.91 mm in Kha Yan Township and 19.50 mm in Thone Gwa Township. The recorded amount of average *rainfall during the flowering season* was 14.64 mm.

Due to heavy rain during the early vegetative stage, 11% of sampled farmers replanted the entire damaged plot of pulses, 10% undertook partial replanting, 13% faced growth retardation and 66% did not face any crop damage. The average *replanting cost* in which the pulses were sown again when rain completely damaged the crop accounted for 21,300 Ks ha^{-1} with a maximum of 453,960 Ks ha^{-1}.

Moreover, regarding to the damage levels of rain incidence during the flowering stage about 40% of the respondents answered that they encountered different levels of yield loss, including 100% losses (8% of farmers), 75% losses (8%), 50% losses (10%) and 25% losses (14%) due to rain, whereas 60% of farmers experienced no damage. A total of 73 farmers out of 182 sampled farmers reported that they failed to achieve the highest yield potential from pulse production due to rain incidence during the flowering season.

The results indicate that the average *yield* of pulses is 1.19 tons ha^{-1}, with a wide range from 0.32 tons ha^{-1} to 2.19 tons ha^{-1}. The *seed rate* used also ranged widely, from 41.56 kilograms (kg) ha^{-1} to 145.27 kg ha^{-1}, with an average of 78.64 kg ha^{-1}.

The mean quantity of *fertilizers* applied, including nitrogenous, phosphate, potash, compound and other foliar fertilizers, measured in kilograms, was about 61 kg ha^{-1} with 0 kg ha^{-1} minimum and about 259 kg maximum ha^{-1}.

The quantity of *chemicals* used, consisting of herbicide and pesticides, widely ranged from 0.3 kg ha^{-1} to 32.95 kg ha^{-1} with an average amount of 9.98 kg ha^{-1}, showing a wide variation in chemical use.

The average utilization of *human labor*, comprising hired (permanent and casual) and family labor, measured in man-days, counted in 8 h/day, was about 88 man-days, with a minimum of 29.65 man-days ha^{-1} and a maximum of 221.15 man-days ha^{-1}, indicating that pulse cultivation was highly labor intensive in the study areas. It accounted for all of the farm activities, such as plowing, sowing, fertilization, chemical spraying, weeding, harvesting and threshing.

The average *land preparation cost* using animal labor and machinery power was about 128,000 Kyats (Ks) ha^{-1}, with a wide variation in the cost of the minimum 43,000 Ks ha^{-1} and the maximum of 296,520 Ks ha^{-1}.

This trend of wide ranges between the minimum and maximum amount of inputs also follows the same trend for other inputs, such as *seed rate*, *fertilizer*, *chemicals* and *human labor*. From these results, pulse farmers can be understood to use production inputs according to their knowledge, preferences, available capital and the weather situation they faced. For example, if the weather is cloudy, they use more chemicals to protect the plants from pests and disease infestation.

About 4% of pulse farmers were female heads of households; the average *age* of the farmers was about 51 years old and they had about 22 years of pulse cultivation *experience* and accomplished seven years of *education*, on average. About 88% of them accessed government *credit*, whereas only 5% participated in *farmer organizations*, such as the village land management organization which was organized by the local authority and normally large-scale farmers were members of these organization and the Saemual Undong village development program which is a project conducted by a collaboration of the Korea International Cooperation Agency (KOICA) and the Ministry of Agriculture, Livestock and Irrigation (MoALI). The farmers who participated in that project can access training arranged by the program and hence improve their technical knowledge about farming and other village development schemes.

However, there is no farm cooperative, particularly for pulse farmers, in the study area. Only 32% of farmers received *training* from the Department of Agriculture (DOA), which consists of cultural practices, plant protection technologies, fertilizer application techniques, good agricultural practices, postharvest technology and organic farming technology, whereas others had not received any technical assistance in pulse production from the DOA extension workers. Among a total of 182 sample farmers, 54% of the farmers were from the Bago Region. The average *pulse area* in the study area was 7.26 hectares in which most of the farmers are large-scale farmers over a range of 0.40 ha to 52.61 ha farms.

4. Empirical Results

4.1. Correlation among Production Inputs, Rainfall and Replanting Costs

In estimating the parameters of the production function, the weather information (*rainfall* in the flowering stage and *replanting cost*) were assumed to be true exogenous variables, which should be considered for inclusion in full specification (hereafter, the terms specification and model will be used interchangeably), as the omission of these variables would lead to upward bias in estimating firm-specific technical efficiency [20]. Table 2 describes the results of correlations between production inputs and *rainfall* and *replanting cost*. The strength of the correlation between *rainfall* and production inputs of *seed rate*, *chemicals and human labor* was moderately strong, whereas the other production variables had a weak but non-zero, correlation with both *rainfall* and *replanting cost*.

Table 2. Correlation among production inputs and rainfall and replanting costs.

	Seed Rate	*Fertilizer*	*Chemicals*	*Land Preparation Cost*	*Human Labor*
Rainfall at flowering (mm)	0.443 ***	0.124 *	–0.439 ***	0.020	0.305 ***
Replanting cost	0.129 *	−0.122	0.119	0.067	0.246 ***

Note: *** and * represent significance at the 1% ($p < 0.01$), 5% ($p < 0.05$) and 10% ($p < 0.10$) levels, respectively. Source: Own estimates.

4.2. Parameter Estimates of the Stochastic Frontier Production Function

The results of the hypothesis testing are presented in Table 3. First, to test the statistical superiority of the full specification, a log-likelihood ratio (LR) test was performed using the log-likelihood values of both short and full specifications reported in Table 4. $LR = -2[\ln L(H_0) - \ln L(H_1)] \sim \chi^2 (J)$, where $\ln L(H_0)$ and $\ln L(H_1)$ are log-likelihood functions of restricted and unrestricted frontier models and J is the number of restrictions [15]. The test result of the one-sided error 25.79 ($p < 0.005$) rejected the null hypothesis and strongly supported the appearance of the full specification against the χ^2 (6, 0.99) value of 16.81. Similarly, the null hypothesis where *rainfall* and *replanting cost* were jointly zero in full specification was also rejected, indicating that *rainfall* and *replanting cost* significantly affected the productivity of pulses and it is worth including these in the full specification.

Table 3. Hypothesis testing.

Hypothesis	Critical Value of χ^2 (d.f, 0.99)	Without Rainfall Effects		With Rainfall Effects	
		LR Statistic	Decision	*LR* Statistic	Decision
Short specification without rainfall variables is enough (to test the statistical superiority of the full specification)	16.81	0	0	25.72 ***	reject
No effect of rainfall on productivity (H_0: $\beta_1 = \beta_2 = 0$)	9.21	0	0	15.26 ***	reject
No presence of technical inefficiency (H_0: $\gamma = 0$)	6.64	19.80 ***	reject	14.12 ***	reject
Constant return to scale in production (H_0: $\alpha_1 + \alpha_2 + \ldots + \alpha_5 = 1$)	15.09	38.18 ***	reject	53.52 ***	reject
No effect of managerial variables on efficiency (H_0: $\delta_5 = \delta_6 = \ldots = \delta_{13} = 0$)	21.67	25.10 ***	reject	28.10 ***	reject

Note: *** represents significance at the 1% ($p < 0.01$) level. Source: Own estimates.

The null hypothesis of no inefficiency effect was strongly rejected in both models by the *LR* tests, which are depicted in Table 3. The γ values of both specifications shown in Table 4 also support the rejection of the previous null hypothesis test, as these γ values are statistically significant at the 1% level of significance in a *t*-test, meaning that about 88% and 79% (Table 4) of the variation in pulse yields in both models, respectively, is due to technical inefficiency rather than random variability among farmers and that the majority of farms in the sample operate below a technically efficient threshold. Moreover, it can be concluded that a traditional least square production function is not adequate and that the Cobb-Douglas production function is an appropriate representation of the data.

As the output of pulses was expressed as the Cobb-Douglas production function, the estimated coefficient values of the variables can be directly read as the elasticities of the function. The total elasticity of the stochastic frontier function represents the proportionate changes in productivity if the inputs change during the production process. A restricted frontier regression was performed for both models with the null hypotheses of a constant return to scale. The *LR* test statistic reported in Table 3 rejected the hypothesis, indicating that pulse production is running under decreasing returns to scale, which is more serious under *rainfall* and *replanting cost* controls in the full model. The result implied that an increase in one unit of input used would be an increase in the output of pulses in the decreased proportion. It also implies that pulse farmers are operating farming activities below the optimal rate and also proved that the rainfall and replanting costs affect the estimates of the production function itself.

The hypotheses testing the zero joint effect of the managerial factors of the farmers was rejected for both specifications at the 1% level of significance, indicating that the technical efficiency level of pulse production mainly relies on managerial factors among farmers.

The maximum-likelihood estimates for the parameters in the frontier function and inefficiency model, using Frontier 4.1 software by Coelli [37], are given in Table 4 for both the short (without *rainfall* and *replanting cost*) and the full (with *rainfall* and *replanting cost*) specifications. In the full model, as expected, *rainfall* has a negatively significant effect on productivity at the 1% level of significance, implying that the higher the *rainfall*, the more crop damage and the lower the productivity that occurred. However, *replanting cost* is positive and significant at the 5% level, indicating that the replanting practice of pulse farmers after heavy rain incidence and damage to the crop can obviously improve the pulse yields compared to doing nothing. This may be because the affected farmers can replant the pulses without a delay in the suitable sowing time.

In both specifications, the *seed rate* and *human labor* coefficients are positive, whereas the coefficient value of *land preparation cost* is negative and these estimated coefficients have a significant impact on productivity.

However, in the short specification, the *chemicals* coefficient has a positively significant impact on yield at the 1% level, whereas it is positive but not significant in the full specification. When the rainfall factors are accounted for in the model, the *chemicals* variable becomes insignificant, depicting one example of the importance of these factors. The *seed rate* is the most dominant input on productivity, followed by *land preparation cost* and *human labo*r in the full model. However, in the short model, the *land preparation cost* variable is the most dominant factor on pulse yields, followed by the *seed rate*, *human labor* and *chemicals*.

Table 4. Maximum likelihood estimates for parameters of the Cobb-Douglas production function.

Variables	Without Rainfall Impact Variables			With Rainfall Impact Variables		
	Coefficients	**Std. Error**	***t*-Ratio**	**Coefficients**	**Std. Error**	***t*-Ratio**
Production function						
Constant	1.253	0.791	1.584	0.978	0.971	1.007
Rainfall at flowering time	-	-	-	−0.071 ***	0.017	−4.139
Replanting cost	-	-	-	0.011 *	0.006	1.903
Seed rate	0.187 *	0.104	1.805	0.345 ***	0.099	3.475
Fertilizer	−0.020	0.015	−1.298	−0.005	0.015	−0.371
Chemicals	0.101 ***	0.031	3.209	0.027	0.035	0.766
Human labor	0.147 **	0.059	2.517	0.206 ***	0.061	3.371
Land preparation cost	−0.219 ***	0.070	−3.153	−0.256 ***	0.071	−3.626
Variance parameters						
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	0.304	0.106	2.880	0.164	0.047	3.479
$\gamma = \sigma_u^2 / \left(\sigma_u^2 + \sigma_v^2\right)$	0.877	0.053	16.417	0.787	0.064	12.211
Log likelihood function	−5.381			7.479		
Technical Inefficiency Effects Function						
Constant	−0.114	1.155	−0.099	0.543	1.085	0.500
100% yield loss from rain	-	-	-	0.818 **	0.377	2.170
75% yield loss from rain	-	-	-	0.883 **	0.384	2.297
50% yield loss from rain	-	-	-	0.346	0.264	1.309
25% yield loss from rain	-	-	-	0.627 **	0.252	2.492
Gender of household head	−1.173 **	0.515	−2.277	−0.798 **	0.359	−2.221
Age of household head	0.614	0.430	1.429	0.286	0.332	0.862
Experience of household head	−0.157	0.191	−0.818	−0.094	0.174	−0.537
Education of household head	0.143	0.179	0.800	0.038	0.177	0.212
Credit access	−0.830 **	0.355	−2.341	−0.623 **	0.232	−2.687
Participation in farmer organization	−0.758 *	0.442	−1.716	−0.546	0.394	−1.385
Training access	−0.711 *	0.403	−1.763	−0.531 *	0.309	−1.717
Location	−0.735 **	0.367	−2.000	−0.601 *	0.308	−1.954
Pulse area	−0.682 **	0.296	−2.303	−0.399 **	0.179	−2.229
Total number of observations	182			182		

Note: ***, ** and * represent significance at the 1% ($p < 0.01$), 5% ($p < 0.05$) and 10% ($p < 0.10$) levels, respectively. Std. Error means standard error. Source: Own estimates.

4.3. Factors Associated with Sources of Technical Efficiency

The estimated results of inefficiency models for both specifications are depicted in the lower panel of Table 4. The results indicate a significant effect of omitting *rainfall* and *replanting cost* variables on the correlates of inefficiency in the model. The coefficients representing the different *100%*, *75%* and *25% levels of yield loss* due to rain incidence during the cropping season have, as expected, a negative significant effect on the technical efficiency of the farmers, except the *50% yield loss* variable, explaining that the rain incidence is one of the determinants used to achieve higher technical efficiency among farmers. However, determining why the *50% yield loss* variable is insignificant requires further investigation.

As shown in the lower part of Table 4, the *gender of household head*, *access to government credit* and *access to training* on pulse production practices, *location* where the farms are located and *pulse area* have a positive and significant effect on technical efficiency in both specifications, although *participation in a farmer organization* was positively significant only in the short specification. The results show that the impact of rainfall incidence has a stronger effect on technical efficiency compared to *participation in a farmer organization*, as the result of that variable becomes insignificant in the full specification. The positive effect of male household heads on technical efficiency may be due to higher motivation, farming knowledge and management skills and the decision-making behavior of a male head on the farming activities compared to a female head.

The result of the dummy variable for *location* explains that farmers in the Bago Region have higher technical efficiency than those in the Yangon Region. The likely reason is that in the Bago Region, pulses are cultivated with more intensive care as the main income-generating crop.

4.4. Frequency Distribution of Technical Efficiencies in both Specifications

The frequency distribution of the technical efficiency indices of pulse farmers is illustrated in Figure 2 in which the prominent feature of incorporating *rainfall* and *replanting cost* variables in the full specification can be virtually seen, indicating a wider distribution of the technical efficiency through each level of efficiency scores than in the short specification. The mean, minimum and maximum technical efficiency levels of both specifications are presented in Table 5. Incorporating the effect of *rainfall* and *replanting cost*, the mean and maximum technical efficiency levels of the full specification will become slightly increased, whereas the minimum technical efficiency level decreases, creating wide variation in technical efficiency scores and indicating that the omission of *rainfall* and *replanting cost* can lead to overestimating the inefficiency of farmers. This result might be due to more precise estimation of the technical efficiency under controlling the environmental variables and is consistent with the previous findings of Rahman and Hasan [3], Sherlund et al. [20] and Hasan et al. [29].

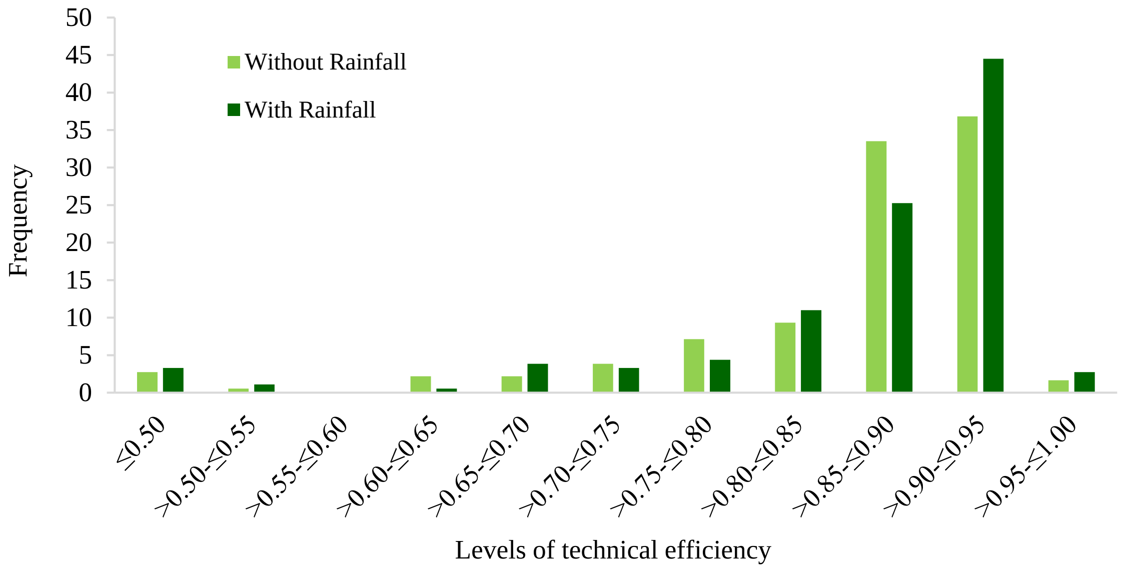

Figure 2. Technical efficiency scores with and without rainfall effects.

Table 5. Technical efficiency estimates with and without rainfall effects.

Items	Without Rainfall	With Rainfall
Mean efficiency score	0.857	0.862
Minimum	0.350	0.314
Maximum	0.957	0.964

Source: Own estimates.

Moreover, with the *rainfall* and *replanting cost* variables, the majority of pulse farmers (83.51%) fall into the highest level (above 0.80–1.00), whereas the short specification resulted in 81.32%, which is less than the full specification. In both specifications, a minimum technical efficiency score of less than 50% included only about 3%, indicating that almost all pulse farmers are achieving relatively high technical efficiency in production. In the short specification, 18.69% of farmers were operating with an efficiency score under 0.80, whereas under the full specification, only 16.49% were in that range. The mean technical efficiency scores of 0.857 in the short specification and 0.862 in the full specification suggested that there was significant technical inefficiency among the pulse farmers and indicating that the inputs used could be reduced by approximately 14% without decreasing the current output level if a farmer's technical efficiency improved to a fully-efficient level so as to increase the gross margin of pulse farmers.

Furthermore, this estimated mean technical efficiency in the full specification also implies that productivity could be increased by 16.00% [{(0.862 − 1.00)/0.862} × 100] [3] with full efficiency improvement. Moreover, the average technically efficient farmers could reduce their cost by 10.58% (i.e., [1 − {0.862/0.964}] × 100) [38–40] and the most technically-inefficient farmers could save costs of 67.43% (i.e., [1 − {0.314/0.964}] × 100) if they achieved the maximum technical efficiency level of their counterparts.

5. Discussion

The strong correlation between the production inputs and environmental production conditions, including rainfall, was also reported by Sherlund et al. [20], while Rahman and Hasan [3] and Hasan et al. [29] found weak but non-zero, correlations between them. These findings indicated the need to control for environmental conditions in estimating firm-specific technical efficiency. *Seed rate*, *fertilizer* and *labor* have a positively significant relationship with *rainfall*, whereas *chemicals* is negatively related, which supports the general idea of a plant and weather relationship when rain occurs, during which pest and disease infection become severe; consequently, more pesticides are used. The *replanting cost* is positively correlated with the *seed rate* and *human labor*; this finding also indicates a reasonable relationship among these variables.

According to the results of the production frontier function, there is ample opportunity to improve technical efficiency (14%) to achieve fully-efficient utilization of farm inputs under the current situation. Rain incidence during the pulse flowering season will decrease pulse productivity and cause farmer losses, consequently resulting in low economic standards among farmers. Therefore, to generate security in the face of such climate-related disasters, which are out of human control, the government should introduce a safety network, such as a weather index-based crop insurance program for farmers to protect family farms from unexpected weather risks and economic losses. Moreover, the results revealed that farmers who faced *100%*, *75%* and *25% yield losses* due to rain have low technical efficiency, which made them experience a low benefit from pulse production.

Replanting the crop will significantly increase pulse productivity. Thus, farmers should undertake replanting practices after damage from rain during the early growth stage. However, to follow the seasonality of pulses, farmers should urgently replant the crop, which demands government support. Therefore, the government should encourage faster decisions during field assessment about the damage level and should quickly provide farmer victims with the emergency support of seed and capital for planting costs; often, the compensation from the government is quite late, delaying replanting and resulting in poor crop performance.

The results revealed that seeds are one of the most important factors for increasing productivity. The result of *seed rate* falls within the findings of Rahman and Hasan [3] in a wheat farmer technical efficiency analysis in Bangladesh. More seed rate use per ha increases the output. The research on improved and locally-adaptable variety development of pulse seeds, which are also preferably adaptive to climate change conditions, should be geared toward making more effective use of seeds and driving productivity improvement through dissemination of quality seeds throughout the pulse growing regions. On the other hand, to avoid the overuse of seeds, research should also focus on area-specific recommendations of seed rates for individual kinds of pulses, which should be developed and suggested to farmers through effective demonstration plots. Moreover, seed storage technologies should be shared with farmers to prevent seed waste.

The increased use of *human labor* would cause pulse yields to increase. The result of the positive impact of *human labor* on productivity is in line with the findings of Kyi and Oppen [22], Latt et al. [25] and Mar et al. [26]; in these studies, the authors estimated the technical efficiency in rice, sesame and mango in the same country, Myanmar.

The result of *chemicals* in the short model depicted that pest and disease control practices are very important for obtaining high yields; however, they should be used with careful attention to the residual effects on crops. Moreover, in the full model, incorporating *rainfall* and *replanting cost* variables, *chemicals* has no significant effect on pulse productivity. The reason might be the mistiming of pesticide application, which decreases the effectiveness of applied chemicals on plants. Therefore, this could be an important consideration for future research.

The negative effect of *land preparation cost* on productivity confirmed the findings of Mar et al. [26] in a technical efficiency analysis of mango farmers in central Myanmar and of Hasan et al. [29] for efficiency estimations of pulse farmers in Bangladesh.

The positive significance of *pulse area* on technical efficiency is in line with the pervious results of Rahman and Hasan [3] and contradicts the findings of Sherlund et al. [20] and Battese et al. [41], who found that smallholder rice farmers are more technically efficient under controlled environmental production conditions. Furthermore, the obtained results may be due to the large-scale farmers obtaining the benefit of training or extension networks for cultural practices as a key informant and who easily access loans for production costs from private money lenders, as the government credit for winter crops is only about 50,000 Ks per hectare, which is insufficient for even the initial production cost, such as land preparation and who easily buy agro-chemicals on credit whenever needed from pesticide companies/dealers, which is a significant difficulty for small farmers.

6. Conclusions and Policy Implications

This research was motivated by the concern that most farmers face heavy rains during the growing season and that crop damage and yield losses due to heavy rains cause extensive losses among farmers. Therefore, the situation calls for an empirical analysis of the technical efficiency of pulse farmers that considers the climate effect. The result may help to draw true inferences, without any unnecessary consequences, toward designing policies that could help to improve pulse productivity while considering the climate effect, which has never been done in the case of Myanmar.

Based on the results of the study, encouraging female and small-scale farmers to participate in training programs would be beneficial for improving the performance of farming practices resulting in higher technical efficiency and, hence, productivity. Furthermore, if farmer organizations can introduce a safety network, such as a crop insurance program for farmers, the efficiency of a cooperative may become significant. The results indicate that conducting practical, effective and efficient training programs that educate pulse farmers can increase the technical efficiency among pulse farmers and can increase productivity. Moreover, building a persistent bond between farmers and extension staff through effective extension activities is necessary for expanding the use of farming technologies. Promoting extension services should also be accelerated with the encouragement of the respective policy-makers for improving farmers' technical know-how and their motivation to accept new or existing technologies.

The provision of credit to farmers should increase, at least to meet the initial cost of production, to improve technical efficiency and the consequent productivity of pules; furthermore, credit should be provided to farmers in time for the planting season. This finding greatly supports the current plan of increasing agricultural credit for upland crops to 125,000 Ks ha^{-1}, which should also be extended to winter crops, like pulses, in Lower Myanmar.

These policy recommendations will fulfill the current needs of farmers and help policy-makers recognize the effectiveness of these recommendations, as pulses are one of the most important crops contributing to the economic development of Myanmar.

Supplementary Materials: Questionnaires for farm household survey and the data file used for analysis. Table S1 Questionnaires for farm household survey of pulse farmers, Table S2 Raw data for Impact of Erratic Rainfall from Climate Change on Pulse Production Efficiency in Lower Myanmar, Table S3 Summary statistic result, Table S4 Frontier result with rainfall and replanting cost variables, Table S5 Frontier result without rainfall and replanting cost variables.

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