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AN ANALYSIS OF OVERALL TECHNICAL, PURE AND SCALE EFFICIENCIES OF RICE FARMS IN SATKHIRA DISTRICT OF BANGLADESH: A DATA ENVELOPMENT APPROACH

Kazi Julfikar Ali[1]*, Md Abdul Khalek[2] and Md Abdur Rashid Sarker[1]

[1]*Department of Economics, University of Rajshahi, Rajshahi-6205, Bangladesh*
[2]*Department of Statistics, University of Rajshahi, Rajshahi-6205, Bangladesh*

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Abstract

This study measures efficiency of *Aman* rice farms and assesses the effect of farm-specific variables on the efficiencies using cross-section data in Bangladesh. Data envelopment analysis (DEA) method is used to measure the efficiency levels of *Aman* rice farms in Bangladesh. We used multi-stage sampling technique to collect the data of 455 rice farms using face to face interview method. The results show that the mean overall technical efficiency, pure technical efficiency, and scale efficiency are 0.75, 0.91, and 0.83, respectively. The beauty of this article is the use of scale efficiency which identifies the three different stages of production. The finding of the scale efficiency shows that about 0.89 percent of the *Aman* rice farm is operating at economies of scale that is really higher than optimal level. The Tobit regression model is employed in order to assess the cause of inefficiencies of rice farms. The results of Tobit regression implies that agriculture policy variable, farmers having bank account for receiving government agricultural assistance, positively relates to the technical efficiency of *Aman* rice farms. The policy implication of these findings implies government assistance such as cash incentive, and extension service need to be extended and implemented with proper targeting.

Keywords: Data envelopment approach, Overall technical efficiency, Pure efficiency, Scale efficiency

Introduction

The most significant sector of the Bangladesh economy is agriculture which creates the primary source of income for the majority of people living in rural areas of the country. Agriculture also contributes to reducing poverty and ensuring food security in the country. Still 45.33 percent of the population is directly employed in agriculture, and approximately 70 percent of the population relies on agriculture in some way or another for their livelihood (GoB,2022).This sector generates 11.38 percent of the economy's GDP (GoB,2022). The share of agriculture to the GDP declined, whilst the contribution of the service and industrial sectors rose due to rural-urban migration and developing service and industrial sectors. Agriculture sector consists of four sub-sectors, namely crops, livestock, forestry and fisheries among crops rice is the main important sector in the sub-sectors of crops and contributes one-half of the agricultural GDP in Bangladesh (BRRI, 2022). Rice is the staple food of about 170 million people of our country (GoB,2022). Moreover, rice contributes to 49 percent of average per capita daily calorie intake and about 36 percent of per capita daily protein intake for Bangladeshi people (BBS,2023).There are three rice seasons in Bangladesh, namely *Aus, Aman,* and *Boro*. *Aus* is the traditional rain fed crops. *Aman* rice cultivation is predominantly rain fed, with planting often occurring during the monsoon season. However, supplementary irrigation is sometimes necessary throughout the planting phase and occasionally during the flowering stage due to capricious behavior of climate. *Boro* is one of the most important rice crops as its share is the highest crop production in our country while *Aman* is the most common type of rice grown in the coast area. In addition to this, around half of the total land area that is used for rice cultivation and provides more than 40 percent to the overall amount of rice that is produced (Rashid et al. 2017).According to the BBS(2023), the farmers' average rice yield for *Aman* rice in our country is at 2.69tons per hectare. This figure is significantly lower when compared to the rice

*Corresponding author: <julfikar.eco@ru.ac.bd>
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yields observed in other Asian nations, as highlighted by Pingali et al. (1997). Our country has made incredible progress in rice production and can now meet its population's food requirements. Our country's rice production has increased from roughly 10 million tonnes in 1971-72 to around 36.6 million tonnes in 2019-2020. It is almost three times as much as we were making before. This remarkable achievement has taken place due to extensive government endeavors to advance the agricultural sector. The actual yield of rice production on farms in our country is significantly lower than the expected yield of rice production (Shelley et al. 2016). The yield gap is a significant issue since it has an impact on the potential for output for both the farmers and for the countries. The yield gap can be minimized by making technological advancements and enhancing the productive capacity of production facilities. The improvement of technology will require further investment; however the enhancement of efficiency will not require any additional investment in the use of inputs. The primary significance of this study is in its potential to provide food security within the rural and urban sectors of our economy. This study contributes to sustainable agriculture which leads to competitiveness of agriculture. In a country like Bangladesh, where much of the economy is dependent on agriculture, efficiency is crucial to the expansion of production. Technical efficiency is a theoretical framework used to assess the ability of farmers to achieve maximum production levels given a specific level of input (Farell, 1957). Our country continues to face challenges in modern agricultural production particularly in the coastal areas. The salinity of south western part of Bangladesh is extremely high as a result of excessive shrimp aquaculture (Billah et al. 2013).The government is currently making extensive endeavors to advance the agricultural sector, in accordance with various policies and plans such as Vision 2041, the 8th Five Year Plan, the National Agriculture Policy 2018, the National Agricultural Extension Policy 2020, the National Agricultural Mechanization Policy 2020, the Master Plan for Agricultural Development in the South, Sustainable Development Goals, and Deltaplan-2020. The budget for the fiscal year 2021-22 has allocated 9,500 crore BDT to be used for agricultural subsidies, including those for fertilizers and other agricultural endeavors (GoB, 2023).

In the backdrop, the objectives of this study are to measure efficiencies and identify the factors causing the inefficiency of *Aman* rice farms in Bangladesh. In order to achieve the first objective, a DEA framework is utilized. Tobit regression model is used to achieve the second objective.

The rest of the paper is organized as follows: immediate next section provides a review of the relevant literature. Afterwards, we present methodology and analytical framework. Thereafter, the empirical results are analyzed and discussed. Finally we sum up the findings and explore policy implications.

Review of literature

Many earlier studies have carried out a series of research on the technical efficiency of rice production. Wadud and White (2000) utilized the Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) method to evaluate the efficiency levels of 150 rice farms located in Bangladesh. They found that environmental degradation and irrigation infrastructure influences the efficiency of rice farms. Coelli et al. (2002) analyzed data from 406 households with the help of DEA method to determine the technical, allocative, scale, and cost efficiencies of producing modern *Aman* and *Boro* rice crops. They found that *Aman* rice had a technical efficiency of 66 percent, while *Boro* rice had a technical efficiency of 69 percent. As a result, it is anticipated that this study will provide significant insights into the levels of technical efficiency of *Aman* rice farms as well as the variables that contribute to inefficiency. Balcombe et al. (2011) employed the double bootstrap approach to demonstrate that education, extension, credit, and age serve as key determinants of efficiency in rice farming within the context of Bangladesh. Jalilov et al. (2019) used a two-stage method involving DEA and Ordinary Least Squares to study the efficiency of 184 rice farms in the Northwest region of Bangladesh and determine the factors influencing this efficiency. According to the findings of the study, 85 percent of rice fields totally achieved DEA efficiency and are operating at the most efficient size possible. Hien et al. (2023) employed a two-stage DEA approach to measure and compare the technical efficiency of conventional and sustainable rice farming households in Vietnam's Long An province based on a sample of 152 farms. The mean technical efficiency score was 81 percent. Additionally, they discovered that farmers that implemented more sustainable approaches had greater levels of technical and scale efficiency, achieving ratings of 90 percent and 91 percent respectively. Saeri et al. (2021) analyzed technical efficiency performance of 88 rice farmers in farming in Ngawi District of East Java Province using DEA method. They found that the average technical efficiency level of rice farmers in Ngawi District, East Java Province is 68 percent which showed that there is still scoped to increase 32 percent. The six variables that have the significant impact on technical efficiency are age, experience, education, spacing, number of families, as well as the quality of the seeds. Miassi et al. (2023) employed the DEA methodology to evaluate the technical efficiency in West Africa, with a specific emphasis on the

Benin Republic involving 200 rice farmers. The study showed that the average technical efficiency score of rice farmers is 51 percent, indicating a potential improvement to 49 percent. Sanghamitra et al. (2023) examined the technical efficiency of 40 rice farmers in the Guntur District of Andhra Pradesh that were part of the Farmer Producer Organization (FPO) using both the DEA and SFA methods. The average technical efficiency of rice farmers was 98 percent. They noticed that Data Envelopment Analysis (DEA) is accounting for a greater amount of variability in technological efficiency compared to Stochastic Frontier Analysis (SFA). This study possesses the capacity to make significant contributions to the existing body of literature on productivity and efficiency primarily focuses on empirical applications pertaining to technical measurements. This research is different from other studies that have been done in a number of ways. Firstly, the majority of the studies did not place sufficient emphasis on pure technical and scale efficiencies of rice farm by identifying the stages of production of farms. Secondly, the sample of farms represents a much broader variety of farms compared to previous studies. Thirdly, there is a limited number of studies that incorporates government policy into this context. This study incorporated a new explanatory variable named agriculture policy which was not analyzed in the past studies as potential determinant of inefficiency of *Aman* rice farming. Finally, the most of the studies is concentrated on solely the issue of technical efficiency and frequently overlooked the returns to scale assessment. So, this study looks at the returns to scale assessment.

Methodology of the study

Selection of the study area, data collection, sampling technique, as well as definition of input and output

The study was conducted in the Satkhira district, located in the south-west region in Bangladesh. Salinity is a well-known problem in this area. Satkhira district consists of seven sub-districts: Satkhira sadar upazila, Shyamnagar, Assasuni, Kaliganj, Debhata, Kalaroa, and Tala. The agriculture in the Satkhira is mostly subsistence farming practiced by smallholders and based on a saline wet rice ecosystem. The study area has great potential for rice production especially *Aman* rice. The collection of primary data was conducted through the utilization of a structured questionnaire. Prior to the development and implementation of the final survey questionnaire, a pre-pilot and pilot survey are carried out. The pre-pilot survey was conducted with the participation of staff and officers from the Kaligonj Agriculture Office and academics of department of economics of Rajshahi University. The pilot survey was conducted with 15 farmers between November and December of 2022. Subsequently, the final survey was conducted between the months of May and June in the year 2023. Multistage sampling method was utilized in order to select the respondents for the study. In the first stage, Satkhira district was chosen purposively. In the second stage, the selection of Kaligonj upazila (lower administrative unit under a district) was selected purposively from Satkhira district was based on its relative rice output. In the third stage, villages were chosen randomly and the respondents were selected randomly by using computer generated random number table in the final stage. The Upazila Agriculture Office provided the information that was used to compile an accurate and up-to-date list of all of the village's farmers. The list comprises 1866 farm household which constitute the population. Finally, a total of 455 farmers from eight villages were randomly chosen to interview for the assessment in the areas of overall technical efficiency, pure efficiency, scale efficiency, and returns to scale.

In order to assess overall technical, pure technical and scale efficiencies, a specific output, namely *Aman* rice output, and eight inputs were selected for analysis. These inputs include land, labour, capital, seed, organic fertilizer, NPK fertilizer, irrigation, and pesticides. Labour consists of both family members (whose hours are imputed for hired labour) and outside contractors who help with activities such as harvesting and threshing, pre- and post-planting crops. The unit of measurement employed was labor-days, which were utilized for the purpose of rice cultivation. Capital refers to the monetary worth attributed to equipment and machinery but in this analysis total number of equipment and machinery is the unit of measurement of capital. Seed is crucial for food security. The quality of seed directly affects the yield. High quality seed result in healthier plant, thereby improving grain quality. Seed is measured in Kg. NPK fertilizer is composed of three essential macronutrients, namely nitrogen (N), phosphorus (P), and potassium (K). The essential nutrients required for optimal plant development and overall plant health. NPK fertilizer can be measured in Kg. Organic fertilizers refer to substances derived from animal sources that are utilized for the purpose of sustaining or enhancing plant nutrition. The number of equal sized *van* is the unit of measurement of organic fertilizer. This *van* can carry roughly 100 Kg. Irrigation is a systematic technique involving the planned application of regulated quantities of water to agricultural land with the aim of facilitating optimal crop growth. The irrigation volume is the number of irrigations applied to the *Aman* rice farms per season. Pesticides are chemical compounds designed to manage and regulate populations of pests. Pesticides are measured in milliliters.

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Measurement of technical efficiency

According to microeconomic theory, firms aim to achieve optimal efficiency in the long-term by operating at the most productive scale size (MPSS), which is defined by constant returns to scale (CRS). In the short-run, firms have the potential to operate within the realm of either increasing or decreasing returns to scale. In the long run, however, they will shift towards CRS by either getting larger or smaller in order to survive in the market's competitive environment. Even, returns to scale (RTS) plays an important concept of production economics as it gives explanation long-run input-output relationships. The concept of returns to scale (RTS) can be explained by Data Envelopment Analysis. The DEA technique is a data driven and nonparametric linear programming frontier method that does not require a functional or distributional form, and can handle the issues of scale (Charnes, et al. 1978). The DEA employs multiple inputs and outputs to assess the relative efficiency of similar Decision-Making Units (DMUs) (Tone, K.et al.2020). There are two types of DEA model: Charnes, Cooper, and Rhodes (CCR) and Banker, Charnes and Cooper (BCC) models. The CCR model is referred to as the constant returns to scale (CRS) model while the BCC model is alternatively referred to as the variable returns to scale (VRS) method. Measurement of technical efficiency was gauged by employing input-oriented CRS and VRS DEA models for the purpose of this study. Dyson et al. (1998) suggest that for DEA analysis, the sample size should exceed the multiplication of the number of inputs and outputs. For this reason, the results of the DEA cannot be generalized for the entirety of the population, and it provides a relative efficiency score rather than an absolute one. According to Coelli et al. (1998), one should select between an input-oriented DEA model and an output-oriented DEA model based on the quantities over which the operator has more control. An input-oriented DEA model was employed in this study because farmers in Bangladesh have greater command over their inputs as opposed to their outputs. A characteristic of production functions is constant returns to scale, which means that if inputs are increased proportionally, outputs are also increased proportionally. This property is often observed in various production processes and is a fundamental concept in production theory.

CCR DEA method

The CCR DEA model is one of the basic DEA models for measuring efficiency. The DEA methodology can be employed under the condition that all farms are capable of functioning at their optimal scale, as posited by Coelli et al. (1998). The ratio form of DEA was presented by Charnes, Cooper and Rhodes (1978).The efficiency score of every DMU, denoted by the symbol θ, is determined by the following formula:

$$\theta_j = \frac{\sum_{r=1}^{s} \mu_r y_{rj}}{\sum_{i=1}^{m} \nu_i x_{ij}} \qquad j, \ldots \quad , n \tag{1}$$

Subject to

$$\frac{\sum_{r=1}^{s} \mu_r y_{rj}}{\sum_{i=1}^{m} \nu_i x_{ij}} \leq 1$$

where, μ_r and ν_i represent the weights of outputs and inputs, respectively. Each of $j, r, and\ i$ shows the number of farms, outputs, and inputs respectively. y_{rj} represents quantity of output r produced by farm j. x_{ij} represents quantity of input i used by farm j. The above ratio form produces a infinite number of solutions. To avoid an infinite number of solutions, Charnes, Cooper and Rhodes (1978) constructed a transformation known as the linear programming problem. The multiplier formulation of an input-oriented CCR DEA model with the constant returns of scale (CRS) model is as follow:

$$\text{Min}\,\theta = \sum_{i=1}^{m} v_i x_{ij}$$

Subject to

$$\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} \mu_r y_{rj} \geq 0 \quad \text{for } j = 1, \ldots, n \tag{2}$$

$$\sum_{i=1}^{m} v_i x_{ij} = 1$$

$$\mu_r \geq 0, v_i \geq 0 \text{ for } r = 1, \ldots, s; \text{ and } i = 1, \ldots, m$$

where, y_{rj} represents quantity of output r produced by farm j. x_{ij} represents quantity of input i used by farm j. θ denotes the input-oriented technical efficiency value, which has a score $0 \leq \theta \leq 1$. If the score of $\theta = 1$, it indicates the DMUs are operating at the production frontier and there is no need to changing the quantity of inputs employed in their production. Even, it can be said that it is globally efficient. On the contrary, if the value of $\theta < 1$, it implies that DMUs is relatively inefficient and it could reduce the level of inputs usage without affecting output. The TE with constant returns to scale is termed to as overall technical efficiency. It evaluates to measure the combined inefficiency of pure technical and scale efficiencies.

VRS DEA model

The VRS DEA model was first proposed by Banker et al. (1984).The VRS DEA model is deemed to be more flexible and offers a more comprehensive depiction of the data as opposed to the CRS DEA model. The constraint imposed by the VRS DEA model assures that an inefficient farm in the region is only compared to other farms of comparable size. Coelli et al. (1998) proposed an input-oriented variable returns to scale DEA model to measure technical efficiency. This VRS DEA model is defined as follows:

$$Min_{\theta,\lambda}\theta = \theta x_i$$

$$\text{Subjectto} \quad \begin{aligned} & -y_i + Y\lambda \geq 0 \\ & \theta x_i - X\lambda \geq 0 \\ & N1'\lambda = 1 \\ & \lambda \geq 0 \end{aligned} \tag{3}$$

where, Y is a matrix that denotes the output from N farms. y_i shows the yield of the ith farm in kilograms. X is an input matrix for N farms. x_i denotes the ith farm's input vector. λ is an $N \times 1$ vector of weights that shows how the peers of the ith farm are added together. $N1'\lambda = 1$ represents convexity constraint. $N1'$ represents matrix with dimension $1 \times N$. θ denotes the input-oriented technical efficiency value, which has a score $0 \leq \theta \leq 1$. The TE with variables returns to scale is referred to as pure technical efficiency. If the value of $\theta = 1$, it indicates the DMUs are operating at the production frontier and there is no need to changing the level of inputs employed in their production. Even, it can be said that it is locally efficient.

DEA Scale Efficiency model

Assessing the scale status of a farm can prove to be a difficult task in the absence of a comprehensive evaluation of scale efficiency. The DEA method initially postulates that all farms operate at the optimal production scale, implying that they exhibit constant returns to scale (CRS). The measurement of scale efficiency is used to examine whether or not the size of the farm that is currently being operated is ideal. The fundamental cause of the problem with technical inefficiency lies in the inefficiency of the scale itself. The computation of scale efficiency involves the division of the technical efficiency obtained from the CCR DEA model by the technical efficiency derived from the BCC DEA model. The formula of scale efficiency is given as follows:

$$SE_i = \frac{TE_{i,CRS}}{TE_{i,VRS}} \tag{4}$$

Scale efficiency is achieved when SE equals 1. Scale inefficiency is displayed when the SE value is less than 1, in this case, the relationship between inputs and outputs does not exhibit efficient scaling. The concept of scale inefficiency arises as a consequence of a farm functioning at a level where there is either an increasing (IRS) or decreasing (DRS) rate of returns to scale.

Non-increasing returns to scale DEA (NIRSDEA) model

This measurement of scale efficiency suffers from the drawback that it does not indicate whether a farm is running under increasing, decreasing, or constant returns to scale. In order to further analyze the concepts of increasing, decreasing, and constant returns to scale, it is necessary to incorporate the term non-increasing returns to scale. The determination of returns to scale (RTS) may be achieved by the resolution of an additional data envelopment analysis (DEA) problem incorporating the concept of non-increasing returns to scale (NIRS). This can be accomplished with the use of the DEA model known as the NIRSDEA model. The specification of the NIRSDEA model is as follows:

$$Min_{\theta,\lambda}\theta = \theta x_i$$

$$\text{Subject to} \quad \begin{array}{l} -y_i + Y\lambda \geq 0 \\ \theta x_i - X\lambda \geq 0 \\ NI'\lambda \leq 1 \\ \lambda \geq 0 \end{array} \tag{5}$$

The constraint of NIRSDEA $NI'\lambda \leq 1$ implies that ith farms cannot be achieved the value which is greater than 1. The efficiency score has $0 \leq \theta \leq 1$. If the total efficiency (TE) score of the NIRSDEA model differs from the TE score of the VRSDEA model, it can be concluded that there exists a phenomenon of increasing returns to scale. If the two entities being compared are same, then the principle of diminishing returns to scale is applicable.

If $SE = \frac{TE_{CRS}}{TE_{NIRS}} > 1$ then a farm carries on increasing returns to scale.

Alternatively, if $SE = \frac{TE_{CRS}}{TE_{NIRS}} < 1$ then a farm carries on decreasing returns to scale.

Overall technical inefficiency results from the inappropriate scale size while pure technical inefficiency is caused by managerial under performance in managing inputs.

Tobit regression model: Determinates of inefficiency

In this study, Tobit model is used to explain the linear relationship between a non-negative dependent variable (Y_i) and one or more explanatory variables (Z_i). The Tobit model can be described with the help of a latent variable $\left(Y_i^*\right)$. The Tobit model is as follows:

$$Y_i^* = Z_i\delta + \omega_i \tag{6}$$

where, Y_i^* is observed if $Y_i^* > 0$ and is unobserved if $Y_i^* \leq 0$. Z_i is a vector of explanatory variables, δ is the parameter, i indicates the observation, and ω_i is the error term which follows the normal distribution. The dependent variable of the Tobit model can be either left-censored or right-censored. The level of inefficiency exhibited by the DEA is quantified based on farm-specific variables, and a regression model is employed to estimate the impact of these variables on farm efficiency. This model uses only indirect inputs that have an effect on efficiency of rice production in Bangladesh. The inefficiency score serves as the dependent variable, while socioeconomic and other farm-specific characteristics serve as the independent ones. According to the findings of Dhangana et al. (2000), the range of the inefficiency scores is from 0 to 1. As a consequence of this, it is impossible to presume that the dependent variable in the regression has a normal distribution. Consequently, the utilization of the Ordinary Least Squares (OLS) technique is not viable, as employing OLS regression for estimation purposes would yield inaccurate parameter estimates (Krasachat, 2003). In this case, Maximum Likelihood estimation method provides the unbiased estimator. The inefficiency model is given below:

$$IE_i = \delta_0 + \delta_1 Z_{1i} + \delta_2 Z_{2i} + \delta_3 Z_{3i} + \delta_4 Z_{4i} + \delta_5 Z_{5i} + \delta_6 Z_{6i} + \delta_7 Z_{7i} + \delta_8 Z_{8i} + \omega_i \tag{7}$$

Where IE_i is dependent variable that exhibits inefficiency score range between 0 and 1 for the ith farm. δ_0 is constant term. Z_{1i} is farmer's age (years). Z_{2i} is years of schooling. Z_{3i} is farming experience(years). Z_{4i} is household size(number of household person). Z_{5i} is access to extension service(Dummy 1= have access to extension service, 0 = otherwise). Z_{6i} is salinity(Dummy 1= suffers from salinity, 0=otherwise). Z_{7i} is the agriculture policy that refers to farmers belongs to bank account (Dummy1= getting subsidy from government at 10 Tk. bank account, 0= otherwise). Z_{8i} is the access to credit(Dummy1= have access to credit,0= otherwise). ω_i is the stochastic error term.

Results and discussion of efficiency

Results from CCR-DEA

In this study, the technical efficiency scores of *Aman* rice farms were determined using CRS and VRS DEA models. Table 1 provides a summary of the results from the CRS DEA, VRS DEA, and scale efficiency models of *Aman* rice farms. The average technical efficiency of the sample farms, as determined by the CCR model, is 0.75. This value varies between 1.00 and 0.37. The average technical efficiency of the sample under BCC model is 0.91 with a minimum score of 0.60 and a maximum score of 1.00. Table 1 makes it abundantly clear that the majority of the sample farms have an overall technical efficiency that falls somewhere in the range of 0.37 to 1.00. The findings presented in Table 1 indicate that a significant proportion of the farms included in the sample exhibit a pure technical efficiency level that lies within the range of 0.60 to 1.00. According to the CCR model, a total of 37 rice farms have been identified as possessing technical efficiency, as evidenced by their score of 1. This score signifies that these farms already occupy a position on the efficient frontier, implying that further enhancement in their production can only be achieved by simultaneously raising the proportion of their all inputs. The overall technical efficiency, pure technical efficiency, and scale efficiency all have averages of 0.75, 0.91, and 0.83, respectively. Pure technical efficiency score (0.91) is greater than scale efficiency score (0.83).

Table1. Frequency distribution of Input-oriented CCR model, BCC model and scale efficiency indexes.

Efficiency Index	Technical efficiency					
	CRS-TE(Overall TE)		VRS-TE(Pure TE)		Scale efficiency	
	Number of farm	% of farm(CCR)	Number of farm	%of farm (BCC)	Number of farm	%of farm(SE)
30-40	1	0.22	0			
40-50	12	2.64	0		5	1.10
50-60	57	12.53	0		25	5.50
60-70	82	18.02	24	5.27	50	10.99
70-80	129	28.35	67	14.73	74	16.26
80-90	92	20.22	65	14.29	129	28.35
90-100	82	18.02	299	65.71	172	37.80
Maximum	1.00 (37)		1.00(185)		1.00(34)	
Minimum	0.37		0.60		0.45	
Mean	0.7534		0.91		0.8306	
Mode	1.00		1.00		1.00	
Standard deviation	0.14405		0.11084		0.13261	

Source: Authors' calculation based on Field Survey, 2023.

Results from BCC DEA model

The TEVRS value is 0.91, which implies that enhancing the farmers' managerial abilities to make better use of their inputs more efficiently would be able to address approximately 9 percent of the inefficiency that currently exists in the framework. This finding seems to be strikingly similar to the result that Chauhan, Mohaptra, and Pandey (2006) obtained in India. There are two major conclusions that can be drawn from these empirical data. To begin, there are considerable opportunities to enhance the levels of pure technical efficiency in *Aman* rice farms. Operating at optimal scales efficiency and getting rid of pure technical inefficiency are two ways that the overall technical inefficiency could be cut by an average of 25 percent. Second, the findings suggest that pure technical inefficiency on the part of rice farms is a major contributor to overall inefficiency in the farms as a whole. To eliminate technical inefficiency in *Aman* rice farms in Bangladesh, the most effective approach would be to adopt the up-to-date farming practices for *Aman* rice cultivation.

Results from scale efficiency

Table 1 provides a summary of the results for scaling efficiency. Scale efficiency score provides important information that farmers can use to evaluate whether or not there should be a change in the scale of production in order to improve efficiency. According to the data presented in Table 1, the majority of the sampled farms have scale efficiency that falls in between 0.45 and 1.0 with an average of 0.83.There are 455 farms total, but only 34 of them are scale efficient. The scale efficiency of approximately 1.10 percent of farms falls between 0.40 and 0.50. The scale efficiency of only 37 percent of farms falls between 0.90 and 1.0. According to the findings of the DEA, increasing the scale of their production could result in a 17 percent improvement in the technical efficiency of their operation. This suggests that the elimination of the problem of increasing returns to scale could result in the greatest increase in overall technical efficiency, whereas the elimination of the problem of decreasing returns to scale would result in an increase in overall technical efficiency to a lesser extent. From the perspective of agricultural policy, this suggests that larger farms are preferable to smaller ones if the goal is to increase the scale efficiency in which rice is produced in Bangladesh.

Results of returns to scale (RTS)

The results of returns to scale are presented in Table 2.These findings show that only 9 percent of the *Aman* rice farms are operating at their optimal scale. If the RTS of the DMU is CRT, it is assumed that the investigated DMU acts as the most productive scale sizes (MPSS).The MPSS is the efficiency frontier point where the average output is the greatest for a given input and output set. Charnes, Cooper and Rhodes (1978) measured the most productive scale sizes for convex production possibility sets. In this case, productivity is unaffected by the size or the scale. This situation arises when the average consumption of inputs is reduced to a minimum and does not change in relation to output.

Table 2.Results of Input-oriented Returns to Scale (RTS) of *Aman* rice farms

RTS	Number of farms	Percent of farms
Increasing returns to scale	407	89
Decreasing returns to scale	11	02
Constant returns to scale	37	09

Source: Authors' calculation based on Field Survey, 2023

According to the findings of the study, just 89 percent of the *Aman* rice farm is operating at economies of scale that really is lower than their optimal level. In this case, the average consumption of inputs gets lower declines whilst output gets higher. This indicates that these farms could keep expanding their size in order to improve the technical efficiency of their operations. As can be shown in Table 2 only 9 percent of the *Aman* rice farms are working above their optimal scale. Moreover it can be said that about 2 percent of the *Aman* rice farms is already oversized in their production operation. These results show that these farms might improve their technical efficiency by shrinking in size. In this situation, the average inputs consumption rises whilst output rises. This situation is called diseconomies of scale. To improve this scale efficiency, farms must useless input mix. Hence, a decrease in output leads to a deduction of the average consumption of inputs. In order to reduce its average consumption of input it must shrink its size, particularly this might be accomplished in a number of ways, including internal decay (i.e. utilizing lower input) and decomposing the farm production.

Factors influencing technical inefficiency of *Aman* rice farms from CCRDEA model

Table 3 shows the results of Tobit regression under CRS model for *Aman* rice technical inefficiency. The coefficient of age is positive and significant at 5 % level. This finding suggests that the efficiency of a farmer declines as their age increases. This is due to the fact that older farmers were not interested in adopting modern farming techniques, which influences the overall productivity of farmers (Albert and Duffy, 2012; Taueso and Lordkipanidze, 2000). This finding is consistent with Lira Mailena, et al. (2014), Dhungana, Nuthall and Nartea (2004), Ogunniyi et al.(2015), Topi et al. (2009).The coefficient of years of schooling has a positive relationship with rice farm technical inefficiency but has no significant impact on technical inefficiency. This conclusion suggests that even highly educated farmers are not making the best use of their available production resources as agriculture is the secondary occupation. This results supports the study of Ogunniyi et al.(2015) but these results do not confirm the findings of Linn and Maenhout (2019), Linh et al. (2017), Mailena et al.(2004) and Dhungana, Nuthall and Nartea(2004). Household size has positive and insignificant influence on technical inefficiency of rice farms under the assumption of CRS. This signifies that when the household size increases the technical inefficiency also rises if other things remain constant. Experience in rice farming is inversely related to technical inefficiency. This finding suggests that producers with more expertise are more effective in their use of input resources. These findings confirm the studies of Mailenaet al. (2014),Ogunniyi et al. (2015), and Linn and Maenhout (2019),while the results of this study are inconsistent with the studies of Huynh-Truong, Huy (2009), Kiatpathomchai(2008) and Waddud (1999).The farmers' access to extension services is a major contributor to the inefficiency of CRS-based rice farms. This shows that efficient use of the input mix is possible provided farmers have access to extension services.

Table 3. Results of Tobit regression under CRS model for *Aman* rice technical inefficiency

Variable	Coefficient	Std. Error	Z-Statistic	Prob
Intercept	0.177170	0.037011	4.786997	0.0000
Age	0.001902	0.000873	2.177392	0.0295
Years of education	0.002433	0.001620	1.501933	0.1331
Experience	-0.001212	0.000888	-1.365560	0.1721
Household size	0.000831	0.002945	0.282344	0.7777
Extension Contract	-0.034703	0.012802	-2.710868	0.0067
Salinity	0.126210	0.013836	9.122186	0.0000
Agricultural policy	-0.066856	0.014153	-4.723686	0.0000
Access to credit	0.002167	0.012781	0.169527	0.8654

Source: Authors' calculation based on Field Survey, 2023

This study provides support for the conclusions reached by Jaforullah and Whiteman (1999), Javed, et al. (2009), Backman, Islam, and Sumelius (2011), and Linn and Maenhout (2019). However, this finding of the extension service is inconsistent with the results of Mailena et al. (2014) which implies the role of extension service is inconclusive. The coefficient of salinity variables had a positive sign and was highly significant. The finding shows that there is positive relationship between salinity and inefficiency of *Aman* rice farms. The variable associated with agricultural policy, which exhibits the highest coefficient, demonstrates a statistically significant adverse effect on the technical inefficiency of *Aman* rice farms. It has been revealed that an agricultural policy variable has a substantial effect in a way that is unfavorable contributing to the technical inefficiency of rice farms. The results obtained from the CRS model demonstrate that the presence of access to credit has an insignificant role in the technical inefficiency observed in rice production.

Factors influencing technical inefficiency of *Aman* rice farms from BCC-DEA model

Table 4 shows the results of Tobit regression under VRS DEA model for *Aman* rice of technical inefficiency.

The parameter estimate of age variable had a positive sign and was insignificant. The findings show that younger farmers are more technically efficient than their more experienced counterparts. This finding confirms the results of Javed et al.(2009).

Table 4. Results of Tobit regression under VRS model for *Aman* rice of technical inefficiency

Variable	Coefficient	Std. Error	Z-Statistic	Prob
Intercept	0.036249	0.051875	0.698765	0.4847
Age	0.000674	0.001247	0.540667	0.5887
Years of education	-0.000345	0.002275	-0.151636	0.8795
Experience	-0.000743	0.001262	-0.589234	0.5557
Household size	0.007777	0.004083	1.904779	0.0568
Extension Contract	-0.021956	0.017901	-1.226533	0.2200
Salinity	0.000799	0.019494	0.040993	0.9673
Agricultural policy	-0.047882	0.019773	-2.421604	0.0155
Access to credit	-0.000619	0.018032	-0.034350	0.9726

Source: Authors' calculation based on Field Survey, 2023

The coefficient of years of schooling is negatively related to technical inefficiency of rice farms under the assumption of VRSDEA. This finding implies that educated farmers do utilize their input resources in the optimum way as most of the educated farmers have engaged in other occupation. The coefficient of household size is positively and significantly influence on technical inefficiency of *Aman* rice farms. This signifies that as the household size rises the technical inefficiency rises if other things remain constant. The agricultural extension contracts obtained by the farmers have a negative and insignificant effect on the inefficiency of rice farms under the VRS model. This indicates that if farmers get extension services, they can effectively utilize their input mix. These findings support the findings of Jaforullah and Whiteman(1999) as well as Backman, Islam, and Sumelius (2011). The agricultural policy variable that has the largest coefficient has a negative and significant effect on the pure technical inefficiency of *Aman* rice farms. It has been shown that agricultural policy variable has a significant role in a manner that is unfavorably contributing to the technical inefficiency of *Aman* rice farms. The results from the VRS model indicate that access to credit plays a substantial negative impact in the technical inefficiency found in *Aman* rice growing operations.

Conclusions and Policy Implications

The objective of this study was to measure efficiency and identifies the sources of inefficiency using nonparametric DEA method. The study employed an input-oriented classical Data Envelopment Analysis (DEA) method to measure the levels of overall technical efficiency, pure technical efficiency, and scale efficiency in Bangladeshi *Aman* rice farms. The Tobit regression technique was used to explore the elements that influence the *Aman* rice farm technical inefficiency level at the farm level. According to the empirical findings, there are likely huge potential to improve levels of efficiency in Bangladesh. It is possible to achieve a 25 percent reduction in the typical level of overall technical inefficiency through the utilization of scales and the elimination of purely technical inefficiencies. Rice farms, according to the input orientation VRS model, had a range of technical efficiencies that went from 60 to 100. The average technical efficiency score under VRS was 91, which indicates that rice farmers may also be able to reduce the amount of inputs they use by 9 percent when maintaining the same output. In addition, the findings demonstrate that the sheer technical inefficiency of rice fields is a considerable contributor to the overall inefficiency of the farms. According to the CRS model, the majority of farmers (92 percent) conducted their activities below the frontier, while only a few rice farmers (8 percent) conducted their activities on the frontier. As a result, the ineffective rice fields in Bangladesh should have their technical efficiencies improved by extension services. Rice growers do not obtain the highest possible return from the resources they invest in their crop. It is still possible for the farms in the survey area to raise their technical efficiency by 25 percent by using best practices for inefficient farms. This result of CRS-TE is in line with the study of Sivasankari, Vasaanthi, and Preama, 2017, Thibbotuwawa, Mugera, and White, 2012; Chauhan, Mohaptra, and Pendey, 2006; and Dhungana, Nuthall, and Nurtea, 2004.This study focuses on the nature of RTS in terms of input oriented DEA method. According to the RTS results, 89 percent of the farms were operating with sub-optimal size and hence the farms could increase their efficiency by increasing their size of activites. This finding implies that a considerable proportion of *Aman* rice farms have experienced increasing returns to scale, which indicates that farms need to expand their current level of operation in order to remain profitable in the future. Only 9 percent of farms were operating at optimal size. This result also indicates that about 2 percent of the *Aman* rice farms were running at super optimal size and hence they could improve their efficiency by decreasing their size of operation. Salinity variable was found to have a positive and significant influence on inefficiency. So, the government could provide salinity tolerant cultivates to farmers as a means to address salinity issues and enhance productivity. Finally, the estimation of the Tobit regression model revealed that the agriculture policy variable had a significant and negative impact on overall and pure technical inefficiencies. The finding indicates that the government agriculture policy variable, specifically farmers holding bank accounts to receive government agricultural assistance, is a significant factor in improving the efficiency of rice fields using both the CCR and VRS techniques. The findings of the study put forward that government interventions have generally proven helpful in improving efficiency. The weakness of our study is that it was carried out only in the coastal area of Bangladesh. Thus, these findings are limited to the particular sample. This finding cannot be generalized to the entire country or other locations due to the potential for study bias. However, the findings and analytical framework of this study might be replicated to the other coastal areas both at home and abroad having similar characteristics. The conventional DEA model is unable to handle the input and output slacks as a result of the radial measuring approach. Furthermore, it is imperative to acknowledge the necessity of including alternative DEA methodologies in future research endeavors within this domain.

Conflict of interest

The authors state that they have no competing interests related to the publication of this paper.

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