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Extent of farm mechanization and technical efficiency of rice production in some selected areas of Bangladesh

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Abstract The research has been conducted to explore the extent of adopting mechanization at farm level and its impact on rice producers' technical efficiency. Primary data and information required for analytical approach have been collected using structured questionnaire through field survey of 200 farm households located in two districts of Bangladesh. Farm households were selected following multi-stage purposive sampling technique and were classified into two groups on the basis of extent of using modern agricultural practices. Technical efficiency is the ratio between actual and potential output of a production unit. Farmers strongly agree that farm mechanization save their precious time which they spend for farming period and also increased overall food production. They also agree that the use of modern machinery improve their consumption level as well as food security. From the profitability analysis of two levels of mechanization, it is apparent that mechanization has positive impact and leading to increase productivity and profitability of rice producers. The results from DEA approach implies that farms with higher level of mechanization are technically more efficient than the others although both farm groups are technically inefficient in rice production. The findings from Tobit regression show that variables such as farming experience, age and levels of farm mechanization were significantly associated with the technical efficiency of sample farms. Inefficiency of farms is negatively influenced by the level of farm mechanization indicated that mechanization is one of the important determinants to improve technical efficiency. So, the applications of modernized farming machineries could be an essential tool for the development of agricultural sector in Bangladesh.

Keywords Farm mechanization · Farmers perceptions · Comparative profitability · Technical efficiency · Data envelopment analysis · Tobit regression model

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Introduction

The mechanization of farming practices throughout the world has revolutionized food production, enabling it to maintain pace with population growth except in some less developed countries, most notably in Africa (McNulty and Grace 2009). Bangladesh is predominately an agricultural country and agriculture is a major sector which contributes about 14.2% to the GDP of the country with a growth rate of 0.5% (IRBD 2017). Paddy is the main staple crop of Bangladesh accounting for 74.85% of total cropped area and 95% of cereal production (BBS 2017). Since independence in 1971, the production of paddy has increased over three folds to 55.5 million tons compared to slightly more than double the population of 160 million and has attained self-sufficiency against shrinking of agricultural land by 0.5% per year (FAO 2014). However, by 2030, the population of Bangladesh would be about 200 million and by 2050 the population would be about 222.5 million that would need a doubling of paddy production in Bangladesh (Alam and Khan 2017). To achieve this target, there is no other better option than to increase production per unit of land as well as cropping intensity. On the other hand, the current labor force employed in on-farm agricultural activities is about 43% would have been reduced to about 36.1% by 2020 (FAO 2017). That poses a great challenge to Bangladesh agriculture to produce almost double the present paddy production with decreasing number of labor force. To face the challenge of feeding growing population with shrinking on-farm labor force, appropriate scale agricultural mechanization would be one of the main options among many innovations and adaptations of appropriate technologies and strategies.

Farmers have different views about the use of mechanization which also influence farmer's socioeconomic status of livelihood both positively and negatively. Moreover, the extent to which agricultural mechanization has influenced farm production depends on the improvements in farm level machinery usage and farming efficiency. Mechanization of farm is needed from the view point of the profitability of agriculture. Therefore, the contribution of farm mechanization on improving farm level efficiency and production has yet to be analyzed in the country context. Most importantly, the farmers are getting the realization that to save time and improve productivity and to do profitable agriculture, there is no other better option than to go for mechanized agriculture. This creates the hope of better mechanization in the years to come. Now, proper planning and positive intension from the higher authority is required. Nevertheless, Bangladesh hopes of further development in the sector with the modern mechanization technologies.

There were several recent studies that focused on the estimation and explanation of farming efficiency e.g. Coelli et al. (2002) estimated on technical, allocative, cost and scale efficiencies in Bangladesh rice cultivation using non-parametric approach. Khai and Yabe (2011) conducted a study on technical efficiency analysis of rice production in Vietnam. Chidambaram (2013) studied the impact of farm mechanization in rice productivity in Cauvery delta zone of Tamil Nadu state. Tun and Kang (2015) analyze the factors affecting rice production efficiency in Myanmar. Mamman (2015) studied the influence of agricultural mechanization on crop production in Bauchi and Yobe states of Nigeria. All of these studies pointed out substantial inefficiency and the possible potentials to improve the agricultural productivity. However, there has been no empirical research on farm mechanization impact on rice production efficiency in Bangladesh. Therefore, the study will focus on influence of farm mechanization on technical efficiency of rice production which will help to identify relationship among farmers' socioeconomic status, farm mechanization and farmers technical efficiency. This is important for the development of agricultural sector as well as overall economic condition of Bangladesh. Considering all of these aspects the present study has the following specific objectives with an aim to contribute to the national policy analysis: to explore the extent of mechanization at different levels of farm operations; to estimate profitability of rice cultivation at different levels of mechanization; and to measure the impact of farm mechanization on technical efficiency of rice production.

Research gap and justification of the study

The literature on agricultural mechanization is quite rich. Various researchers have approached the issue from various angles. However, our main concern is to study the impact of farm mechanization on rice production technical efficiency. The economic impact of agricultural mechanization adoption in Ondo State, Nigeria have been influenced by education, extension visit and machine access (Owombo et al. 2012). Different researches showed and experimented that the farm size and the machineries are the important factors deciding the rice production (Chidambaram 2013); mechanical harvesting for sugarcane marketing efficiency enhancement (Shinde et al. 2013). Similarly, Tun and Kang (2015) obtained a better understanding about the impact of farm mechanization on rice production efficiency using data envelopment analysis (DEA) and the stochastic frontier approach (SFA) in Myanmar. It is also examined that scale-appropriate machinery can increase returns to land and labour, although substantial capital investment required can preclude smallholder ownership in South Asia (Mottaleb et al. 2016). Ratolojanahary (2016) studied on designing of an agricultural mechanization strategy in sub Saharan Africa and suggests that the cost of labour influences the uptake of agricultural mechanization. With the expansion of HYV rice crop in 1970s, increased demand for mechanized irrigation, tillage, pest management and post-harvest processing of crops brought about significant changes in cropping pattern and cropping intensity in Bangladesh (Mandal 2017). However, several studies in different parts of the world measures farm level efficiency analysis with the application of agricultural mechanization and found positive results (Bäckman et al. 2011; Asadullah and Rahman 2009; Nasrin 2017; Islam 2010; Coelli et al. 2002; Wadud 2003). Therefore, this research contributes to literature by being the first to find out such impact of farm mechanization on technical efficiency of rice production in a developing economy like Bangladesh.

Above review reveals that, no studies have found in literature in dealing with the impact of agricultural mechanization on farm efficiency and rice production in Bangladesh. To assess the effectiveness of mechanization in raising farm production, the improvements in farming efficiency have to be measured. For efficient use of machineries and better acceptance of modern agricultural implements, farmer's perception about mechanization have to be measured. The main concentration of this research is on finding out the effect of agricultural mechanization on efficiency differentials across farms which will assist policy makers in identifying ways for refining agricultural policies in order to improve production performances of different farm groups.

Materials and methods

The research utilizes primary data for analytical tools which have been collected from field survey through using structured questionnaire. The samples were selected through a multi-stage purposive sampling technique. Bangladesh is divided into eight administrative divisions. Among them, two districts namely, Dinajpur and Mymensingh under two divisions were selected for necessary data collection on the basis of rice farming concentration. From each district, four sub-districts and four villages were selected after consultation with key informants from Department of Agricultural Extension (DAE) and Bangladesh Rice Research Institute (BRRI). A total of 200 farm households from the selected sub-districts were interviewed purposively along with some focus group discussions. The primary criterion for selecting these regions are the concentration of rice farming activities through mechanization. After data collection, the farms were classified into two groups to study the technical efficiency: a) farms with more than 50% mechanization (those farms which use farm machineries for operating equal to or more than 50% of agricultural operations); and b) farms with less than 50% mechanization (those farms which practice mechanization for operating less than 50% farming operations (Fig. 1). Land preparation, planting, weeding, fertilizer application, pesticides application, irrigation, harvesting and threshing are the main eight farming operations in rice production which are considered for possible mechanization in the study areas. Descriptive statistical tools such as; average, percentages, ratios, etc. were used to explore the extent of farm mechanization. The technical efficiency of rice growing farmers was measured by using non-parametric analysis (data envelopment analysis). After that, the Tobit regression model gave estimations for the impact of farm mechanization on farm technical efficiencies (Fig. 1).

Measurement of farmers' perception about farm mechanization

Farmers' perception regarding farm mechanization is investigated in this research. For this perception index, Likert scale questionnaire is followed. A Likert scale questionnaire is the one in which the subjects are asked to mark how much they agree with the point of view in the item (statement) (Elia et al. 2015; Jannat and Uddin 2016). In this study, this scale is used to assess the perception regarding use of mechanization in agriculture. The research includes 7 positive

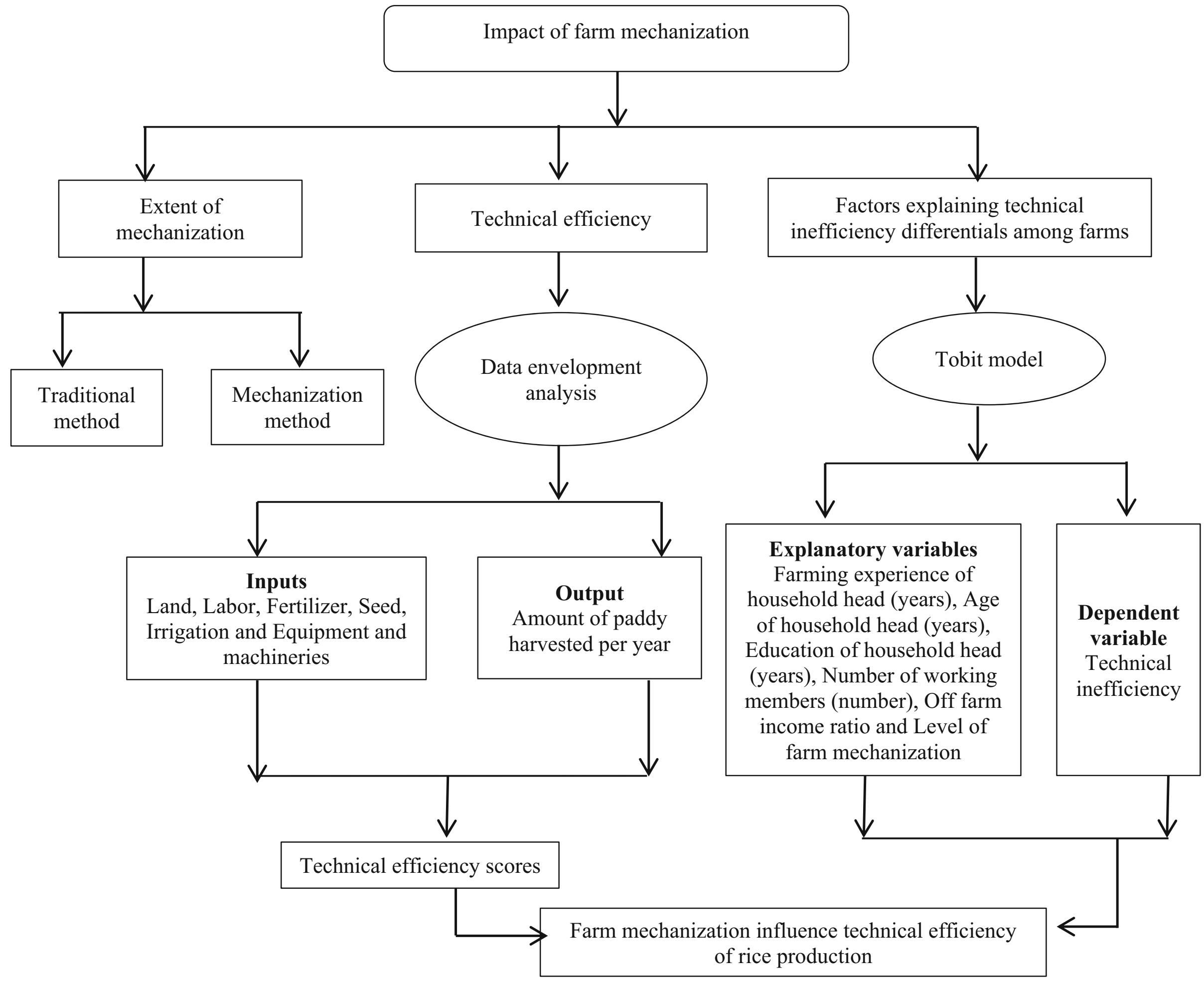

Fig. 1 Conceptual framework

statements related to the use of farm mechanization following 5-point Likert scale score. The scoring is as follows: Strongly agree—(+ 2); Agree—(+ 1); Neither agree nor disagree—(0); Disagree—(− 1) Strongly disagree—(− 2). Perception index for each statements was calculated by using perception index (PI). The mean score for each statement was also calculated. The perception index for each statement has been arranged in rank order according to the extent of agreement which appears in Table 3. Perception index is found to vary from 80 to − 2 for sampled farmers. The Table 3 reveals the perception index score and the ranking of the statements based on the perception index.

Profitability analysis of rice production

Per hectare profitability of enterprise production, from the view point of individual farmers was measured in terms of gross return, gross margin, net return and benefit–cost–ratio. The formula needed for the calculation of profitability is discussed as follows (Dillon and Hardaker 1993):

Gross return (GR)

The following equation was used to estimate GR:

$GR = P \times Q$; where GR is the gross return; P is the sale price of the product; and Q is the yield per hectare. Gross margin was calculated by:

GM = GR − TVC; where GM is the gross margin; GR is the gross return; and TVC is the total variable cost. The following algebraic form of net return was used for estimation:

NR = GR − (TFC + TVC); where NR is the net return; GR is the gross return; TFC is the total fixed cost; and TVC is the total variable cost.

Benefit–cost–ratio (BCR); The formula of calculating BCR (undiscounted) was as follows:

BCR = GR − (TFC + TVC); where BCR is the benefit–cost–ratio; TFC is the total fixed cost; and TVC is the total variable cost.

Empirical model for evaluating the impact of farm mechanization on technical efficiency

To assess the effectiveness of farm mechanization in raising farmers' technical efficiency, an empirical approach consisting of two parts has been employed in this research following Nasrin et al. (2018). At first, a non-parametric approach is employed to compute technical efficiency scores for individual farms. Technical efficiency (TE) is related to the farm's ability to achieve highest possible output from a given level of input or obtaining a given level of output using minimum feasible amounts of inputs (Varian 1992). Efficient utilization of resources is more important than maximizing the amount of resources for both economic and social welfare of the country. For that purpose, technical efficiency in rice production is considered in this research. Efficiency can be estimated by employing either parametric or non-parametric methods. However, Nasrin et al. (2018) argued that the parametric approach may not be appropriate when farmers face different factor endowments following explanations of (Ali and Flinn 1989). This situation is also observed in this research and therefore, non-parametric approach has been employed. Data envelopment analysis (DEA) is one of the most important non-parametric approaches for estimating efficiency which does not impose any prior parametric restrictions on the production technology as compared to parametric approach and hence is less sensitive to model misspecification (Cooper et al. 2007). It avoids the requirement of any distributional assumption for the inefficiency terms (Coelli 1995). There is no specific criterion regarding which method is superior to another, so the choice of a particular method depends on the researcher. Therefore, DEA, a non-parametric mathematical programming approach to efficiency estimation, has been applied in this research. This approach allows the researcher to estimate efficiency scores for any sample sizes. Moreover, it has the advantage of evaluating technical as well as allocative and economic efficiencies.

DEA involves the use of linear programming methods to construct a non-parametric piecewise frontier over the data in order to calculate efficiencies and allows the researcher to estimate efficiency scores for any sample sizes. The efficiency scores vary from zero (a zero output from non-zero inputs) to one (the most efficient farms located at the frontier) (Nasrin et al. 2018). The input based technical efficiency (TE) under variable returns to scale (VRS) is obtained by solving the following problem (Banker et al. 1984):

$$\mathrm{TEi} = \mathrm{Min}_{\theta\lambda}\theta \tag{1}$$

$$\text{Subject to} \quad \begin{aligned} &-\mathrm{yi} + \mathrm{Y}\lambda \geq 0 \\ &\theta \mathrm{xi} - \mathrm{X}\lambda \geq 0 \\ &\mathrm{N1}\lambda = 1 \\ &\lambda \geq 0 \end{aligned}$$

where θ is a scalar; yi is a vector (m × 1) of rice output of the ith farm; xi is a vector of (k × 1) of inputs of the ith farm; Y is the rice output matrix (n x m) for n farms; X is the rice input matrix (n x k) for the n farms; N1 is an N × 1 vector of ones; and λ is an N × 1 vector of constants. The value of θ is the technical efficiency score for ith farm. It will satisfy: θ ≤ 1, with a value of 1 indicating a point on the frontier and hence, a technically efficient farm. The linear programming (LP) problem is solved N times to obtain a value of θ for each farm in the sample. The technical efficiency (TEi) calculated for farm i using Eq. (1). The value for TEi will be ≤ 1, with a value of 1 meaning the farm is technically efficient and less than 1 meaning the farm is technically inefficient, respectively (Nasrin et al. 2018).

Econometric model for identifying the impact of farm mechanization

Once the technical efficiency scores are estimated from DEA, technical inefficiency scores are calculated for each farm by subtracting the efficiency scores from 1 as the value of one implies the most efficient farms at the frontier. Then, a Tobit regression is run to explain the inefficiency differences among farms using a set of farm specific variables as well as 'level of farm mechanization' variable. The Tobit model is the most appropriate in this particular case since the dependent variable, the calculated technical inefficiency scores, is censored at 0. Let the following regression equation is assumed:

$$IEi = \beta iXi + \omega i \quad (2)$$

where βi denotes a (n × 1) vector of unknown parameters, Xi is a (n × 1) vector of explanatory variables defined and ωi is a (n × 1) vector of residuals that are independently and normally distributed with mean zero and variance σω2. As the value of inefficiency is zero for some farms, applying OLS to Eq. 2 will result in biased and inconsistent estimates (Nasrin et al. 2018). Instead, a censored regression model developed by Tobin (1958) can be specified as follows:

IEi = βi Xi + ωi if IEi* > 0, that is, inefficiency is not zero; and
IEi = 0 otherwise, that is, inefficiency is zero.

The log likelihood function for the Tobit model is written as follows (Peter and Maddala 1992):

$$\log L = \Sigma 0 \log(1-\phi) + \Sigma 1 \log\left(1/\sqrt{2\pi\sigma^2\omega}\right) - \Sigma 1\left(1/2\sigma^2\omega\right)(IEi - \beta iXi)^2 \quad (3)$$

Using the maximum likelihood estimation, the Tobit model was estimated for sample farms. Based on available literature and insights gained from the field survey, six explanatory variables were considered for Tobit regression model. These are: farming experience of household head (years), age of household head (years), education of household head (years), number of working members, off-farm income ratio and one dummy variable namely, level of farm mechanization (1 = farms with more than 50% mechanization and 0 = farms with less than 50% mechanization).

Selection and measurement of variables used in models

Using DEA approach, the efficiency scores for all farms have been estimated. From field survey, data on output and input quantities are obtained. The output is measured as kilograms of paddy harvested per farm per year. The inputs used for DEA analysis are farm size, total labor used for paddy cultivation, amount of fertilizer and seed used, irrigation cost per farm and equipment and machinery cost. These are the main inputs used in rice production in Bangladesh. Manure and pesticides use are two additional variables which are not used by all farms. Therefore, these cost items are not included in DEA analysis. The measurement of these variables is shown in Table 5.

Results and discussion

Socioeconomic characteristics of farm households

Socioeconomic characteristics deals with various indicators such as age distribution and farm experience of household heads, years of schooling, No. of working members, land utilization and household income. The age range of farm households in the sample area varies from 20 to 90 years with an average of 46 years (Table 1). It is notable that 45% of farmers fall in the age group of 35–48 years; 20% of farmers fall in the age group of 49–62 years. They are expected to have the physical and mental ability to adopt new technologies as well as modern machineries for rice production. The minimum farming experience is 5 years and the maximum is 65 years with an

Table 1 Socioeconomic features of the respondents. *Source*: Field Survey, 2018

Particulars	Percentage
Age (years)	
35–48 years	45
49–62 years	20
Farming experience (Value)	
Mean	30.45
Maximum	65
Minimum	5
No. of working members (Value)	1.65
Farmers' educational level (% of farmers)	
Illiterate	28.3
Sign only	20.0
Primary to high school	38.3
Household income	
Farm activities	53
Non-farm activities	47

average farming experience of 30.45 years. The average number of working members is 1.65. The study reveals that most of the farmers are experienced in farming and now a days family members have less interest in farming activities as cost of production is increasing irrespective of price of output. One of the important and important aspects concerning planning decisions about adaptation of mechanization in agriculture is the education level of the farmers. It is expected that the educational level of farmers has the potentiality to adopt new productivity increasing technologies and machineries and efficient utilization of this machineries. The study reveals that most of the household head completed primary level education and went to high school. A number of farmers are illiterate in which most of them are aged farmers in the study area as there were less educational facilities. Field survey has revealed that about 53% of total income is generated from farm activities. On the other hand, rest (47%) of the amount is generated from alternative sources of income.

Exploration of the extent of mechanization at different levels of farm operation

Mechanization of rice farming in study areas means the use of machineries like tractor, power tiller, rice transplanter, power pump, sprayer, combine harvester, thresher machine to carry out different farm activities such as land preparation, planting, weeding, fertilizer and pesticide application, irrigation, harvesting and threshing, respectively. Following Table 2, land preparation is fully mechanized in the study areas. That means, human and animal power sources are no longer in use for tilling land today. On the other hand, all the farmers practiced traditional method for application of fertilizer and they are not using any equipment or machinery. For both planting and harvesting, about 96.7% farmers follow traditional method while only 3.3% farmers follow mechanization. The extent of mechanization varies among different operations of rice cultivation. Overall, on average about 45% farmers practice mechanization to some extent in the study areas while about 55% are following traditional methods for different farming activities (Table 2). The study has clearly revealed the varying levels of mechanization among the various operations of rice cultivation. The extent of mechanization varied from 0% (fertilizer application) to 100% (land preparation) between different farming operations. This reveals that, Bangladesh is still lag behind in mechanizing various operations fully.

Farmer's perception about farm mechanization

Farmers' perception regarding farm mechanization is investigated in this research. Table 3 showed that the highest score (80) is found for 6th statement. That means most of the farmers agree that the practice of agricultural mechanization saves time. 'Agricultural mechanization increases food production' got the 2nd rank with the PI of 76 and agricultural mechanization Improve living standard got 3rd rank with PI of 73. Farmers also believe that mechanization decreases unemployment (4th); increases food consumption and ensure nutritional security (5th). Majority of the farmers agree with the statements in a positive way. However, a considerable number of farmers 5 for third

Table 2 The extent of mechanization by farm households. *Source*: Author's calculation based on field survey, 2018

Farming operations	Percentages of responses	
	Traditional method	Mechanized method
Land preparation	0	100
Planting	96.7	3.3
Weeding	88.3	11.7
Fertilizer application	100	0
Pesticides application	25	75
Irrigation	1.7	98.3
Harvesting	96.7	3.3
Threshing	33.3	66.7
Average	55.2	44.8

Table 3 Farmers' perception about farm mechanization. *Source*: Author's calculation based on field survey, 2018

Sl. no.	Statements	Perception index	Rank
1	Agricultural mechanization Increases food production	76	2
2	Agricultural mechanization Increases food consumption and ensure nutritional security of the household	50	5
3	Agricultural mechanization Increases income of the household	5	6
4	Agricultural mechanization Increases profit margin	− 2	7
5	Agricultural mechanization Decreases unemployment	68	4
6	Agricultural mechanization Saved time	80	1
7	Agricultural mechanization Improve living standard	73	3

statement and − 2 for fourth statement, respectively) were undecided about the benefits of farm mechanization in terms of increasing income and profit margin. Because they thought that the usage of different machineries in agricultural activities increases the cost of production which reduces the profit margin (Table 3). It also saves farmers valuable time. As a result, they could engage themselves in more productive works which support their family income. Employment opportunities are also created which reduces unemployment rates. So, farmers overall living standard improves as perceived by them due to the adoption of farm mechanization.

Explanation of estimated technical efficiency of rice production

Data Envelopment Analysis (DEA) is employed using the computer software package DEAP version 2.1 for estimating the technical efficiency scores for rice production in the study areas. Technical efficiency scores and summary statistics of rice farming are presented in Table 4. The results from DEA approach show that the average technical efficiency values are 83% for farms with more than 50% mechanized and 64% for farms with less than 50% mechanized, respectively. It implies that farms with more than 50% mechanized is more efficient than others. It also implies that the average technical inefficiency ranges from 17% to 36% indicating that there is a potential to improve the existing technical efficiency of the sample farmers without reducing both the levels of input used and the existing technology (Table 4). Therefore, the estimated results from non-parametric approach indicate that the inefficient sample farmers can improve their technical efficiency in rice production to catch up the efficient sample farmers in these regions.

Profitability analysis at different levels of mechanization

The profitability structure of rice farming in the study areas have been estimated and presented in Table 4. The results are presented in such a way to know the comparative performance of farms practicing at different levels of mechanization. Farms with less than 50% mechanization are those farms where less than 50% operations are mechanized that means among the eight farming operations, less than four operations are done with machineries. Again, farms with more than 50% mechanization are those farms where more than 50% operations are mechanized that means among the eight farming operations equal to or more than four operations are done with machineries.

While comparing between the farms with less than 50% mechanization and farms with more than 50% mechanization, the total variable cost has worked out to Tk. 33136.2 (USD 404.1) per acre for farms with less than 50% mechanization and Tk. 33907.8 (USD 413.51) per acre for the farms with more than 50% mechanization, proving that lesser the use of mechanization the lesser will be the cost of rice production. The overall analysis of the cost structure has revealed that the farms with less than 50% mechanization have the cost advantage over the farms with more than 50% mechanization. The average cost of cultivation of rice per farm is BDT 35822.9 (USD 436.86) for former

Table 4 Profitability of sample farmers. *Source*: Author's estimation based on field survey, 2018

Particulars	Mechanized less than 50%	Mechanized more than 50%
Variable cost		
Human labour (Tk.)	13087.5 (159.60)	14980.4 (182.68)
Machine labour (Tk.)	5114.8 (62.38)	5179.1 (63.16)
a. Total labour cost (Tk.)	18202.3 (221.98)	20159.6 (245.85)
Seeds/seedlings (Tk.)	1483.7 (18.09)	1422.5 (17.35)
Manures and fertilizer (Tk.)	3849.4 (46.94)	5256.1 (64.10)
Plant protection (Tk.)	1238.7 (15.11)	1077.9 (13.15)
Irrigation (Tk.)	6413.0 (78.21)	3997.2 (48.75)
b. Working capital (Tk.)	12984.7 (158.35)	11753.6 (143.34)
c. Interest on operating capital @ 12.5% (Tk.)	1949.2 (23.77)	1994.6 (24.32)
I. Total Variable Cost (a + b+c) (Tk.)	33136.2 (404.10)	33907.8 (413.51)
Fixed cost		
Land (Tk.)	1984.4 (24.2)	1573.9 (19.19)
Depreciation cost on machineries (10%) purchased value (Tk.)	702.2 (8.56)	2783.0 (33.94)
II. Total Fixed Cost (Tk.)	2686.7 (32.76)	4356.8 (53.13)
III. Total Cost (I + II) (Tk.)	35822.9 (436.86)	38264.6 (466.64)
Main product (quintal)	29.0 (3.20 tons)	35.3 (3.89 tons)
d. Value of main product (Tk.)	60645.8 (739.58)	71825.1 (875.92)
e. Value of by product (Tk.)	5804.5 (70.79)	6411.7 (78.19)
IV. Gross income (d + e) (Tk.)	66450.4 (810.37)	78236.8 (954.11)
V. Gross margin (IV–I) (Tk.)	33314.2 (406.27)	44329.0 (540.60)
VI. Net income (IV–III) (Tk.)	30627.5 (373.51)	39972.1(487.46)
BCR	1.85	2.04

Figures in the parenthesis indicate USD value and conversion rate was 1 USD = BDT 82.0

group while the latter group had incurred the average cost of cultivation at BDT 38264.6 (USD 466.64) per acre, revealing that the cost of cultivation increases as the level of mechanization increases. On production side, the average productivity of farms with more than 50% mechanization is 35.3 quintal (3.89 tons) per acre, while the farms with less than 50% mechanization are able to produce only 29 quintals (3.20 tons) per acre. This factor might be mainly attributed to the advantage of mechanical paddy harvesting and threshing which help in reducing post-harvest losses of paddy production. The result of BCR reveal that farmers who use more machineries in their farming operations get higher profit margin (2.04) than those who use less machineries (1.85) in rice production (Table 5). Comparing the two levels of mechanization, it is apparent that mechanization will lead to increased productivity and profitability. Though cost of production increases, output per farm and gross income also increases at a higher rate with the rising level of farm mechanization. The improved productivity and gross return compensate the overall cost of production.

Determinants for differences in technical inefficiency and impact of farm mechanization

Data Envelopment Analysis (DEA) is estimated using the computer software package DEAP version 2.1 for estimating the technical efficiency scores for rice production at the farm level. The study reveals that the estimated mean value of technical efficiency score for the farms with more than 50% mechanization is about 83% and for farmers with less than 50% mechanization is about 64% (Table 6). The results have clearly indicated that efficiency of farms increases as the level

Table 5 Description and measurement of variables used in DEA. *Source*: Author's calculation, 2018

Variables Output	Description Amount of paddy harvested per year	Unit of measurement kg/farm/year
Inputs		
Land	Total cultivable land	Acre/farm/year
Labor	Total labor used for paddy	Man- day/farm/year
Fertilizer	Total amount of fertilizer used	kg/farm/year
Seed	Total amount of seed used	kg/farm/year
Irrigation	Cost incurred for irrigation	BDT/farm/year
Equipment and machineries	Cost incurred for equipment and machineries	BDT/farm/year

Table 6 Technical efficiency scores for rice farming and summary statistics. *Source*: Author's estimation, 2018

Technical efficiency (%)	Levels of farm mechanization	
	Farms with more than 50% mechanization	Farms with less than 50% mechanization
21–40	0	21.7
41–60	16.2	21.7
61–80	27.0	34.8
81–100	56.8	21.7
Mean technical efficiency (%)	83	64
Maximum technical efficiency (%)	100	100
Minimum technical efficiency (%)	51	34

of mechanization increases. Minimum technical efficiency of farms with more than 50% mechanization is about 51% which is also greater than farms with less than 50% mechanization (about 34%). For farms with more than 50% mechanization, about 56.8% of total farmers have technical efficiency greater than 80% and there have no sampled farmers who have technical efficiency score less than 40%. Accordingly, Data Envelopment Approach (DEA) explore that farms with more than 50% mechanization are technically more efficient than the other level of farm mechanization. But, majority of the farms of both levels of mechanization are technically inefficient.

The Table 7 shows the descriptive summary of explanatory variables used in Tobit model for estimating the impact of farm mechanization on technical inefficiencies. Here, mean of age and farming experience of household head are 43.72 years and 30.45 years, respectively, indicating that farmers are in working age group and have proper farm experience which is necessary for effective farm operations. Mean value of off farm income ratio is 0.34 which indicates that crop cultivation is the main source of income of the sample farmers. About 34% of total income is derived from off-farm activities. The average level of farm mechanization (0.62) points out that about 62% farms use machineries to operate more than 50% of farming activities while 38% farms use machineries to operate less than 50% of farming activities. The overall study clearly indicates that farm mechanization increases the technical efficiency of rice production.

Table 8 shows the Tobit estimation results to evaluate the influence of farm mechanization on technical inefficiency. The estimated coefficient of farming experience turns out significant and negative. Several empirical researches namely, Nasrin (2017), Sek (2015), Bäckman et al. (2011), Bozoglu and Ceyhan (2007), Huffman (2001) and Kalirajan and Flinn (1983) have also reported a significant negative

Table 7 Descriptive statistics of explanatory variables included in Tobit model. *Source*: Author's estimation, 2018

Variables	Mean	Standard deviation
Farming experience of household head (years)	30.45	15.83
Age of household head (years)	43.72	14.38
Education of household head (years)	6.5	4.91
Number of working members (number)	1.65	0.80
Off-farm income ratio	0.34	0.25
Level of farm mechanization (1 = farm with more than 50% mechanization; 0 = otherwise)	0.62	0.49

Table 8 Maximum likelihood estimates for factors explaining technical inefficiency differentials among farms (Tobit estimation results). *Source*: Author's estimation, 2018

Variables	Coefficient	Standard error	*p* value
Farming experience of household head (years)	− 0.01436*	0.00249	0.000
Age of household head (years)	0.00878*	0.00241	0.001
Education of household head (years)	− 0.00023	0.00581	0.967
Number of working members (numbers)	0.23588	0.03515	0.505
Off-farm income ratio	0.14801	0.11355	0.198
Levels of farm mechanization	− 0.12825**	0.05431	0.022
Constant	0.23503	0.11769	0.052
Model summary			
LR chi2 (6)	51.66		
Probability	0.000		
Number of observations	200		
Pseudo R^2	1.1168		
Left-censored observations at technical inefficiency ≤ 0	17		

* and ** indicate 1% and 5% significance level

impact of farming experience on farm inefficiency. On average, if farmers attain one additional year of experience, this will reduce their technical inefficiency by 0.01%. Results suggest that farmers with greater experience would spend more time in the farming activities which exhibit greater efficiency than those with less time involved in farming. Because the experienced farmers have the skills and know-how that come with the time spent on farming in uncertain production environment, rice farmers' expertise assists them in ensuring the optimal timing and use of inputs and thereby, reduces their technical inefficiency.

The age of the household head is significantly and positively related with technical inefficiency of rice production. Tis result is supported by the study of Wadud (1999) who also found that the coefficient for the age of farmers for technical inefficiency is positive. On average, if age of the farmers increases by one year, this will increase their technical inefficiency by 0.009%. This would mean that the younger farmers are more technically efficient than aged farmers. They would have the potential and abilities to work hard for maximizing yield and productivity. They would also have the interest to learn new things and want to apply new method in agricultural operations to get a higher efficiency (Table 8).

Education of household head has positive but insignificant effect on technical inefficiency. This may happen because with increasing years of education, farmers would tend to shift to various off-farm income generating activities as revealed from field survey. The insignificant impact could be justified because of the problem of underemployment of surplus labor in agriculture with the result that the number of working adults is not a significant indicator of technical efficiency. Bäckman et al. (2011), Rahman (2004), Wadud (2003), Coelli et al. (2002) also did not find any significant effect of education on technical efficiency. However, Asadullah and Rahman (2009) and Khai and Yabe (2011) argued that higher education increases efficiency significantly and education is a necessary element for increasing technical efficiency in rice production. The estimated value of off-farm income ratio turns out positive but insignificant in the model. This result conforms to the findings of Asadullah and Rahman (2009) and Coelli et al. (2002) who showed that off-farm income variable is positively and insignificantly related with inefficiency. However, Nasrin (2017) found that relatively higher off-farm income increases the economic efficiency of rice farmers. The estimated result would suggest that the more hours a farmer spends on off-farm activities; the less time would be devoted by him to farming operations while resulting in higher inefficiency (Table 8).

Level of farm mechanization has a significant negative effect on technical inefficiency of rice production. Tun and Kang (2015) showed that the mechanical tools used in farming activities have positive and significant relation to the efficiency indexes. Chidambaram (2013) also revealed a significant positive effect of machines on agricultural production. That means, by reducing technical inefficiency, farm mechanization has been helpful to bring about a significant improvement in agricultural productivity and efficiency. A policy, focusing on a combination of all these factors, will appear with significant improvement in technical efficiency in the country.

Conclusions and policy implications

The main aim of this study is to explore the relationship between agricultural production and farm mechanization. For that purpose, at first the level of farm mechanization practice at different farming operations is explored and farmer's opinion about the impact of mechanization on their livelihood is perceived. The study reveals that Bangladesh is still lag behind in mechanizing various operations fully due to availability of modern agricultural machinery and it's spare parts. The results of the study have clearly indicated that higher level of mechanization increases the overall technical efficiency of the farms. The contribution of level of farm mechanization along with other influencing factors in reducing these inefficiencies has been measured using Tobit regression. Level of farm mechanization has a significant negative effect on technical inefficiency of rice production. That means, by reducing technical inefficiency, farm mechanization has been helpful to bring about a significant improvement in agricultural productivity and efficiency. Moreover, the success of farm mechanization will be augmented by putting equal emphasis on other efficiency enhancing factors such as, facilitating income generating activities in rural areas, providing regular extension services. So, special emphasis should be placed on the adaptation of machineries in different level of farming operations for the overall development of agricultural sector which enhance national strength. Development of rice sector industry which is the basic foundation for agriculture sector will require investment in farm mechanization to drive agricultural growth and productivity. Therefore, the policy makers should consider the role of farming machinery as an important issue and should give more emphasis on the development of farm mechanization in the country.

The generalization of the findings of this study is subject to certain limitations. For instance, the study areas were selected to only two districts of Bangladesh because of limited time and resource allocation. Agricultural characteristics of these study areas might not make a sense on overview of the country. The sample size may not be statistically sufficient but can contribute to develop understanding about the extent of farm mechanization and technical efficiency of rice production in these regions. Even, the outcomes of Tobit model are only rough indicators. As a supporting tool it can contribute to the debate on determinants for differences in technical inefficiency and impact of farm mechanization in relation to the qualitative and quantitative as well as social, economic and environmental variables, primarily at the district level. So, there exists scope for policy planners to adapt the model and change the variables according to necessity.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no issue of competing interest.

Research involving human participants and/or animals This article does not contain any studies with human participants or animals performed by any of the authors.

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