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Rice farmers' technical efficiency under abiotic stresses in Bangladesh

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ABSTRACT

This study was an attempt to investigate the economic performance of stress tolerant rice varieties in different abiotic stress prone areas (submergence, drought, and salinity) of Bangladesh. The study used production frontier approach to measure the technical efficiency at the farm level. Benefit-cost analysis revealed that farmers in all stress environments obtained positive margin on cash cost basis and the profit became negative on full cost basis in all environments with exception for submergence. That means rice production was marginally benefited to farmers in all the stress environments. Farm specific technical efficiency of all stress environments indicated that large farmers were comparatively more efficient due to their economic solvency as they could apply adequate amount of inputs in due time with proper doses. Inefficiency model indicated that farm size, farmers 'education, households' size, farming experience, extension contact, and main occupation of the farmers, were the important factors causing variations in the efficiency. However, BRRI released stress tolerant rice varieties had significant positive impact on technical efficiency. Plausible policies have been recommended according to the study outcomes.

Contribution/ Originality

This study covered three different stress prone environments (saline, submergence, and drought) of Bangladesh to measure the productivity and efficiency of rice farming. The study also identified the impact of adopting stress tolerant rice varieties in the respective stress prone areas. Researchers and policymakers can use the findings of this study to enhance rice productivity and technical efficiency in the stress prone areas of Bangladesh.

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1. INTRODUCTION

Bangladesh is one of the most susceptible nations to the impacts of climate change due to her inconvenient terrestrial position, plane and lowland setting coupled with social and economic conditions (Huq and Ayers, 2007; Siddique *et al.*, 2014). Different types of natural calamities visit Bangladesh almost every year (Siddique *et al*., 2013). Most of the predicted hostile outcomes of climate change aggravated the prevailing stresses that impeded the agricultural productivity (Rahman, 2011). Rice is the main cereal crop, which are seriously affected by climatic factors. Rice grows in three distinct seasons round the year, which covers around 77% (11.42 mha) of the total cropped area and contributes 93% to the total food grain production annually (BBS, 2015; BER, 2015). It is the principal source of agricultural GDP and livelihoods to majority of the rural population, which delivers near 62% and 46% of average daily calorie and protein consumption, respectively (HIES, 2010).

However, multiple abiotic stresses are affecting to rice in Bangladesh. Early rainy season and extreme rainwater can trigger flooding that affect rice seedlings, while a late appearance mostly leads to severe water stress (Mahmood *et al*., 2004). Highly and moderately flood prone crop areas have been recorded around one million and five million hectares, respectively. Flood visits over 18 districts of Bangladesh almost regularly. Drought hits in North-western part of the country mainly due to unequal dissemination of rainfall. About 5.7 million hectares of rain-fed area is affected by drought (Daily Star, 2014). Another considerable threat is the coastal area of Bangladesh, which contains 19 districts and 32% of the country's geographical area wherein 28% of the total populations live (Rahman *et al.*, 2013). Coastal zone could make a substantial contribution to the agriculture as well as the economy through achieving the national goal of accelerating poverty reduction and food security. The average crop yield is very low in this region, which is obviously due to salinity problems, low soil fertility and drought in the dry season**.** Different levels of salinity seriously affect about 1.02 million hectares of cropland (BARC, 2011). Given above backdrop, Bangladesh Rice Research Institute (BRRI) has been released 86 contemporary rice varieties (including 6 hybrids). Out of these varieties about 26 are climate resilient (BRRI, 2017). The features of these stress tolerant varieties are given in Appendix I. The present yield potentialities of these stresses tolerant varieties are being fainter day by day due to recently revealed biotic and abiotic stresses. Therefore, it is essential to examine the potentiality of these stress tolerant rice varieties in accordance of facing the threads of changing climate. Thus, this study has been designed to explore the technical efficiency among stress porn rice farmers' in Bangladesh.

Many studies have led to profitability and efficiency analysis of several crops farming in Bangladesh and abroad. For instance, Rahman (2003) showed, about 23% profit inefficiency exists in modern rice cultivation due to agronomic management, experience and economic solvency of the farmers. Hyuha *et al.* (2007) analyzed the inefficiency in Uganda using stochastic profit and inefficiency function. The result presented that, the factors of profit inefficiency was farmers' literacy and extension contact. Rahman *et al.* (2014) studied that the inefficiency factors among the Golda (*Macrobrachium rosenbergii*) farmers in coastal areas were level of education, training and farm size. Rahman *et al.* (2013) exposed that the age of the farmers', literacy level, and training had positive meaningful impact on efficient maize cultivation in Bangladesh. Piya *et al.* (2012) conducted a case study in Nepal that suggested that the degree of commercialization, farmers' age, education, share of agriculture in total household income, and sharecropping had significant impact on the efficiency of rice farming. Mottaleb *et al.* (2014) find out that production loss of rice is due to the drought, and technical inefficiency comes from floods in Bangladesh. Osti (2016) discovered that, drought condition is the cause of reduction productivity and efficiency of the rice.

The mentioned studies used the stochastic frontier (SF) approach to measure the efficiency of various crop farming. Some of them are based on the rice sector in Bangladesh. However, this study was designed to cover the three abiotic stresses of rice farming in Bangladesh. These are submergence, drought and salinity. This study also focused on the impact of BRRI released stress tolerant varieties by taking dummies on those.

2. METHODOLOGY

2.1. Study area

The study has accompanied in 12 stresses prone districts of Bangladesh during 2014/15 to 2016/17. The stress environments were; (i) Submergence, (ii) Saline and (iii) Drought.

The locations for the study were:

A. **Submergence:** Rangpur (RNP), Kurigram (KRG), Lalmonirhat (LMH) and Gaibandha (GB) districts;
B. **Saline prone:** Satkhira (SKH), Patuakhali (PTK), Khulna (KHL) and Bagerhat (BGT) districts; and,
C. **Drought prone:** Rajshahi (RJH), Chapainawabgonj (CNG), Kushtia (KUT) and Natore (NTR) districts.

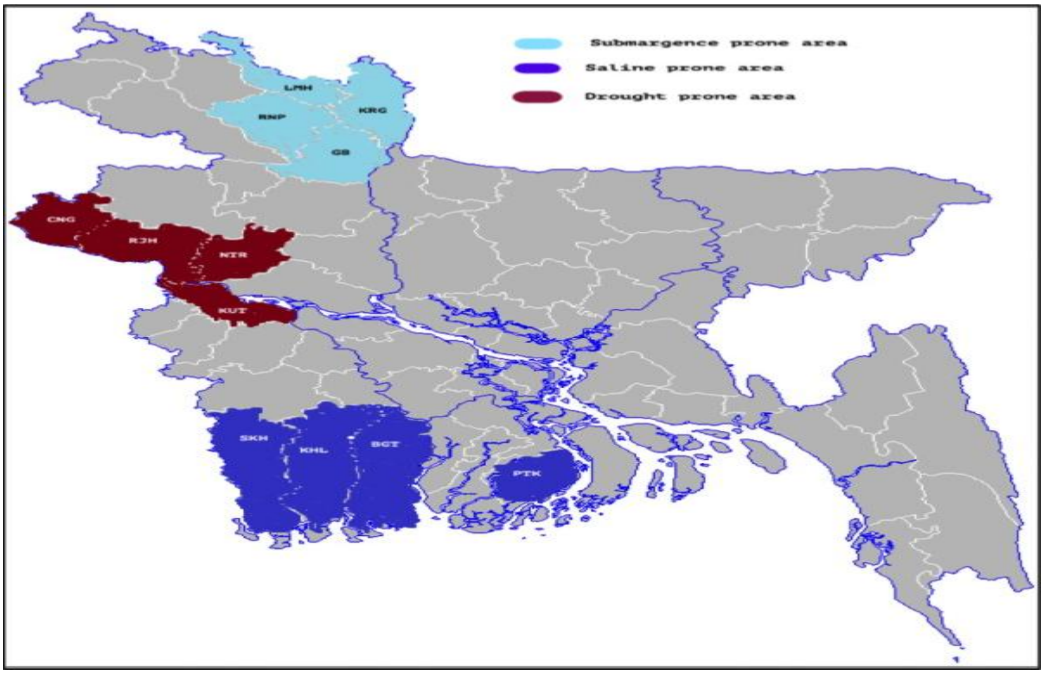

Figure 1: Selected stress prone study areas

2.2. Data collection

Sample stratification technique was used to among the respondents. The stratums of the study were flood/submergence, saline and drought prone areas, respectively. Data of submergence and drought areas were in Aman[1] season for the period of 2014/15 and that of Boro[2] season for saline areas of 2015/16 were collected with the help of trained enumerators. From each of the stress environments 100 respondents who cultivated stress tolerant rice varieties were randomly selected and interviewed with pretested structured questionnaires. Thus, about 300 respondents for submergence, drought and saline environments were collected. Besides, information on area cultivated by diverse stress tolerant

[1]Aman: A season from 16 July to 15 Octobera
[2]Boro: A season from 16 October to 15 March. Source: AIS (2016)

rice varieties in different stress environments was collected from the Department of Agricultural Extension (DAE). Stochastic production function (SPF) model was used for measuring technical efficiency of stress tolerant rice cultivation and also determine the factors influencing the inefficiencies.

2.3. Analytical procedure: activity budget

The following conventional profit model was applied to examine the profitability level of stress tolerant rice varieties in the study areas.

$$\Pi = TR - TC$$

Where,

$\prod$= Net return (Tk./ha); TR = Total return (Tk./ha); TC = Total costs (Tk./ha)

Thus, the model can be written as:

$$\prod = \sum q_y \cdot P_y + \sum q_b \cdot P_b - \sum_{i=1}^{n}(X_i \cdot P_{xi}) - FC \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, q_y = Total quantity of (paddy) output (kilogram (kg)/ha); P_y = Price of (paddy) output (Tk./kg); q_b = Total quantity of by-product (kg/ha); P_b = Price of the by-product (Tk./kg); X_i = Quantity of the i^{th} input; P_{xi} = Price of the i^{th} input; FC = Fixed cost (Tk./ha); and $i = 1, 2, 3, \ldots, n$.

2.4. Theoretical model for efficiency estimation

Technical efficiency generally describes the farm's capacity to attain maximal output from a fixed set of inputs. A farm is efficient if we can't increase its production without adding more inputs or decrease input without decreasing output with a given set of technology (Cooper and Kumbhakar, 1995). The technical efficiency of a farm is stated as the ratio of the attained output of that farm and the output of a full efficient farm that producing on the frontier. By the conditions of the SF models, the technical efficiency of the i^{th} farm can be written as:

$$TE_i = \frac{\text{Observed output}}{\text{Maximum attainable output}}$$

$= \exp(-u_i)$

$= \exp[-E\{u_i / (v_i - u_i)\}]$

$= 1 - E\{u_i / (v_i - u_i)\}$ (ignoring high order of exponential series)

$= \frac{y}{f(X_i\beta_i)\exp(V_i)} = \frac{y_i}{y_i^*}$ ………………… (2)

Here $y = f(X_i\beta_i)\exp(V_i)$ is the farm particular SF. If y_i is equivalent to y_i^*, then TE_i=1, reveals 100% efficient. The variation between y_i and y_i^* is fixed in u_i (Dey *et al.*, 2000). u_i= 0 means output of i^{th} farm lies on the stochastic frontier. u_i<0 means output of the farm lies below the frontier that indicates inefficiency of the farm.

The mean of the technical efficiency is presented as:

$$TE = E\left[\exp[-E\{u_i / (v_i - u_i)\}]\right] = E[1 - E\{u_i / (v_i - u_i)\}]$$

2.5. Empirical model

Empirical Cobb Douglas production frontier function for the sample farmers was specified as:

$$\ln y_i = \beta_0 + \beta_1 \ln x_1 + \beta_2 \ln x_2 + \beta_3 \ln x_3 + \beta_4 \ln x_4 + \beta_5 \ln x_5 + \beta_6 \ln x_6 + \beta_7 \ln x_7 + \beta_8 \ln x_8 + \beta_9 \ln x_9 + \beta_{10} \ln x_{10} + \eta x_{11} + \varepsilon_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, ln = Natural logarithm; y = Yield of paddy (kg/ha); β_0 = Constant; $\beta_i's$ = Coefficients; x_1= Human labor (man-days/ha); x_2 = Land preparation cost (Tk./ha); x_3 = Seed used (kg/ha); x_4= urea (kg/ha); x_5= TPS (kg/ha); x_6= MoP (kg/ha); x_7 = Herbicides cost (Tk./ha); x_8= Pesticides cost (Tk./ha); x_9= Irrigation charge (Tk./ha); x_{10} = Land rental value (Tk./ha); x_{11} = Varietal dummy; and, ε_i = random error term. It can be decomposed as $v_i - u_i$ where v_i is the random error and u_i is the non-negative random term related to technical inefficiency. The u_i can be expressed as:

$$u_i = \delta_0 + \delta_i Z_i \qquad \text{.................... (4)}$$

Where, δ_j = Unknown parameters to be estimated; δ_0= Constant; Z_{1i} = Natural logarithm of operating land (ha); Z_{2i} = Age of ith farmers (years); Z_{3i} = Education (Years of schooling); Z_{4i} = Household size (person/hh); Z_{5i} = Working age population (no.); Z_{6i} = Dummy for farmers occupation (1 for one, 0 for more than one); Z_{7i} = Dummy for training (1 = yes, 0 = otherwise); Z_{8i} = Extension contact dummy (1: if yes, 0: otherwise).

The β and δ coefficients are the parameters to be estimated. The variance of the estimation can be presented as: $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2 / \sigma^2$.

Where, γ parameter has the value between zero and one.

It is important to note that the inefficiency effects model (equation 4) can only be anticipated if the inefficiency effects are stochastic and have a certain distributional measurement. Hence, there is interest for testing the hypotheses of the existence of inefficiency-

$$H_0: \gamma = \delta_1 = \cdots = \delta_8 = 0;$$

i.e., farmers are completely efficient for producing rice in stress prone areas. This null hypothesis is measured by the generalized likelihood-ratio statistics as:

$$\lambda = -2[\ln\{L(H_0)\} - \ln\{L(H_1)\}] \qquad \text{.................... (5)}$$

Here, $L(H_0)$ and $L(H_1)$ are the likelihood estimated values of null and alternative hypotheses, respectively. If the null hypothesis is factual, λ has nearly a Chi-square distribution (Coelli, 1995). $L(Ho)$ is the log-likelihood value in the OLS estimation whereas $L(H_1)$ is the likelihood value in the Maximum Likelihood Estimation. Usually, Ho is rejected if the generalized likelihood–ratio statistic (λ) is greater than the tabulated χ^2 value taken from the Kodde and Palm (1986), with the degree of freedom is the number of restrictions plus one. Frontier package 4.1 (Coelli, 1994) has been used for the estimations.

3. RESULTS AND DISCUSSION

3.1. Summery statistics of the stress tolerant rice variety cultivation

It is revealed from the summary statistics (Appendix II) that the average yield of submergence and drought tolerant rice varieties were 3.27 t/ha and 3.80 t/ha, respectively in T. Aman season and there showed lower yield compared to national average (4.06 t/ha). The average yield of saline tolerant rice varieties was 4.17 t/ha in Boro season, which was also lower compared to national average (5.63 t/ha). The farmers of submergence, drought and saline areas employed 97, 114 and 109 man-days/ha, respectively as human labors. The seed rates were 50, 44 and 43 kg/ha for the submergence, drought and saline areas, respectively, indicating farmers used higher amount of seed than BRRI recommended rate (25 to 30 kg/ha, BRRI, 2017). The submergence prone areas' farmers used lower doses of fertilizers than the drought and saline prone areas. The farmers were not much interested to apply herbicide according to the recommendation because of its increasing trend of cost. The main problem of drought prone area in T. Aman season was inadequate rainfall which affected the crop production in different stages; like, establishment, active tailoring, flowering, maturity and ripening stages. For this purpose, farmers have to provide supplemental irrigation to reduce the yield loss, which incurred a remarkable cost (Tk. 4636/ha). Irrigation cost at the saline prone area was a bit higher (Tk. 16,310/ha) but rental value was much low (Tk. 13,670/ha) compared to national average (Tk. 20,110/ha, BRRI annual review report, 2015-16) in Boro season. There is no irrigation cost in the submergence areas.

Farm specific variables of technical efficiency revealed that average age of the surveyed farmers' varied from 42 to 44 years and their average level of education did not cross 5 years. Almost half of the saline prone areas farmers had diversified income sources and maximum of the others stress prone areas farmers' occupation was crop farming only. The average size of the stress prone farm families was medium. It varied from 4 to 5, which was more or less same to the national average (4.50); among them working age population varied from 2.74 to 3.23 persons per family. Each family occupied on an average, 143 and 145 decimals of operated land in submergence and drought areas, respectively, but it was lower (121 decimals) in saline prone areas. More than 35% farmers received rice production training; while about 60% farmers had no contact with the extension department.

3.2. Estimation of costs and return of stress tolerant rice cultivation

The unit cost of production was the highest (22.51 Tk./kg) in saline prone environment followed by submergence (19.82 Tk./kg) and drought (19.40 Tk./kg) environments (Figure 2). This is because of the higher irrigation cost incurred in saline areas. All other cost items were almost same in different environments of the study areas.

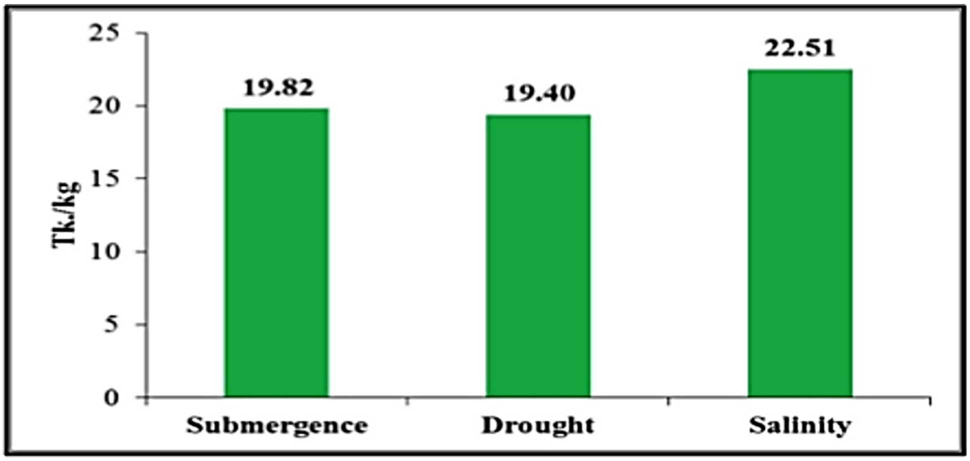

Figure 2: Unit cost of production (Tk./kg)

Per hectare return of stress tolerant rice cultivation was shown in figure 3. The gross return of saline areas (77,770 Tk./ha) was higher, followed by drought (67,837 Tk./ha) and submergence (65,486 Tk./ha) environments. But the gross margin was highest in drought environment (12,612 Tk./ha) followed by submergence (9,312 Tk./ha) and saline (666 Tk./ha) areas. This is because of higher market price of the paddy and lower variable cost incurred in drought areas. On full cost basis, net return was negative in all environments, except submergence prone areas due to higher rental value of land and depreciation cost. Although net return is negative, farmers cultivate rice in Bangladesh because of their food solvency. Farmers are very much concern about positive gross margin and the fixed costs are hidden as they are operating on their own land with self-labor.

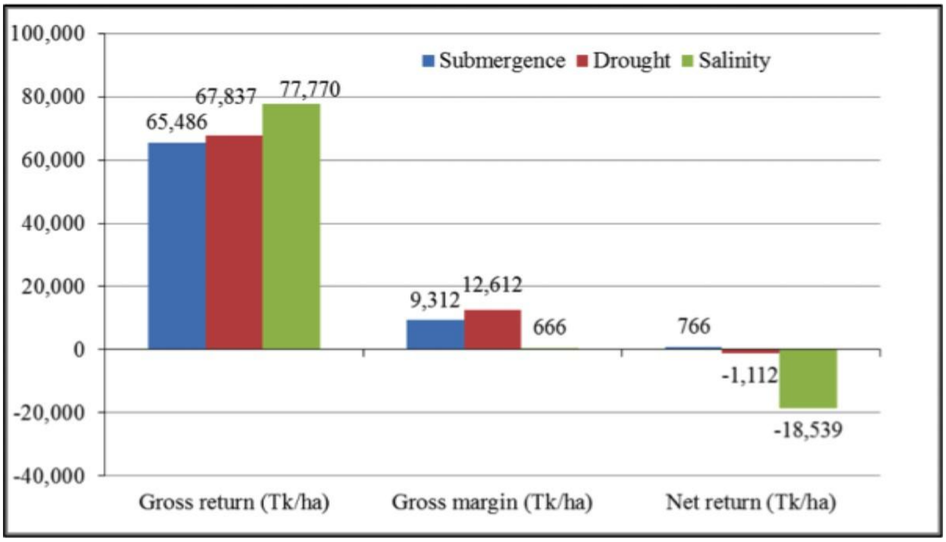

Figure 3: Per hectare return of stress tolerant rice cultivation

3.3. Maximum likelihood estimation (MLE) of the stochastic frontier Cobb-Douglas production function

The empirical results of MLE of stochastic Cob-Douglas frontier production function revealed that seed rate, urea fertilizer, rental value of land and variety were positively significant, indicating these variables influenced the yield and adoption level of submergence tolerant rice cultivation (Table 1). Seed rate and type of variety had strong effect on yield, implying that recommended doses of seed rate and suitable submergence tolerant rice variety (BRRI dhan 52) could increase the yield level substantially. Whereas, negative coefficients of labor, TSP and pesticide showing inverse relationship on yield, indicated that there is no further scope to increase yield by employing these extra inputs in the production process.

In drought environment, urea fertilizer, irrigation and variety had positive effect on yield indicated that there is further opportunity to increase yield by applying additional supplemental irrigations as well as cultivates drought tolerant rice varieties i.e., BRRI dhan56. Besides, negative value of significant coefficient of human labor, seed rate, TSP and MoP fertilizer implying that improper use of seeds/seedlings, excess labor and fertilizer might have decreased the yield level. Mechanical cost for land preparation, herbicide cost for weeding, pesticide cost and rental value of land had no strong impact on yield in drought prone areas.

For saline areas, MoP fertilizer, irrigation cost and varietal dummy had positive effect on yield. That means, BRRI dhan47 had potentiality to increase farm productivity with the help of fresh water irrigation in saline environment. Additionally, potassium fertilizer makes the root systems strong and long that entered into deep of the soil and avoid the salinity of upper soil. However, significant negative value of the coefficient of labor, seed-rate, urea and pesticide cost suggested that there is no further benefit from increased use of these inputs on farm productivity. Coefficients of mechanical cost for land preparation, TSP fertilizer, herbicide cost, and land rent had no significant impact on yield in saline prone areas.

Table 1: MLE of the stress prone rice farmers in Bangladesh

Ecosystem		Submergence	Drought	Saline
Independent variables	Parameters	Co-efficient	Co-efficient	Co-efficient
Constant	β_0	1.895** (0.860)	0.155* (0.083)	7.872*** (2.766)
Ln Human labour (man-days/ha)	β_1	-0.192** (0.083)	-0.021** (0.008)	-0.125* (0.070)
Ln Mechanical cost (Tk./ha)	β_2	0.179ns (0.126)	0.079ns (0.065)	0.082ns (0.516)
Ln Seed (kg/ha)	β_3	0.117*** (0.037)	-0.364*** (0.106)	-0.024** (0.011)
Ln Urea (kg/ha)	β_4	0.089* (0.046)	0.232* (0.130)	-0.186* (0.102)
Ln TSP (kg/ha)	β_5	-0.028** (0.013)	-0.078** (0.035)	0.262ns (0.578)
Ln MoP (kg/ha)	β_6	0.040ns (0.032)	-0.227* (0.120)	0.050** (0.024)
Ln Herbicide cost (Tk./ha)	β_7	0.131ns (0.121)	0.063ns (0.047)	0.015ns (0.046)
Ln Pesticide cost (Tk./ha)	β_8	-0.082** (0.036)	0.022ns (0.019)	-0.026* (0.015)
Ln Irrigation cost (Tk./ha)	β_9	-	0.112*** (0.029)	0.205*** (0.074)
Ln Land rent (Tk./ha)	β_{10}	0.135* (0.185)	-0.044ns (0.030)	-0.002ns (0.008)
Dummy for variety	η	0.112*** (0.034)(1=BRRI dhan52, 0=otherwise)	0.026** (0.011) (1=BRRI dhan56, 0=otherwise)	0.025** (0.011) (1=BRRI dhan47, 0=otherwise)

***, ** and * shows significant at 1%, 5% and 10% levels, respectively. The parenthesized values are the standard errors of the estimates

3.4. Testing hypothesis

Table 2 shows the findings from hypothesis testing. The null hypothesis was H_0: There was no inefficiency effect (gamma, $\gamma = 0$) or technical inefficiency in the model was absent. This hypothesis was strongly rejected for all of the areas, as the estimated values of LR were more than the critical χ^2, representing the existence of technical inefficiency effect in rice the production. Confirming this result of γ (0.99, 0.91 and 0.98 for the submergence, drought and saline environment, respectively) of the desired model in the Table 3. It (γ) was closer to one that ensured the existence of high-level inefficiencies among the sample rice farmers that supported MLE as the adequate estimation.

Table 2: Generalized likelihood ratio test of null hypotheses for parameters of the inefficiency function

Ecosystems	Test of null hypothesis (Farmers' are completely efficient in producing rice), γ=0	Test statistics (λ)	df	Critical values at 95% ($\chi^2_{0.05}$)	Remarks
Submergence	$\gamma_{sb} = \delta_1 = \ldots = \delta_8 = 0$	46.14	9	16.27	Reject H_0
Drought	$\gamma_d = \delta_1 = \ldots = \delta_8 = 0$	16.85	9	16.27	Reject H_0
Saline	$\gamma_{sa} = \delta_1 = \ldots = \delta_8 = 0$	19.36	9	16.27	Reject H_0

Note: Critical values are at 5% probability level with (k +1) degrees of freedom, where k = number of restriction (Kodde and Palm, 1986)

3.5. The inefficiency effect model estimation

The coefficient of operated land was negative and significant, indicating that an increase in farm size leads to decrease inefficiency. So, larger farms were more efficient than the smaller farms in the stress prone areas. Farmers' age coefficient was positive and statistically significant, indicating that the older farmers are less efficient than the younger farmers. The reason might be that older farmers contributed less effort to the farming activities and they were also laggard innovative than younger one to adopt modern technologies in stress prone areas.

The coefficients of farmers' education (0.012) showed significant positive effect in the submergence area, indicating that more educated farmers are technically more efficient. It was due to the fact that as educated farmers might have other alternative sources of income; so their attention was not fully devoted on agriculture as a means of livelihoods. The result also showed that an increase in the household size led to a decrease in inefficiency. Because, larger household sizes along with more working forces, able to provide sufficient emphasis on farming activities besides other occupations. The coefficient of working age population had negative effect on inefficiency in submergence and drought areas, indicating that more working force can reduce inefficiency substantially. Farmers' occupation and training had no significant impact on the submergence prone areas, but these had robust effect on rice production in terms of increasing efficiency in the drought and saline areas. Because farmers in drought and saline prone areas had no much alternative occupations for livelihoods; so, they bequeathed full devotion to agriculture as a profession and participated in agriculture related training courses minutely. The coefficient of dummy for extension contact was negatively and highly significant, indicating that more extension linkage reduces technical inefficiency in submergence and saline areas. Information about the production packages of stress tolerant rice varieties were disseminated and distributed to the farmers' field through the extension department mainly. So, the farmers who had active linkage with the extension personnel received the information/materials earlier and performed better (Table 3).

Table 3: Parameters of inefficiency effect model of stress tolerant rice farming

Technical inefficiency effect model Ecosystems Variables	Parameters	Submergence Coefficient	Drought Coefficient	Saline Coefficient
Constant	δ_0	0.012^{*} (0.007)	-0.098^{*} (0.051)	0.345^{**} (0.167)
Ln Operated land (ha)	δ_1	-0.072^{**} (0.029)	-0.013^{***} (0.004)	-0.030^{***} (0.011)
Farmers age (years)	δ_2	0.011^{***} (0.004)	0.214^{*} (0.121)	0.014^{*} (0.008)
Farmers education (year of schooling)	δ_3	0.012^{*} (0.007)	0.004^{ns} (0.003)	0.021^{ns} (0.020)
Household size (person/hh)	δ_4	-0.005^{*} (0.002)	0.181^{ns} (0.165)	-0.042^{*} (0.023)
Working age population (number)	δ_5	-0.016^{**} (0.006)	-0.254^{**} (0.106)	0.029^{ns} (0.041)
Dummy for farmers' occupation (1=one, 0=more)	δ_6	-0.080^{ns} (0.069)	-0.224^{**} (0.110)	-0.011^{**} (0.005)
Dummy for training (1=yes, 0=otherwise)	δ_7	-0.091^{ns} (0.073)	-0.418^{***} (0.148)	-0.087^{**} (0.040)
Extension dummy (1 if yes, and 0, otherwise)	δ_8	-0.102^{***} (0.035)	-0.156^{ns} (0.152)	-0.051^{***} (0.018)
Variance factors				
Sigma-squared	σ^2	0.037^{***} (0.013)	0.069^{***} (0.016)	0.025^{***} (0.007)
Gamma	γ	0.990^{***}	0.914^{***}	0.981^{***}

	(0.331)	(0.128)	(0.312)

Note: ***, ** and * shows significant at 1%, 5% and 10% levels, respectively. Values in the parentheses represent the standard error of the parameter estimates

3.6. Farm specific technical efficiency distribution

The sampled stress prone regions farms' technical efficiency distribution is presented in Table 4. The overall mean technical efficiency in the submergence prone area was about 80% with a range of 57% to 95%, implying that on an average, sample farmers cultivating rice about 80% of the prospective frontier production level, based on current level of inputs and technologies. The mean efficiency for the drought and saline areas were 77% and 74%, respectively. The findings of the analysis also revealed that, the average technical inefficiency was about 20%, 23% and 26% for the submergence, drought and saline prone environment, respectively which could be minimized through using stress tolerant varieties, improved seeds, fertilizers and better farm management practices.

Table 4: Farm specific technical efficiency distribution pattern

Efficiency level (%)	Submergence	Drought	Saline
Mean	0.80	0.77	0.74
Maximum	0.95	0.96	0.97
Minimum	0.57	0.45	0.49
Standard deviation	0.11	0.14	0.12

Source: Authors' calculation from the results of Frontier 4.1 package program

4. CONCLUSION

Abiotic stresses are severe constrains of rice cultivation in Bangladesh. Rice production is marginally benefited to farmers in the stress prone areas. The cost of production of saline areas is (22.51 Tk./kg) higher than submergence (19.82 Tk./kg) and drought (19.40 Tk./kg) areas, respectively. The farmers in drought areas received higher gross margin (12,612 Tk./ha) than submergence (9,312 Tk./ha) and saline (666 Tk./ha) areas due to lower production cost and higher market price of paddy. The study revealed that inputs use in the production process was not judicious as per recommendation in all environments. The adoption of stress tolerant rice varieties had positive impact on increasing farm productivity. The farmers have opportunities to increase rice yield by efficient use of inputs in the production process. More than twenty percent of the existing inefficiency of the rice farms in the stress prone areas of Bangladesh can be reduced with the better farm management practices.

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Appendix

Appendix I: BRRI developed stress tolerant HYV rice varieties

Ecosystems	Season	Name of the variety	Silent features of the variety
Salinity	Aus	BRRI dhan55	Yield: 5.0 t/ha, growth duration 105 days, plant height 100 cm, amylose 21%, long slender grain, moderately salinity, drought and cold tolerant, released date 2011
	Aman	BRRI dhan40	Yield: 4.5 t/ha, growth duration 145 days, plant height 110 cm, amylose 25.7%, medium bold grain, moderately salinity tolerant during the last phase of life cycle, released date 2003
		BRRI dhan41	Yield: 4.5 t/ha, growth duration 148 days, plant height 115 cm, amylose 24.6%, longish bold grain, moderately salinity tolerant during the last phase of lifecycle, released date 2003
		BRRI dhan53	Yield: 4.5 t/ha, growth duration 125 days, plant height 105 cm, amylose 25.9%, medium slender grain, moderately salinity tolerant during the last phase of life cycle, released date 2010
		BRRI dhan54	Yield: 4.5 t/ha, growth duration 135 days, plant height 115 cm, amylose 26%, medium slender grain, moderately salinity tolerant during the last phase of life cycle, released date 2010
		BRRI dhan73	Yield: 3.5-6.0 t/ha, growth duration 125 days, plant height 120 cm, amylose 27%, medium slender grain, saline tolerance at 8 ds/m (whole lifecycle), released date 2015
		BRRI dhan78	Yield: 4.5, growth duration 135 days, plant height 118 cm, amylose 25.2%, medium slender grain, can tolerate 6-9 ds/m salinity, Flag leaf erect and tall, released date 2016
	Boro	BRRI dhan47	Yield: 6.0 t/ha, growth duration 145 days, plant height 105 cm, amylose 26.1%, medium bold grain, can tolerate 6 ds/m (whole life cycle), released date 2007
		BRRI dhan55	Yield: 7.0 t/ha, growth duration 145 days, plant height 100 cm, amylose 21%, long slender grain, moderately salinity, drought and cold tolerant, released date 2011
		BRRI dhan61	Yield: 6.3 t/ha, growth duration 150 days, plant height 96 cm, amylose 22%, medium slender and white grain, salinity tolerant, released date 2013

		BRRI dhan67	Yield: 6.0 t/ha, growth duration 145 days, plant height 100 cm, amylose 24.6%, medium slender and white grain, higher tolerance at 8 ds/m (whole life cycle), released date 2014
Submergence	Aman	BRRI dhan44	Yield: 5.5, growth duration 145 days, plant height 130 cm, amylose 27.2%, bold grain, tidal submergence, released date 2005
		BRRI shan51	Yield: 4.5 t/ha, growth duration 157 days, plant height 90 cm, amylose 25%, medium slender and transparent grain, submergence tolerant at 14 days, released date 2010
		BRRI dhan52	Yield: 5.0 t/ha, growth duration 155 days, plant height 116 cm, amylose 25%, high elongation rate, medium bold grain, submergence tolerant at 14 days, released date 2010
		BRRI dhan76	Yield: 5.0 t/ha, growth duration 163 days, plant height 140 cm, amylose 24%, lodging tolerance, tidal submergence, released date 2016
		BRRI dhan77	Yield: 5.0 t/ha, growth duration 155 days, plant height 140 cm, amylose 24%, lodging tolerance, tidal submergence, released date 2016
		BRRI dhan79	Yield: 5.5, growth duration 160 days, plant height 112 cm, amylose 25.2%, flag leaf erect and tall, Medium slender and white grain, Submergence at 18-21 days, released date 2017
Drought	Aus	BRRI dhan42	Yield: 3.5 t/ha, growth duration 100 days, plant height 100 cm, amylose 26.1%, medium slender white grain, drought tolerant, released date 2004
		BRRI dhan43	Yield: 3.5 t/ha, growth duration 100 days, plant height 100 cm, amylose 26.7%, high elongation rate, medium slender white grain, drought tolerant, released date 2004
		BRRI dhan65	Yield: 3.5-4.0 t/ha, growth duration 99 days, plant height 88 cm, amylose 26.8%, medium slender and white grain, shattering resistance, moderate drought tolerant (Rain fed), released date 2014
	Aman	BRRI dhan56	Yield: 4.0 t/ha, growth duration 110 days, plant height 115 cm, amylose 23.7%, medium bold and white grain, drought tolerance (14-21 days) at reproductive stage, released date 2011
		BRRI dhan57	Yield: 4.0 t/ha, growth duration 105 days, plant height 115 cm, amylose 25%, grain size as *Jirashail* & Minikit type, can tolerate & escape (10-14 days without rain) terminal drought, released date 2011
		BRRI dhan66	Yield: 4.5 t/ha, growth duration 115 days, plant height 120 cm, amylose 23%, medium slender and white grain, protein enriched, can tolerate drought at reproductive stage, released date 2014
		BRRI dhan71	Yield: 4.5 t/ha, growth duration 115 days, plant height 108 cm, amylose 24%, medium slender grain, lodging tolerant, drought tolerant at reproductive phase in rain fed lowland rice ecosystem, released date 2015

Source: BRRI (2017)

Appendix II: Summary statistics of stress tolerant rice farming in Bangladesh

Ecosystem Variables	Submergence Mean	Drought Mean	Saline Mean
Yield (ton/ha)	3.27 (0.50)	3.80 (0.87)	4.17 (0.85)
Human labour (man-days/ha)	97 (13.93)	114 (36.09)	109 (13.8)
Seed rate (kg/ha)	50 (10.25)	44 (10.59)	43 (8.4)
Mechanical cost (Tk./ha)	5828 (610.96)	7595 (2189.31)	7870 (1303.1)
Urea (kg/ha)	171 (17.72)	182 (41.22)	178 (13.28)
TSP (kg/ha)	83 (9.07)	110 (19.49)	104 (13.04)
MoP (kg/ha)	64 (11.96)	86 (13.65)	90 (12.16)
Herbicide cost (Tk./ha)	1499 (226.11)	1387 (417.91)	1510 (305.69)
Pesticide cost (Tk./ha)	2163 (434.06)	3135 (1393.43)	2254 (796.05)
Irrigation charge (Tk./ha)	-	4636 (1607.69)	16,310 (2315.68)
Land rental value (Tk./ha)	13,330 (1288.47)	14,383 (3294.26)	13,670 (2024.67)
Varietal dummy (BRRI dhan52, BRRI dhan56 and BRRI dhan47) (%)	68 (0.47)	54 (0.50)	42 (0.50)
Farm-specific variables			
Farmers age (years)	43 (10.05)	42 (9.85)	44 (9.84)
Only one occupation (%)	77 (0.42)	60 (0.49)	53 (0.50)
Education (years of schooling)	5 (3.75)	3 (3.19)	3 (3.16)
Family size (person/hh)	4.39 (0.92)	5.22 (1.39)	4.32 (1.14)
Working age population (no./hh)	2.74 (1.37)	3.23 (1.12)	3.22 (1.34)
Average operated land (decimal)	143 (52.67)	145 (0.43)	121 (81.8)
Training attended (%)	41 (0.50)	38 (0.48)	35 (0.48)
Extension contact (%)	34 (0.48)	41 (0.50)	39 (0.49)

Figure in the parentheses indicates standard deviation