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Farm Level Environmental Efficiency in Summer Paddy Production and its Determinants: A Study of the Brahmaputra Valley in Assam

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JEL Codes
C31, C34, Q00, Q15.

INTRODUCTION

Agricultural production generates both desired and undesired outputs (Fare et al., 1993), which is the function of some environmentally non-detrimental and environmentally detrimental inputs. However, in the production and productivity analysis of the agriculture sector till the 1980s, the inclusion of the negative impact of indiscriminate use of environmentally detrimental inputs or production of undesired outputs was limited (Reddy, 1995; Chung et al., 1997). The issue of sustainable agriculture gained importance only after the first UN Conference on Human Environment, 1972, in the agricultural research works in the 1980s. The increasing use of chemical fertiliser and pesticides as a composite package of modern agricultural production techniques since the green revolution in the 1960s helped India become self-sufficient in food production (Basu & Nandi, 2014; Singh, 2015). However, the excessive use of these detrimental inputs has created various environmental problems relating to water pollution and soil de (Sharma & Thaker, 2011). Given the increasing for food, the use of chemical fertilisers cannot be in agricultural activities to a great extent in the ne (Larson & Vroomen, 1991; Wu, 2011) due to increasing population and relatively lower produ productivity of organic farming. Therefore, effic of these inputs is critical to making agriculture environmentally conservative, given the adequate production and use of other normal inputs. So, recent research on the efficiency analysis of agriculture has expanded its scope from conventional technical, allocative, scale and economic efficiency to environmental efficiency (EE) (Moreaua et al., 2012).

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The empirical development of environmental efficiency is deeply rooted in agricultural sustainability and eco-efficiency, as sustainable agriculture is technically efficient and environmentally less degrading (FAO, 2012). Agricultural sustainability is a multidimensional measurement which includes economic, social and ecological indicators (Hansen, 1996; Esty et al., 2005; Reig et al., 2010; 2010a). Similarly, eco-efficiency is an output-oriented measure, and it is the ratio of desired and undesired outputs in agriculture as estimated by Tyteca (1996), Huppes and Ishikawa (2005); Picazo-Tadeo et al. (2009); Moutinho et al. (2018). In contrast, environmental efficiency is an input-oriented measure, and it is the ratio of the minimum feasible quantity of an environmentally detrimental input to its observed quantity, which could be used to produce a definite amount of the desired output along with environmentally non-detrimental inputs (Reinhard et al., 1999). Thus, it indicates the scope of reducing the quantity of detrimental inputs without altering the level of agricultural production. Reinhard et al. (1999) used the translog stochastic frontier analysis to estimate environmental efficiency within the framework of conventional efficiency measurements where at least one environmentally detrimental input is used in the production process.

The result of the translog stochastic frontier model showed that attaining technical efficiency is a precondition for environmental efficiency; however, it does not ensure a strong positive relationship between the two measures. This methodology was extensively used in the estimation of environmental efficiency subsequently by Graham (2004); Zhang and Xue (2005); Abedullah and Mustaq (2010); Vu et al. (2019); Bai et al. (2019); Bibi et al. (2021). In studies, the output-oriented technical efficiency is also calculated using the maximum likelihood estimates and compared with the environmental efficiency scores. The studies find that the technical efficiency scores of the farmers are higher than the environmental efficiency scores. The studies also revealed that the farmers with higher technical efficiency scores have higher environmental efficiency scores (Reinhard et al., 2000; Ying-heng et al., 2015). Korhonen and Luptacik (2004); Graham (2004); Kuosmanen and Kortelainen (2005); Hoang and Alauddin (2012); Moreno-Moreno et al. (2018) used the data envelopment analysis (DEA) method for estimating environmental efficiency of the agriculture sector. Reinhard et al. (2000) concluded that DEA cannot identify whether the environmentally detrimental inputs are suitable for the model since it is a deterministic estimation. Likewise, Hoang and Alauddin (2012) decompose the economic, environmental and eco-efficiency of agricultural production estimation in the OECD countries and find that the input-oriented technical efficiency is higher than the input-oriented environmental efficiency. The significant advantage of the stochastic frontier analysis (SFA) model is that it could incorporate the technical inefficiency function while estimating the production function; hence the issue of biased estimation in the technical inefficiency effect model does not arise. Similarly, the SFA can identify the suitability of the environmentally detrimental inputs in the model.

Paddy is the principal food crop of Assam, as rice is the staple food of the Assamese people (Pegu & Hazarika, 2016). Paddy also covers the highest area under cultivation. The three varieties of paddy cultivated in Assam are winter, summer and autumn. It covered 56.23, 11.84 and 3.81 per cent of the total cultivated area under all crops in 2019-20 (Directorate of Economics and Statistics, 2021). Notably, the area under summer paddy has increased from 0.20 per cent in 1951-52 to 19.76 per cent in 2019-20 of the total area under paddy.

Moreover, the average yield of summer paddy has been the highest among the three varieties of paddy in Assam. In 2019-20, the average yield of summer paddy was 2,593 kg/ha, which was 2,160 and 1,543 kg/ha for winter and autumn paddy, respectively. The increase in output is attributable to the relatively higher use of modern inputs like HYV seeds, irrigation, chemical fertiliser and pesticides in summer paddy production. However, indiscriminate use of pesticides and chemical fertilisers may have implications for environmental pollution-related policies. Therefore, the objective of the present study is to estimate the time-invariant environmental efficiency of the summer paddy farmers and analyse the socio-economic variables that affect it significantly.

METHODOLOGY

Study Area and Sampling Design

The present study used both primary and secondary data for analysis. The primary data were collected from 432 sample summer paddy farmers selected through a multi-stage random sampling from 16 villages of 4 non-contiguous districts of the Brahmaputra Valley of Assam. The Brahmaputra Valley was selected as it covered about 94.59 per cent of the total area under the summer paddy of Assam in 2017-18. The valley was divided into four agricultural sub-valleys: Upper Brahmaputra Valley (UBV), North Bank Plain Valley (NBPV), Central Brahmaputra Valley (CBV) and Lower Brahmaputra Valley (LBV). Therefore, in the next stage, one district from each valley was selected- Golaghat from UBV, Sonitpur from NBPV, Nagaon from CBV and Barpeta from LBV, having the highest area under summer paddy during the same period. Finally, 10 per cent of the farmers cultivating summer paddy were randomly sampled in every 16 villages for farm-level data collection. The data were collected using a pre-tested and structured questionnaire.

The Translog Stochastic Frontier Model

For the estimation of environmental efficiency, the translog stochastic frontier analysis was used as developed by Reinhard et al. (1999), and used later on by Abedullah and Mustaq (2010); Vu et al. (2019); Bai et al. (2019); Bibi et al. (2021). The input-oriented environmental efficiency is defined as the ratio of minimum feasible use of the environmentally detrimental inputs to the actual use in a production process given the observed production level of the desired output and quantity of the environmentally non-detrimental inputs (Reinhard et al., 1999). Hence, it is an extended measure of the conventional technical efficiency measurement of a farm where technical efficiency is a necessary condition for obtaining environmental efficiency. The general form of stochastic production function is

$$Yi = f(Xi, Zi, \beta) \exp(Vi - Ui) \; Vi = N(0, \lambda_v^2) Ui \geq 0 \text{ and } Ui \sim N^+(0, \lambda_u^2) \quad (1)$$

Where,

Yi = Vector of the quantity of production of summer paddy

Xi = Vector of environmentally non-detrimental inputs

Zi = Vector of environmentally detrimental inputs

β = Parameters to be estimated

Vi = Random error

Ui = Non-negative technical inefficiency error

In the model, the variance parameters are calculated using the formula

$$\lambda_s^2 = \lambda_V^2 + \lambda_U^2; \; \mu = \frac{\lambda_U^2}{\lambda_V^2 + \lambda_U^2} = \frac{\lambda_U^2}{\lambda_S^2} \text{ and } 0 = \mu = 1 \quad (2)$$

In Equation-2, λ_s^2 represents the variance parameter. The value of μ represents the existence of a stochastic variable that affects the technical inefficiency of the summer paddy farmers. If the value of μ was near unity, it indicated the presence of technical inefficiency in summer paddy production. Therefore, the output-oriented technical efficiency was estimated using

$$TE_i = \frac{Yi}{f(X_i, Z_i, \beta) \exp(Vi - U_i)} = \exp(-U_i) \quad (3)$$

However, according to Reinhard et al. (2000); Zhang and Xue (2005); Abdulai and Abdulai (2016); Bibi et al. (2021), the translog stochastic production function was more appropriate for estimating the input-oriented environmental efficiency than the conventional Cobb-Douglas production function. Therefore, for empirical estimation, the translog stochastic production function was defined as

$$\ln Y_i = \beta_0 + \beta_1 \ln Land + \beta_2 \ln Lab + \beta_3 \ln Cap + \beta_4 \ln Fetz + \beta_5 \ln Pest + ½\beta_{11}(\ln Land)^2 + ½\beta_{22}(\ln Lab)^2 + ½\beta_{33}(\ln Cap)^2 + ½\beta_{44}(\ln Fetz)^2 + ½\beta_{55}(\ln Pest)^2 + \beta_{12} \ln Land \ln Lab + \beta_{13} \ln Land \ln Cap + \beta_{14} \ln Land \ln Fetz + \beta_{15} \ln Land \ln Pest + \beta_{23} \ln Lab \ln Cap + \beta_{24} \ln Lab \ln Fetz + \beta_{25} \ln Lab \ln Pest + \beta_{34} \ln Cap \ln Fetz + \beta_{35} \ln Cap \ln Pest + \beta_{45} \ln Fetz \ln Pest + (Vi - Ui) \quad (4)$$

Where

Y_i = Output of summer paddy (q/acre)

Land = Size of land in acre

Labour (Lab) = Imputed cost of labour (₹/acre)

Capital (Cap) = Cost of machines (₹/acre)

Fertilizer (Fetz) = Quantity of fertiliser used (kg/acre)

Pesticides (Pest) = Quantity of Pesticides used (litre/acre)

In the production function, fertilisers and pesticides were considered detrimental, and land, labour and capital were considered non-detrimental inputs for the environment. Hence modification was required in Equation-4 to estimate environmental efficiency. Environmental efficiency was related to technical efficiency because it denoted the farmer's ability to reduce the use of the inputs which adversely affect the environment without altering the quantity of normal inputs and output level (Reinhard et al., 1999). Therefore, environmental efficiency could be defined as

$$EE = \min\{\theta : f(X, \theta Z) \geq Y\} \leq 1 \quad (5)$$

Here, θ is the environmental efficiency score. Now, following the methodology developed by Reinhard et al. (1999), lnFetz and lnPest are replaced with θFetz and θPest and by setting U_i=0 and thereafter the new form of translog production function becomes

$$\ln Y_i = \beta_0 + \beta_1 \ln Land + \beta_2 \ln Lab + \beta_3 \ln Cap + \beta_4 \ln \theta Fetz + \beta_5 \ln \theta Pest + ½\beta_{11}(\ln Land)^2 + ½\beta_{22}(\ln Lab)^2 + ½\beta_{33}(\ln Cap)^2 + ½\beta_{44}(\ln \theta Fetz)^2 + ½\beta_{55}(\ln \theta Pest)^2 + \beta_{12} \ln L \text{ and } \ln Lab + \beta_{13} \ln L \text{ and } \ln Cap + \beta_{14} \ln L \text{ and } \ln \theta Fetz + \beta_{15} \ln Land \ln \theta Pest + \beta_{23} \ln Lab \ln Cap + \beta_{24} \ln Lab \ln \theta Fetz + \beta_{25} \ln Lab \ln \theta Pest + \beta_{34} \ln Cap \ln \theta Fetz + \beta_{35} \ln Cap \; \theta \ln Pest + \beta_{45} \ln \theta Fetz \ln \theta Pest + (Vi - Ui) \quad (6)$$

So, if a farm attains full environment efficiency the output in Equations-4 and 6 will be equal. Now, by equating these two equations and further mathematical expansions, we get

$$\beta_4(\ln \theta Fetz - \ln Fetz) + \beta_5(\ln \theta Pest - \ln Pest) + ½\beta_{44}(\ln \theta Fetz \ln \theta Fetz - \ln Fetz \ln Fetz) + ½\beta_{55}(\ln \theta Pest \ln \theta Pest - \ln Pest \ln Pest) + \beta_{14} \ln L \text{ and } (\ln \theta Fetz - \ln Fetz) + \beta_{15} \ln Land (\ln \theta Pest - \ln Pest) + \beta_{24} \ln Lab (\ln \theta Fetz - \ln Fetz) +$$

β_{25}lnLab (lnθPest-lnPest) + β_{34}lnCap (lnθFetz-lnFetz) + β_{35}lnCap(lnθPest-lnPest) + β_{45}(lnθFetz lnθPest-lnFetz lnPest)+Ui=0 (7)

Again, LnEE=Lnθ=Ln($\frac{\varphi Z}{Z}$); hence the Equation-7 can be written as

$$(\tfrac{1}{2}\beta_{44} + \tfrac{1}{2}\beta_{55}+)+\beta_{45})\ln^2 EE + \{\beta_4 + \beta_5 + \beta_{44}\ln Fetz + \beta_{55}\ln Pest + \beta_{14}\ln Land + \beta_{15}\ln Land + \beta_{24}\ln Lab + \beta_{25}\ln Lab + \beta_{34}\ln Cap + \beta_{35}\ln Cap + \beta_{45}(\ln Fetz + \ln Pest)\}\ln EE + U_i=0 \quad (8)$$

The Equation-8 is in the standard form of a quadratic equation $ax^2+bx+c=0$, and hence it can be expressed as

$$a(\ln EE)^2 + b\ln EE + Ui = 0 \quad (9)$$

Using the standard solution for a quadratic equation, we get-

or $$\ln EE = \frac{-b \pm \sqrt{b^2 - 4aUi}}{2a} \quad (10)$$

$$EE = \exp\left(\frac{-b \pm \sqrt{b^2 - 4aUi}}{2a}\right)$$

or

$$EE = \exp\left(\frac{-b + \sqrt{b^2 - 4aUi}}{2a}\right) \quad (11)$$

Since " $\exp\left(\frac{-b - \sqrt{b^2 - 4aUi}}{2a}\right)$ " cannot be accepted in the model if Ui=0, the exponential of EE will be equal to zero when '+√' is used as explained by Reinhard et al. (1999), Reinhard et al. (2000), Abedullah et al.(2010) Bibi et al. (2021) and Zhang & Xue (2005). Therefore,

$$EE = \exp[-\{\beta_4+\beta_5+\beta_{44}\ln Fetz+\beta_{55}\ln Pest+\beta_{14}\ln Land+\beta_{15}\ln Land+\beta_{24}\ln Lab+\beta_{25}\ln Lab+\beta_{34}\ln Cap+\beta_{35}\ln Cap+\beta_{45}(\ln Fetz+\ln Pest)\}+\{\beta_4+\beta_5+\beta_{44}\ln Fetz+\beta_{55}\ln Pest+\beta_{14}Land+\beta_{15}\ln Land+\beta_{24}\ln Lab+\beta_{25}\ln Lab+\beta_{34}\ln Cap+\beta_{35}\ln Cap+\beta_{45}(\ln Fetz+\ln Pest)\}^2-4(\tfrac{1}{2}\beta_{44}+\tfrac{1}{2}\beta_{55}+\beta_{45})U_i\}^{0.5}]/(\beta_{44}+\beta_{55}+2\beta_{45}) \quad (12)$$

Again if we consider only pesticides as the environmentally detrimental input in the production function, the result could be written using the same line of derivation as

$$EE=\exp[\{\beta_5 + \beta_{55}\ln Pest + \beta_{15}\ln Land + \beta_{25}\ln Lab + \beta_{35}\ln Cap + \beta_{45}(\ln Fetz\}+ \{\beta_5 + \beta_{55}\ln Pest + \beta_{15}\ln Land + \beta_{25}\ln Lab + \beta_{35}\ln Cap + \beta_{45}(\ln Fetz)\}^2-(2\beta_{55}U_i\}^{0.5}]/\beta_{55} \quad (13)$$

For Equation-13, the formula '+√' was also used for measuring environmental efficiency for the single detrimental input pesticides. Moreover, to analyse different socio-economic variables that may had an impact on the environmental efficiency scores of the summer paddy farmers, a regression model was used, which was specified in Equation-14.

$$EE= \beta_0+ \beta_1 FEXP + \beta_2 EDUC+ \beta_3 ACCTC + \beta_4 EXTSN + \beta_5 TENANC + \beta_6 L_1 + \beta_7 L_2 + \beta_8 L_3 + \mu_i \quad (14)$$

Where,

EE= Environmental efficiency score of the farmer.

μ_i= Random disturbance term is assumed to be normally distributed with zero mean.

So, to estimate the environmental efficiency of summer paddy farmers, the β parameters were estimated in FRONTIER 4.1 using maximum likelihood estimation for translog stochastic frontier production function defined in Equation-4.

RESULTS AND DISCUSSION

The perusal of Table 1 showed that the average yield of summer paddy was 2.24 q/acre among the sample farmers of the Brahmaputra Valley. The average production varied between a maximum of 3.96 q/acre and a minimum of 1.29 q/acre of cultivated land, implying that the summer paddy farmers produced approximately 5.5 q/ha. The variation of the yield was not very high. It was 33.003 per cent, with a standard devi[illegible] ave yield of summer paddy was [illegible] te autumn paddy in Assam. K[illegible] use, average size of operational holding was 2.94 acres. [illegible] indicated that most summer paddy farmers were small and marginal farmers. The maximum size of operational holdings was 11.57 acres, and the smallest size was 1.33 acres. Nonetheless, the standard deviation of

Table 1. Summary of the statistics of output and inputs used in the translog stochastic frontier model

Variables	Maximum	Mean	Minimum	S.D.	CV (Per cent)
Yield of SP (q/acre)	3.96	2.24	1.29	0.738	33.003
Land (acres)	11.57	2.94	1.33	1.442	75.10
Labour (₹/acre)	6072.75	2538.56	1055.09	1398.89	55.01
Capital (₹/acre)	10760.85	7894.71	2299.65	1819.91	23.05
Fertiliser (kg/acre)	96.31	64.13	0	39.04	60.87
Pesticides (litre/acre)	12.1	3.54	0	2.01	56.77

Source: Field survey.
S.D.: Standard deviations.
CV: Coefficient of variation.

landholdings was only 1.442. On the other hand, the coefficient of variation was 75.10 per cent.

Similarly, the average imputed cost of labour was ₹2538.56 per acre, which varied from a maximum of ₹6072.75 per acre to a minimum of ₹1055.09 per acre. The contribution of family labour to the imputed cost was more than the hired labour. On average, 87.54 per cent of the total labour cost was the imputed cost of family labour, and only 12.46 per cent was the cost of hired labour. Besides, the use of machinery in summer paddy production or the mechanisation of summer paddy production depended mainly on rented machines. Only 23.38 per cent of the farmers used owned mechanical equipment in summer paddy production, and 12.50 per cent used rented machines. Thus, the majority of the summer paddy farmers used both owned and hired mechanical equipment in production. The lower level of income of the farmers and the small size of operational holdings were the reasons for relying on hired mechanical equipment. Therefore, the average cost of capital in summer paddy production was ₹7894.71 per acre, with a standard deviation of 1819.91 and a coefficient of variation of 23.05.

The use of chemical fertilisers in summer paddy production was also higher than the average use in the agriculture sector of Assam. In 2017–18, the average use of chemical fertilisers (NPK) in Assam was only 80.87 kg/ha compared to all India's average of 128.21 kg/ha. However, in summer paddy, the average use of NPK fertilisers was 64.13 kg/acre, or about 158.40 kg/ha. The high use of chemical fertilisers might have implications for environmental efficiency. The average use of chemical fertilisers varied from a maximum of 96.31 kg/acre to 0. About 5.32 per cent of the farmers had not used NPK fertilisers in different field study locations. These farmers either had used organic fertilisers or had not used fertilisers at all. Similarly, the use of pesticides also varied from 12.1litre/acre to 0. The average use of pesticides was 3.54 litre/acre in the Brahmaputra valley, where the standard deviation was only 2.01 and the coefficient of variation was 56.77 per cent.

Estimation of the Parameters of Translog Stochastic Production Function

The statistical and econometric justification for adopting the translog production function was derived from the likelihood ratio test. The formula for the likelihood ratio test was $-2[\ln\{L(Ho)\}-\{\ln(H_1)\}$, where the Ho and H_1 were the value of the log-likelihood of the Cobb-Douglas production function and translog stochastic production function model, respectively. It was estimated that the log-likelihood for the Cobb-Douglas production function was 201.358, and for the translog stochastic production function, it was 257.471. Therefore, the log-likelihood ratio test value was =112.226 [-2(201.358-257.471)], which was greater than the critical value of χ^2 was 18.307 and statistically significant. Hence, the null hypothesis was rejected, and the use of the translog stochastic production function to estimate the parameters was statistically justified in the present study. As the results in Table 2 showed that the sigma squared value was significantly greater than zero, and was significant statistically. Therefore, the translog stochastic model estimated was a good fit, and the assumption made for the distribution of the composite error term was valid. Moreover, the gamma value was significant statistically; hence, the variation in summer paddy output was affected by technical inefficiency. The gamma coefficient was 0.8838; therefore, 88.38 per cent of the variation in the output of summer paddy was caused by technical inefficiency in the model. Again, the coefficients of the variables used in the translog stochastic frontier analysis were significant at different levels. For example, the coefficients of the logarithm of land, pest and capital were statistically significant. However, the coefficients of labour and fertiliser were found to be non-significant statistically.

Environmental Efficiency of Paddy Farmers for Single (Pesticides) and Joint (Chemical Fertiliser and Pesticides) Detrimental Inputs

The environmental efficiency for the single detrimental input was calculate[illegible] and joint environmental efficien[illegible] in[illegible] Equation-12 based on coeff[illegible]slog stochastic frontier production function (Table 3). The results presented in Table 3 indicated that the mean environmental efficiency for pesticides was much lower than the joint environmental efficiency. The mean environmental efficiency for pesticides was 0.423 compared to the joint mean efficiency of 0.639. Nevertheless, the standard deviation of the efficiency score of pesticides was almost the same as the combined efficiency. Consequently, the coefficient of variation for pesticides was 18.43 per cent which was higher than the coefficient of variation for joint efficiency (11.46). The maximum value of environmental efficiency for pesticides varied from 0.623 to 0.165, whereas in the case of joint efficiency, it was 0.806 to 0.427.

There were also differences in the value of the environmental efficiency measure in different field study locations as shown in Table 3. The mean joint environmental efficiency of the detrimental inputs for Barpeta and Nagaon was almost the same, and these were lower than Golaghat and Sonitpur. It was the highest in Sonitpur (0.660), followed by 0.658 in Golaghat, 0.620 in Nagaon and 0.615 in Barpeta. It was because the farmers in Nagaon and Barpeta used more chemical fertilisers

Table 2. MLE estimates of translog stochastic frontier analysis

Parameters	Coefficients	Standard error	t-ratio
β_0	-1.4451	1.4849	-0.9180
β_1(lnLand)	1.6638**	0.7735	2.1509
β_2(lnLab)	0.5229	0.4989	1.0481
β_3(lnCap)	1.7663*	0.9461	1.8669
β_4(lnFetz)	0.6182	1.3977	0.4423
β_5(lnPest)	1.6894**	0.7638	2.2116
β_{11}\{1/2(lnLand)^2\}	1.0628*	0.6352	1.6730
β_{22}\{½(lnLab)^2\}	0.0487***	0.0176	2.7577
β_{33}\{½(Cap)^2\}	-0.1175	0.3994	-0.2978
β_{44}\{½(lnFetz)^2\}	-0.2952***	0.0775	-3.8078
β_{55}\{½(lnPest)^2	-0.1583***	0.0576	-2.7476
β_{12}(lnLandlnLab)	0.1059	0.1171	0.9039
β_{13}(lnLandlnCap)	-0.4084	0.4486	-0.9105
β_{14}(lnLandlnFetz)	0.1776	0.3151	0.5637
β_{15}(lnLandlnPest)	0.4058**	0.1798	2.2569
β_{23}(lnLablnCap)	-0.1882*	0.1068	-1.7614
β_{24}(lnLablnFetz)	0.0818**	0.0362	2.2605
β_{25}(lnLablnPest)	-0.0081	0.0241	-0.3365
β_{34}(lnCaplnFetz)	-0.0986	0.3094	-0.3189
β_{35}(lnCaplnPest)	-0.3491**	0.1638	2.1307
β_{45}(lnFetzlnPest)	-0.0170	0.0442	-0.3854
sigma^2	0.160***	0.0024	6.6397
gamma	0.8839***	0.0348	25.3489
Log-Likelihood		257.471	

****, ** and * Significant 1, 5 and 10 per cent levels.*

Table 3. Summary Statistics of EE Scores estimated for summer paddy farmer

Districts	EE for pesticides				Joint EE for both pesticides and chemical fertiliser			
	Maximum	Mean	Minimum	SD	Maximum	Mean	Minimum	SD
Barpeta	0.623	0.381	0.187	0.069 (18.11)	0.806	0.615	0.457	0.081 (13.30)
Golaghat	0.606	0.415	0.157	0.081 (19.51)	0.710	0.658	0.591	0.043 (6.57)
Nagaon	0.551	0.451	0.241	0.042 (9.31)	0.741	0.620	0.327	0.088 (14.22)
Sonitpur	0.526	0.448	0.165	0.067 (14.95)	0.738	0.660	0.475	0.066 (10.04)
Overall	0.623	0.423	0.165	0.078 (18.43)	0.806	0.639	0.427	0.073 (11.46)

SD: Standard deviation.
The Figures in the parentheses are Coefficient of Variation (CV) in percentage.

than those of Golaghat and Sonitpur. The reasons were not known adequately, but different location-specific variables in the use of NPK fertilisers in summer paddy might have some impact (Table 3).

However, compared to chemical fertilisers, the mean environmental efficiency for pesticides was also the highest in Sonitpur (0.448). On the contrary, it was also the lowest in Barpeta (0.381). Therefore, in Barpeta, the farmers used the detrimental inputs with the lowest efficiency. On the contrary, this was not the case for Nagaon and Golaghat. The frequency distribution of the farmers depending on the environmental efficiency scores indicated that maximum farmers were included in the medium frequency distribution, followed by the lowest percentage of the farmers in both the lowest and largest frequency distribution class. The frequency distribution is reported in Table 4.

The perusal of Table 4 showed that 83.10 per cent of the farmers were included in the category of 0.301-0.500, which was 79.40 per cent for the joint environmental efficiency in the range of 0.501–0.700. The Pearson coefficient of correlation for the two environmental efficiency scores was 0.924. Therefore, it could be concluded that the farmers with higher efficiency for pesticides were also achieving higher efficiency in the use of the inputs jointly.

Factors influencing the Environmental Efficiency of Summer Paddy Farmers: A Truncated Regression Analysis

The issue of the impact of different farm-level socio-economic variables on the environmental efficiency of a farm is vital for policy implications. As the value of EE lies theoretically between 0 and 1 or 0 to 100 per cent, some researchers used the Tobit regression model to explain the variables for environmental efficiency. However, the two-step Tobit regression is subjected to biased estimation. Alternatively, Abdulai and Abdulai (2016) used the fractional regression model and concluded that access to credit, access to extension, and farming experience positively impact farms' environmental efficiency. Similarly, Vu et al. (2019) applied the truncated regression model and concluded that the age and education of the farmers and their farming experience positively affected their environmental efficiency. In contrast, access to credit and family size affected it negatively. So, the truncated regression model was used in the present study as it was more appropriate and free from biasness in estimation (Vu et al., 2019). The summary of the regressors affecting environmental efficiency and used in the truncated regression model was shown in Table 5. The farming experience (FEXP) of the respondent farmers was expected to affect environmental efficiency positively since experienced farmers use the inputs, including the environmentally detrimental inputs, more judiciously than less experienced farmers. Similarly, farmers with access to extension services (EXTSN) and higher education levels (EDUC) were anticipated to use fertilisers and pesticides properly. Therefore, the coefficients of these two variables were also expected to bear positive signs. On the other hand, engagement in tenancy (TENANC) was expected to negatively affect environmental efficiency, as it was found in the present study that fixed rent in cash and kind were the two dominant forms of tenancy contracts used by summer paddy farmers. In both cases, the tenant farmers had to give a pre-fixed amount of cash or quantity of summer paddy production to the landowner, irrespective of the actual production quantity. Hence, the farmers used more pesticides and chemical fertilisers in summer paddy to maximise their share of total production, reducing tenant farmers' environmental efficiency. Likewise, the annual family income of most of the farmers was low, with the average yearly income of the family of the summer paddy farmers in the Brahmaputra valley being

Table 4. Frequency distribution of the EE scores for summer paddy farmers

Districts	EE for pesticides			Joint EE (Pesticides+NPK fertiliser)		
	0.100-0.300	0.301-0.500	Above 0.501	0.300-0.500	0.501-0.700	Above 0.701
Barpeta	2.42	97.58	-	10.19	79.62	10.19
Golaghat	10.19	79.73	10.18	0.81	98.39	0.80
Nagaon	19.15	79.79	1.06	3.77	68.87	27.36
Sonitpur	3.77	72.65	23.58	12.77	65.95	21.48
Overall	8.33	83.10	8.57	6.48	79.40	14.12
Pearson coefficient of correlation between the EE for pesticides and joint EE						0.924

Source: Estimated by the author.

estimated at ₹1,10,650.50 only. Due to that reason, if the farmers had access to credit in any form, they were expected to use even more chemical fertilisers in summer paddy cultivation to increase the marketable surplus. Hence, the access to credit (ACCTC) variable was also likely to be negative in the regression model. Moreover, as Barpeta had the lowest average joint environmental efficiency score, it was taken as the reference location, and after that, three location dummies viz. L_1, L_2 and L_3 were included in the model to examine the impact of location-specific variables on the environmental efficiency scores.

The empirical truncated regression model, including these independent variables as shown in Equation-14, was estimated in STATA 14.2, and the results are presented in Table 6. The multicollinearity problem among the dependent variables in the regression model was checked using VIF, and its value was less than 5 for all the variables. Therefore, it could be concluded that the model does not have multicollinearity. Additionally, heteroskedasticity was checked using the Breusch-Pagan test, and its value was 269.83, which was significant statistically. The test result indicates that heteroskedasticity was present in the model. Therefore, the robust standard error was estimated to correct the problem in the regression model. As explained above, the truncated regression model results showed that all the independent variables were significant at different significance levels and with expected signs.

The variables of farming experience, education level of the respondent and access to extension services were positively affecting the environmental efficiency of the summer paddy farmers, implying that the increase in farming experience, level of education and access to

Table 5. Summary of the regressors of the truncated regression model for environmental efficiency

Regressors	Description	Expected signs
Farming experience (FEXP)	In Years	+
Access to credit (ACCTC)	Dummy (0=Yes, 1=No)	-, +
Education level of the respondent (EDUC)	Completed years of schooling (in Years)	+,-
Engagement in tenancy (TENANC)	Dummy(0=No, 1=Yes)	-
Access to extension (EXTSN)	Dummy (0=Yes, 1=No)	+
Location dummy for Golaghat (L_1)	Taking Barpeta as the reference category, 1= Golaghat and 0=otherwise)	
Location dummy for Nagaon (L_2)	Taking Barpeta as the reference category, 1= Nagaon and 0=otherwise)	
Location dummy for Sonitpur (L_3)	Taking Barpeta as the reference category, 1= Sonitpur and 0=otherwise)	

Table 6. Estimates of truncated regression model for environmental efficiency

(n = 432)

Test of Heteroskedasticity	Breusch-Pagan Test, $\chi^2(1)$= 269.83 , P>χ^2= 0.000, Result: Presence of Heteroskedasticity				
Variables	**Coefficients**	**Robust standard error**	**Z**	**p>|z|**	**VIF**
FEXP	0.0015*	0.0011	1.78	0.082	1.05
EDUC	0.2231***	0.0089	25.03	0.000	2.94
ACCTC	-0.0036**	0.0028	-2.16	0.003	1.14
EXTSN	0.1527***	0.0272	5.60	0.000	1.95
TENANC	-0.4565***	0.0338	-13.48	0.000	1.97
L1	-0.0070**	0.0031	-2.23	0.026	1.75
L2	-0.0058	0.0032	-1.23	0.256	1.63
L3	-0.0147***	0.0028	-5.16	0.000	1.47
Constant	0.0490***	0.0068	71.14	0.000	
Wald χ^2			2480.23		
Prob>χ^2			0.000		

****, ** and * Significant 1, 5 and 10 per cent levels.*

extension increased the environmental efficiency. The results were similar to the findings of Abdulai and Abdulai (2016); Vu et al. (2019). The analysis of the positive impact of the extension of environmental efficiency in the agriculture sector was also similar to the study of Wang and Shen (2016).On the other hand, access to credit and engagement in tenancy negatively affected environmental efficiency. As explained above, the majority of the tenant farmers were engaged in fixed-rent tenancy, and the average use of chemical fertiliser by these farmers was higher than the other farmers. The result of access to credit and its negative impact on environmental efficiency was opposite to the study of Abdulai and Abdulai (2016), where they found a positive relationship between access to credit and the environmental efficiency of the farms. The relationship was negative in the present study because the annual family income of the summer paddy farmers was low, which restricted them from using more chemical fertilisers in summer paddy production. Therefore, when they got access to credit, they got the incentive to use a higher quantity of chemical fertilisers for higher production. Again, in the case of location dummies, all the coefficients had negative signs, but the coefficient of Nagaon was not significant. Nevertheless, the coefficients of Golaghat and Sonitpur were significant statistically. Therefore, it implied that Golaghat and Sonitpur had higher environmental efficiency than the reference location Barpeta.

CONCLUSIONS

Based on the time-invariant input-oriented EE, it can be concluded that the summer paddy farmers had a significant scope of reducing the use of pesticides and chemical fertilisers without changing the quantity of summer paddy production and the use of different environmentally non-detrimental inputs in the Brahmaputra valley of Assam. Significantly, the EE for the single input pesticides was even lower than the joint EE. Therefore, in place of an overall policy for reducing the use of both environmentally detrimental inputs, separate policies would be more practical for improving EE. Moreover, focusing on greater penetration of farmers' training, broader extension services, managing fixed-rent tenancy and controlling non-institutional credit will positively influence the EE of farmers. These measures will not only reduce negative environmental pressures in the agro-ecosystem but also improve the sustainability of the summer paddy production process in different field study locations of the Brahmaputra valley.

REFERENCES

Abdulai, A., & Abdulai, A. (2016). Examining the impact of conservation agriculture on environmental efficiency among maize farmers in Zambia. *Environment and Development Economics, 22*(1), 177-201.

Abedullah, K.S., & Mustaq, K. (2010). Environmental efficiency analysis of basmati rice production in Punjab, Pakistan: Implications for sustainable agricultural development. *The Pakistan Development Review, 49*(1), 57-72.

Bai, X., Salim, R., & Bloch, H. (2019). Environmental efficiency of apple production in China: A translog stochastic frontier analysis. *Agricultural and Resource Economics Review, 2019*, 1-22.

Basu, D., & Nandi, A.K. (2014). Farm mechanisation and rationality of labour Use in Indian agriculture: A frontier analysis of cost of cultivation data. *Indian Journal of Agricultural Economics, 69*(3), 336-346.

Bibi, Z., Khan, D., & Ul-Haq, I. (2021). Technical and environmental efficiency of agriculture sector in South Asia: A stochastic frontier analysis approach. *Environment, Development and Sustainability, 23*, 9260-9279.

Chung, Y.H.R., Fare, R., & Grosskopf, S. (1997). Productivity and undesirable outputs: A directional distance function approach. *Journal of Environmental Management, 51*, 229-240.

Directorate of Economics and Statistics. (2021). *Statistical handbook of Assam*. Directorate of Economics and Statistics, Government of Assam, Guwahati.

Esty, D.C., Levy, M., Srebotnjak, T., & de Sherbinin, A. (2005). *Environmental sustainability index: Benchmarking national environmental stewardship*. Yale Center for Environmental Law and Policy, New Haven, USA.

FAO. (2012). *How to feed the worl*[illegible] O. Retrieved from https://www.fa[illegible]s/wsfs/docs/expert_paper/How_to_[illegible]050.pdf.

Fare, R., Grosskopf, S., Lovell, C.A.K., & Yaisawarng, S. (1993). Derivation of shadow prices for undesirable outputs: A distance function approach. *The Review of Economics and Statistics, 75*(2), 374–380.

Graham, M. (2004, February). *Environmental efficiency: Meaning and measurement and application to Australian dairy farms* (pp. 1-16). Paper Presented at the 48th Annual AARES Conference, Melbourne, Victoria.

Hansen, J.W. (1996). Is agricultural sustainability a useful concept? *Agricultural Systems, 50*(1), 117-143.

Hoang, V.N., & Alauddin, M. (2012). Input-orientated data envelopment analysis framework for measuring and decomposing economic, environmental and ecological efficiency: An application to OECD agriculture. *Environmental and Resource Economics, 51*, 431-452.

Huppes, G., & Ishikawa, M. (2005). A framework for quantified eco-efficiency analysis. *Journal of Industrial Ecology, 9(4)*, 25–41.

Korhonen, P.J., & Luptacik, M. (2004). Eco-efficiency analysis of power plants: An extension of data envelopment analysis.

European Journal of Operational Research, 154, 437-446.

Kuosmanen, T., & Kortelainen, M. (2005). Measuring eco-efficiency of production with data envelopment analysis. *Journal of Industrial Ecology, 9*(4), 59-72.

Larson, B.A., & Vroomen, H. (1991). Nitrogen, phosphorus and land demands at the US regional level: A primal approach. *Journal of Agricultural Economics, 42*, 354-364.

Moreaua, P., Ruiz, L., Mabon, F., Raimbault, T., Durand, P., Delaby, L., Devienne, S., & Vertès, F. (2012). Reconciling technical, economic and environmental efficiency of farming systems in vulnerable areas. *Agriculture, Ecosystems and Environment, 147*, 89-99.

Moreno-Moreno, Juan-J., Velasco Morente, F., & Sanz Diaz, M.T. (2018). Assessment of the operational and environmental efficiency of agriculture in Latin America and the Caribbean. *Agricultural Economics-Czech, 64*(2), 74-88.

Moutinho, V., Robaina, M., & Macedo, P. (2018). Economic-environmental efficiency of European agriculture - A generalized maximum entropy approach. *Agricultural Economics-Czech, 64*(10), 423-435.

Pegu, N.C., & Hazarika, C. (2016). Growth and instability of rice production in Assam. *International Research Journal of Interdisciplinary and Multidisciplinary Studies*, 2(4), 39-46.

Picazo-Tadeo, A.J., Ernest R.M., & Estruch, V. (2009). Farming efficiency and the survival of valuable agro-ecosystems: A case study of rice farming in European Mediterranean Wetlands. *Open Environmental Sciences, 3*, 42-51.

Reddy, V.R. (1995). Environment and sustainable agricultural development: Conflicts and contradictions. *Economic and Political Weekly, 30*(12), A21-27.

Reig, E., Aznar, J., & Estruch, V. (2010). A comparative analysis of the sustainability of rice cultivation technologies using the analytic network process. *Spanish Journal of Agricultural Research*, 8(2), 273-284.

Reig, M., Ernest, J.A., Gomez-Limon.,A., & Picazo-Tadeo, J.(2010a). Ranking farms with a composite indicator of sustainability. *Agricultural Economics, 42*, 561-575.

Reinhard, S., Lovell, C.A.K., & Thijssen, G. J. (1999). Econometric estimation of technical and environmental efficiency: An application to Dutch dairy farms. *American Journal of Agricultural Economics, 81*, 44-60.

Reinhard, S., Lovell, C.A.K., & Thijssen, G.J. (2000). Environmental efficiency with multiple environmentally detrimental variables estimated with SFA and DEA. *European Journal of Operational Research, 121*, 287-303.

Sharma, V.P., & Thaker, H. (2011). Demand for fertilisers in India: Determinants and outlook for 2020. *Indian Journal of Agricultural Economics, 66*(4), 638-661.

Singh, G. (2015). Agricultural mechanisation development in India. *Indian Journal of Agricultural Economics*, *70*(1), 64-82.

Tyteca, D. (1996). On the measurement of the environmental performance of firms: A literature review and a productive efficiency perspective. *Journal of Environmental Management, 46*, 281-308.

Vu, T.H., Peng, K.C., & Chung, R.H. (2019). Evaluation of environmental efficiency of edible canna production in Vietnam. *Agriculture, 9*, 1-14.

Wang, Y., & Shen, N. (2016). Agricultural environmental efficiency and agricultural environmental Kuznets curve based on technological gap: The case of China. *Polish Journal of Environmental Studies*, *25*(3), 1293-1303.

Wu, Y. (2011). Chemical fertiliser use efficiency and its determinants in China's farming sector. *China Agricultural Economic Review, 3*(2), 117-130.

Ying-heng, Z., Xiao-heng, Z., Xu, T., Xian-hui, G., Peng, Z., & Bin-jian, Y. (2015). Technical and environmental efficiency of hog production in China: A stochastic frontier production function analysis. *Journal of Integrative Agriculture, 14*(6), 1069-1080.

Zhang, T., & Xue, B.D. (2005). Environmental efficiency analysis of China's vegetable production. *Biomedical and Environmental Sciences, 18*, 21-30.