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Technical Efficiency of Resource-Conserving Technologies in Rice -Wheat Systems: The Case of Bihar and Eastern Uttar Pradesh in India

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Abstract

This study has evaluated the technical efficiency of farmers engaged in rice-wheat cropping systems in North-eastern India, who are using Resource-Conserving Technologies (RCTs) such as Zero Tillage (ZT) and Direct Seeded Rice (DSR). These technology promotions are being carried out under the intervention of the Cereal Systems Initiative for South Asia (CSISA) project, primarily funded by the Bill and Melinda Gates Foundation. The resource-conserving technologies are being promoted as part of conservation agriculture supported by the project. The data used in this study have been derived from the socio-economic surveys conducted in Eastern Uttar-Pradesh and Bihar in North-eastern India during the *kharif* season of 2009 and *rabi* season of 2010. A stochastic frontier analysis was carried out to investigate and compare the determinants of technical efficiency among the farmers receiving intervention and those who are not. The study has revealed that farmers receiving CSISA intervention have realized higher levels of technical efficiency. Additionally, farmers who are receiving subsidies and farmers who are planting more diversified crops have higher levels of technical efficiency.

Key words: Conservation agriculture, Direct seeded rice, India, Resource-conserving technology, Technical efficiency, Stochastic frontier, Zero tillage

JEL Classification: O30; Q18; O22

Introduction

The Cereal Systems Initiative for South Asia (CSISA) project, funded primarily by the Bill and Melinda Gates Foundation, aims to decrease hunger and malnutrition and increase food and income security of farmers living in South Asia through the accelerated development and deployment of new cereal varieties, sustainable cropping systems management practices, and agricultural policies. The project predicts that within the next ten years, four million farmers in South Asia will have an increase in yield of 0.5 t/ha over five million hectares (Mha) and an additional two million farmers will have an increase in yield of 1.0 t/ha over 2.5 Mha for cereal crops. To achieve these gains the project relies on the increased availability of high-yielding, high-quality, and stress-tolerant varieties of rice, wheat, and maize. Additionally, the widespread adoption of sustainable cropping systems practices and better access to information for farmers, at the household level, will be crucial in achieving this prediction. The sustainable attainment of this projected yield increase

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will result in a 30 per cent increase in nitrogen and water-use efficiency over the current levels. It is estimated that at least five million tonnes of additional food grain will be produced annually, with an additional economic value of at least US $1.5 billion per year. The use of Resource-Conserving Technologies (RCTs) will also help farmers gain substantial savings in energy use and other production costs. Six million poor rural households will have increased their annual income by at least US $350 per year. Additionally, affordable prices of staple cereals will benefit hundreds of millions of rural and urban landless poor.

India has the largest area but the lowest yield for rice in Asia. The conventional paddy-growing tracts are in a crisis due to social, biological, and technical setbacks (Devi and Ponnarasi, 2009). Therefore, a more efficient technology is needed to improve rice-wheat production. Achieving self-sufficiency in rice and wheat production will depend on the level of the farmers' productivity, which can be determined by the rates of their adoption of improved technologies and efficiency in resource use (Idiong, 2007). In the case of India, there are wide fluctuations also in the yields of rice-wheat production. This can be explained under the issue of efficiency in the resources used by rice-wheat farmers.

This study aims to estimate the technical efficiency and identify the factors that affect the technical performance of farmers practicing Zero Tillage (ZT) wheat and Direct Seeded Rice (DSR), under the intervention of the Cereal Systems Initiative for South Asia project. This study intends to answer the following questions: is the technical efficiency level of the rice and wheat farmers who are receiving CSISA intervention higher than those farmers who are not? Additionally, what demographic and socio-economic variables are the determinants of technical efficiency of these farmers?

Analytical Methods and Models

Farrell (1957) illustrated his ideas of efficiency using a simple example involving firms that use two inputs (x_1 and x_2) to produce a single output (q), under the assumption of constant return to scale. The curve SS' in Figure 1 represents the unit isoquant of fully efficient firms and permits the measurement of technical efficiency. If a given firm uses quantities of

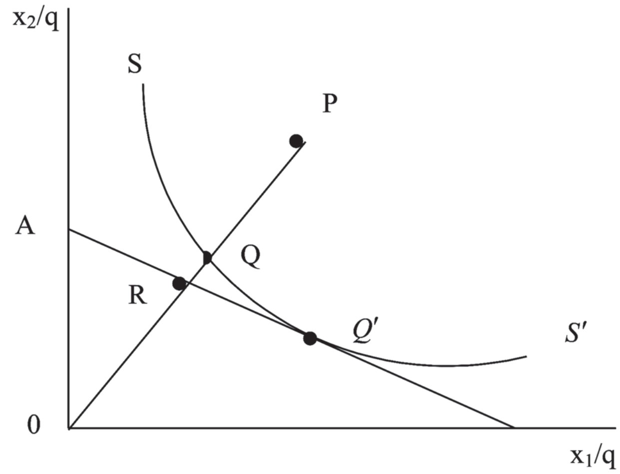

Figure 1. Technical efficiency (Farrell, 1957)

inputs, defined by the point P, to produce a unit of output, the technical inefficiency of that firm is represented by the distance QP, which is the amount in which all inputs could be proportionately reduced without a reduction in output. This is usually expressed in percentage terms by the ratio QP/OP, which represented the percentage in which all inputs can be optimally reduced to achieve technically efficient production. Hence, the technical efficiency (TE) of a firm can be measured by the ratio:

$$TE = OQ / OP \qquad \ldots(1)$$

Technical inefficiency is equal to 1 – *OQ/OP* and takes a value between zero and one. Hence, it provides an indicator of the degree of technical inefficiency of the firm. A value of one implies that the firm is fully technically efficient (Coelli *et al.*, 2005).

The stochastic frontier production function was independently proposed by Aigner *et al.* (1977) and Meeusen and van den Broeck (1977). The original specification involved a production function specified for cross-sectional data which had an error-term with two components, one to account for random effects and the other to account for technical inefficiency.

Following Battese (1992), the stochastic frontier production function can be expressed in the form of Equation (2):

$$Y_i = f(x_i;\beta)\exp(V_i - U_i) \qquad \ldots(2)$$

where, Y_i represents the possible output level of the i^{th} production unit with i ranging from 1,2,…,N; $f(x_i;\beta)$ is a suitable function (e.g., Cobb-Douglas or translog form) given the vector of inputs x; while β is a vector of parameters to be estimated. V is the symmetric error-term accounting for random variations in output due to factors outside the control of the farmer such as weather, disease infestation, other calamities, and measurement error. The distribution of the symmetric error-component V is assumed to be independently and identically distributed as $N(0, \delta_v^2)$.

On the other hand, U represents the error-term associated to technical inefficiency relative to the stochastic frontier, which assumes only positive values. The distribution of the one-sided component, U, is assumed to be half normally $(U \geq 0)$ distributed as $\left|N(O, \delta_u^2)\right|$ and thus, measures shortfalls in production from its notional maximum level Y^*. If U is equal to 0, then the farm lies on the frontier obtaining maximum output given variable and fixed inputs. However, if U is greater than 0, then the farm is inefficient and the production lies below the frontier function. The distance of Y_i from Y^* measures the extent of the farmers' technical inefficiency. Therefore, the larger the one-sided error, the more inefficient the farm is.

The technical efficiency of an individual producing unit is defined in terms of the ratio of the observed output to the maximum production of the corresponding frontier output, given the best available technology. Thus, the technical efficiency of unit i, in the context of the stochastic frontier production function is given in the form of Equation (3):

$$
\begin{aligned}
TE_i &= Y_i / Y_i^* \\
&= f(x_i; \beta) \exp(V_i - U_i) / f(x_i; \beta) \exp(V_i) \\
&= \exp(-Ui)
\end{aligned}
\qquad \ldots(3)
$$

where, Y_i is an observed output and Y_i^* is the frontier output. X_i, βs and V_i are as defined earlier. In this case, Y_i achieves its maximum value of $f(x_i; \beta) \exp(V_i)$ if and only if TE_i is 1. Otherwise, a value of TE_i less than 1 provides a measure of the shortfall of the observed output from maximum feasible output in an environment characterized by stochastic elements that vary across producers.

This study has identified the appropriate form of the frontier production function by choosing between the Cobb-Douglas or transcendental logarithmic (translog) specifications. The translog form is expressed by Equation (4):

$$
\ln Y_i = \beta_0 + \sum_{j=1}^{n} \beta_j \ln X_{ji} + \frac{1}{2} \sum_{k=1}^{n} \sum_{j=1}^{n} \beta_{kj} \ln X_{ki} \ln X_{ji} + \varepsilon_i \qquad \ldots(4)
$$

where, Y_i is the output of the ith farmer; X is a vector of n input variables; $X_k X_j$ is the pair-wise interaction of two inputs; e is the random error-term; ln is the natural logarithm, and i is the number of observations with a total of n samples. The Cobb-Douglas form is simply a reduced form of the translog model where the interaction terms between inputs are assumed to be unimportant and equal to zero, as Expressed in Equation (5):

$$
\ln Y_i = \beta_0 + \sum_{j=1}^{n} \beta_j \ln X_{ji} + \varepsilon_i \qquad \ldots(5)
$$

To establish the appropriate form of the production function, the Likelihood Ratio test is used. Specifically, the test confirms the validity of the assumption that the interaction terms are not important and hence these can be dropped. To determine whether the Cobb-Douglas or the translog transformation provided the best fit for the data, the following Likelihood Ratio test was used (Maddala, 2001):

$$
LR = n \ln \left[\frac{RRSS}{URSS} \right] \qquad \ldots(6)
$$

where, *RRSS* is the residual sum of squares of the restricted model (Cobb-Douglas model), *URSS* is the residual sum of squares of the unrestricted model (translog function), n is sample size, and r is number of restrictions. The expected signs of these variables with respect to technical inefficiency are summarised in Table 1.

In this study, five inputs were used in the specification of the production function, namely X_{1i} as the amount of seed used (kg/ha), X_{2i} as the human labour used (human-day/ha), X_{3i} as the amount of urea used (kg/ha), X_{4i} as the amount of diammonium phosphate (DAP) used (kg/ha), X_{5i} as the amount of agro-chemicals used (L/ha). The variable agro-

Table 1. Expected different signs for variables determining technical inefficiency

Variable	Parameters	Expected sign
Age	δ_1	+/-
Education	δ_2	-
Seed subsidy	δ_3	-
Geographical location	δ_4	+/-
Cropping system	δ_5	-
Type of irrigation	δ_6	-
Production system	δ_7	-
Type of seed	δ_8	+/-
Experience	δ_9	-
Membership of organization	δ_{10}	-

chemicals is the aggregate value of insecticides and herbicides that was used by the farmer per hectare.

A second model was specified in the study to establish the socio-economic factors that affect the level of technical efficiency of the farmers. Following Coelli *et al*. (2005); the technical inefficiency model was specified as per Equation (7):

$$TI_i = \delta_0 + \sum_{j=1}^{8} \delta_j Z_{ji} + \sum_{k=1}^{3} \delta_k D_{ki} \qquad \ldots(7)$$

where, TI_i is technical inefficiency of farmer i, is a vector of unknown parameters, D_1 is a dummy variables for the use of urea, with a value of 1 if farmers are not using urea and 0 otherwise, D_2 is a dummy variables for DAP, with a value of 1 if farmers are not using DAP and 0 otherwise, D_3 is a dummy variables for the use of agro-chemicals, with a value of 1 if farmers are not using herbicides and insecticides and 0 otherwise, Z_1 is the age of the farmer respondent (years), Z_2 is the time period the respondent has been in school (years), Z_3 is a dummy variable of seed subsidy for production activities (1: yes, 0: no), Z_4 is a dummy variable for geographical location (1: Eastern Uttar Pradesh, 0: Bihar), Z_5 is a dummy variable for cropping system (1: rice-wheat, 0: otherwise) , Z_6 is a dummy variable for type of irrigation (1: water pump, 0: otherwise) , Z_7 is a dummy variable for production system (1: irrigated lowland, 0: otherwise), and Z_8 is a dummy variable for type of seed (1: modern variety, 0: otherwise).

Study Area and Data

In this study, the field surveys were conducted during the *kharif*-2009 and *rabi*-2010 seasons in the two major rice-wheat producing regions in India: Bihar and Eastern Uttar Pradesh (EUP). The focus of the survey was on direct seeded rice and zero-tillage wheat.

Data from 132 sample farmers (91 of whom had intervention from the CSISA project and 41 without intervention) were used in the analysis of kharif-2009. Almost an equal number of farmers receiving CSISA intervention were sampled from Bihar and EUP; 58 per cent and 42 per cent were sampled, respectively.

As part of the expansion of the CSISA project, the number of participants in *rabi*-2010 was increased by more than double compared to the *kharif*-2009 season. Some farmers from the *kharif* season were returning participants in the *rabi* season. The study maintained the acquisition of nearly identical sample sizes for Bihar and EUP in *rabi*-2010 with a total of 230 with-intervention households and 108 without-intervention households.

The collected primary data included general information on socio-demographic characteristics, seasons and crops grown, production activities, input use, labour inputs, machinery use, production inputs, and costs for the seasons of *kharif*-2009 and *rabi*-2010. Secondary data pertaining to rice-wheat production, area, and yield were gathered from various official Indian government websites and statistical publications. Determinants of technical inefficiency in rice and wheat production were investigated by using Frontier version 4.1, Tim Coelli's computer program for stochastic frontier production estimation.

Results and Discussion

Results of the likelihood ratio test failed to reject H_0 for with-intervention farmers in both rice and wheat. This implies that the Cobb-Douglas is the best fit for the data of with-intervention farmers. In contrast, without-intervention farmers in both seasons were found to have the translog model as a better fit.

Table 2 shows the maximum likelihood estimates of the production function model for rice and wheat farmers. The sigma-square values were statistically significant for all the models, affirming the correctness of the specified assumptions of the distribution of

Table 2. Maximum likelihood estimates of production function model with- and without- intervention farmers, *kharif*-2009 and *rabi*-2010, Easter Uttar Pradesh and Bihar, India

Variable	*Kharif*-2009		*Rabi*-2010	
	With-intervention farmers	Without-intervention farmers	With-intervention farmers	Without-intervention farmers
Constant	7.113	8.718	7.563	-3.681
	(0.689)	(0.970)	(0.272)	(2.963)
ln (Seed)	0.137	0.059	0.119*	2.307***
	(0.111)	(1.224)	(0.062)	(0.588)
ln (Labour)	0.102	0.253	0.016	2.185***
	(0.094)	(0.842)	(0.025)	(0.767)
ln (Urea)	-0.006	0.816	0.027	1.054
	(0.060)	(0.901)	(0.039)	(0.844)
ln (DAP)	0.098***	-1.452*	0.007	-0.636
	(0.032)	(0.819)	(0.009)	(0.508)
ln (Chemical)	-0.033	16.868***	-0.046***	0.020
	(0.069)	(0.968)	(0.011)	(0.347)
ln (Seed)*ln(Labour)	-	-0.239	-	-0.418***
		(0.189)		(0.154)
ln (Seed)*ln(Urea)	-	0.170	-	-0.254
		(0.212)		(0.168)
ln (Seed)*ln(DAP)	-	0.066	-	0.193*
		(0.079)		(0.102)
ln (Seed)*ln (Chemical)	-	1.572***	-	0.003
		(0.354)		(0.077)
ln (Labour)*ln(Urea)	-	-0.236**	-	0.038
		(0.108)		(0.026)
ln (Labour)*ln (DAP)	-	0.349**	-	-0.055**
		(0.162)		(0.028)
ln (Labour)*ln (Chemical)	-	-3.954***	-	-0.004
		(0.556)		(0.044)
ln (Urea)*ln (DAP)	-	-0.031	-	0.009
		(0.071)		(0.007)
ln (Urea)*ln (Chemical)	-	-0.519	-	0.016
		(0.615)		(0.029)
ln (DAP)*ln (Chemical)	-	0.084	-	-0.024
		(0.200)		(0.021)
Sigma-squared	0.240***	0.076***	0.467***	0.075***
	(0.067)	(0.018)	(0.116)	(0.012)
Gamma	0.366*	0.999***	0.938***	0.619***
	(0.222)	(0.000)	(0.020)	(0.148)

Notes: *, ** and *** are statistically significant at 10 per cent, 5 per cent and 1 per cent levels, respectively.
Values given within parentheses are standard errors.

composite error-term. The gamma values for all models were also statistically significant, meaning that variation in output of paddy could be attributed to technical inefficiency.

The only significant variable discovered for rice farmers who were receiving intervention was the amount of DAP that was applied, indicating that increasing DAP would increase paddy productivity. Rice farmers who did not receive intervention also had DAP application as a significant variable; however, in this group, the sign is negative, indicating that an increase in DAP application will decrease the productivity of paddy. The application of chemical (all chemicals, excluding fertilizer) was also found to be significant for without-intervention rice farmers; numerous interaction variables were also found to be significant in this model.

With-intervention wheat farmers had the amount of seed applied as well as the amount of chemical applied as significant variables. Without-intervention wheat farmers also had the amount of seed as a significant variable. Additionally, the amount of labour-use, as well as numerous interaction variables were found to be statistically significant for without-intervention wheat farmers.

Determinants of Technical Inefficiency

The maximum likelihood estimates of the determinant of the technical inefficiency model are presented in Table 3. The use of DAP was found to be a determinant of technical efficiency for all farmers in this study. The DAP-use was statistically significant at 10 per cent for all rice farmers and significant at 1 per cent for all wheat farmers. All farmers who applied DAP experienced an increase in technical efficiency. There were no rice farmers that were not receiving intervention from the CSISA project who received seed subsidies. All other groups, with-intervention rice farmers, with-intervention wheat farmers, and without-intervention wheat farmers, were found to be more technically efficient as a result of receiving seed subsidies.

Rice and wheat farmers who were receiving intervention were found to be more technically efficient if they lived in Bihar. However, this result is ambiguous because there are so many factors that can change from one region to another. In this example, it could be a difference in weather, soil conditions, or even the technologies that are being promoted through the CSISA project in the different regions.

Wheat farmers who were receiving intervention were found to be more technically efficient if they were engaged in an irrigated lowland production system and used a water pump for irrigation. They were also found to be more technically efficient if they were members of an organization related to agriculture.

Crop diversity was found to make all rice farmers as well as without-intervention wheat farmers more technically efficient. Conversely, wheat farmers who received CSISA intervention, were found to be more technically efficient if they were engaged in a rice-wheat cropping system. Although it is too early to say with certainty, the study does indicate that the CSISA-promoted RCTs in rice-wheat production are having a positive impact on the wheat systems.

A Comparison of Mean Values of Technical Efficiency

A comparison of technical efficiency levels between with- and without-intervention, for all sample farmers in *kharif*-2009, is presented in Table 4. The mean technical efficiency of with-intervention rice farmers was higher than of without-intervention rice farmers. The t-test showed that the mean difference of technical efficiency levels between these two categories of farmers was significant at one per cent level. The standard deviation of with-intervention rice farmers was smaller than without-intervention rice farmers, indicating that with-intervention farmers were more stable than without-intervention farmers.

The comparison of technical efficiencies between with-intervention and without-intervention wheat farmers showed that the former had a higher level of technical efficiency than the latter. The difference for wheat farmers was also statistically significant at one per cent level. The standard deviation was lower for with-intervention wheat farmers than for without-intervention group, indicating that with-intervention farmers were more stable than without-intervention farmers.

Distribution of Technical Efficiency

The distribution of the mean value of technical efficiency during the *kharif*-2009 rice season is depicted in Figure 2. The value of technical efficiency

Table 3. Determinants of technical inefficiency model, with- and without-intervention farmers, *kharif*-2009 and *rabi*-2010, Eastern Uttar Pradesh and Bihar, India

Variable	*Kharif*-2009		*Rabi*-2010	
	With-intervention farmers	Without-intervention farmers	With-intervention farmers	Without-intervention farmers
		Technical inefficiency estimates		
Constant	-0.483	-0.140	-0.140	0.544
	(0.925)	(0.034)	(0.707)	(0.376)
Dummy urea[1]	0.088	-	0.000	-0.819
	(0.785)		(1.000)	(1.628)
Dummy DAP	-0.935*	-0.863*	-1.410***	-1.363**
	(0.474)	(0.439)	(0.521)	(0.647)
Dummy chemical	-0.200	-0.225	-0.108	0.001
	(0.227)	(0.223)	(0.230)	(0.106)
Age	-0.014	0.003	0.001	0.001
	(0.012)	(0.006)	(0.009)	(0.003)
Years in school	-0.001	0.056***	-0.017	-0.004
	(0.031)	(0.019)	(0.021)	(0.008)
Seed subsidy[2]	-0.420*	-	-1.882**	-0.458*
	(0.246)		(0.890)	(0.245)
Geographical location	0.554**	-0.158	0.903*	0.025
	(0.277)	(0.178)	(0.455)	(0.155)
Cropping system	1.461**	0.440***	-0.514*	0.300***
	(0.671)	(0.161)	(0.310)	(0.105)
Type of irrigation	0.144	0.094	-0.912*	-0.190
	(0.406)	(0.278)	(0.470)	(0.167)
Production system	-0.070	0.100	-0.508*	-0.112
	(0.290)	(0.194)	(0.290)	(0.080)
Type of seed	0.059	-0.085	0.055	0.066
	(0.565)	(0.187)	(0.485)	(0.184)
Year working on farm[3]	-	-	0.002	0.001
			(0.008)	(0.003)
Member of organization[3]	-	-	0.403*	0.083
			(0.229)	(0.076)

Notes: *, ** and *** are statistically significant at 10 per cent, 5 per cent and 1 per cent levels, respectively.
Values given in parentheses are standard errors.
[1]All without-intervention farmers in *kharif*-2009 used urea
[2]Without-intervention farmers in *kharif*-2009 did not receive seed subsidy
[3]Data not available for *kharif*-2009

Table 4. Mean technical efficiency levels between with- and without-intervention farmers

Item	With-intervention farmers	Without-intervention farmers	Difference
	***Kharif*-2009**		
Mean	0.725 (0.213)	0.600 (0.234)	0.125***
Minimum	0.288	0.161	-
Maximum	0.971	1.00	-
	***Rabi*-2010**		
Mean	0.806 (0.138)	0.640 (0.213)	0.166***
Minimum	0.122	0.294	-
Maximum	0.968	0.975	-

Notes: *** denotes statistical significance at 1 per cent level
Values given within parentheses are standard errors.

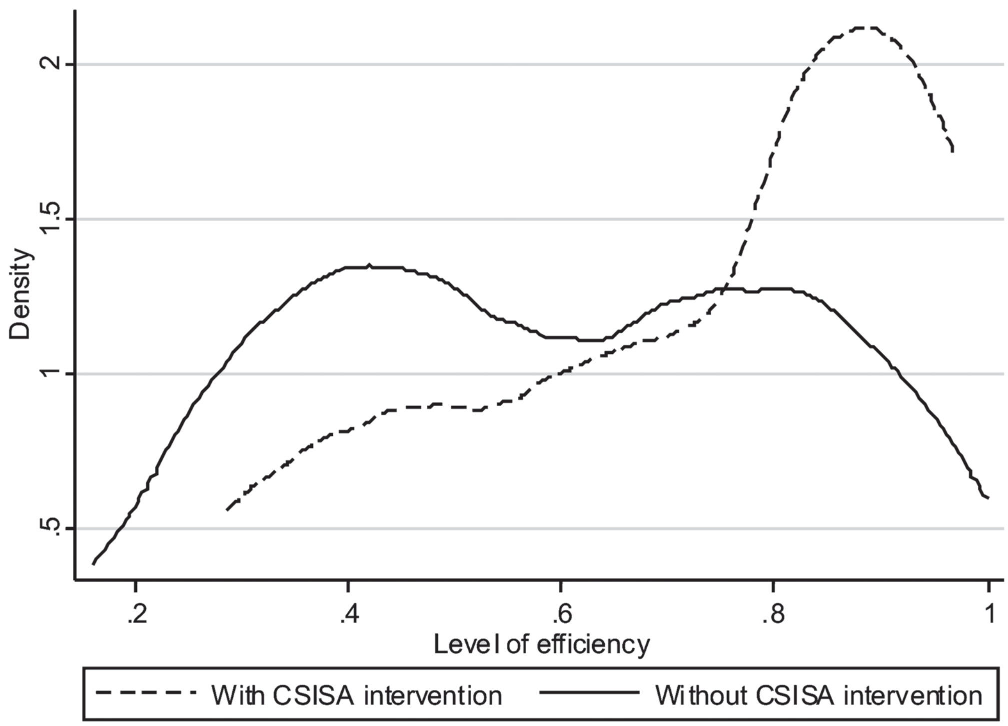

Figure 2. Distribution of technical efficiency level of rice farmers in *kharif*-2009

of with-intervention rice farmers indicated that they could improve their efficiency by 27.5 per cent. The percentage of farmers receiving intervention who had levels of technical efficiency higher than the mean value was 56 per cent. The mean value of technical efficiency for without-intervention rice farmers was 60 per cent and it ranged between 16 per cent and 100 per cent efficiency levels. This result shows that the without-intervention farmers could improve their efficiency by about 40 per cent. Only 46 per cent of without-intervention farmers had levels of technical efficiency higher than the mean level. This implies that, in general, farmers receiving intervention were more technically efficient than those not receiving intervention.

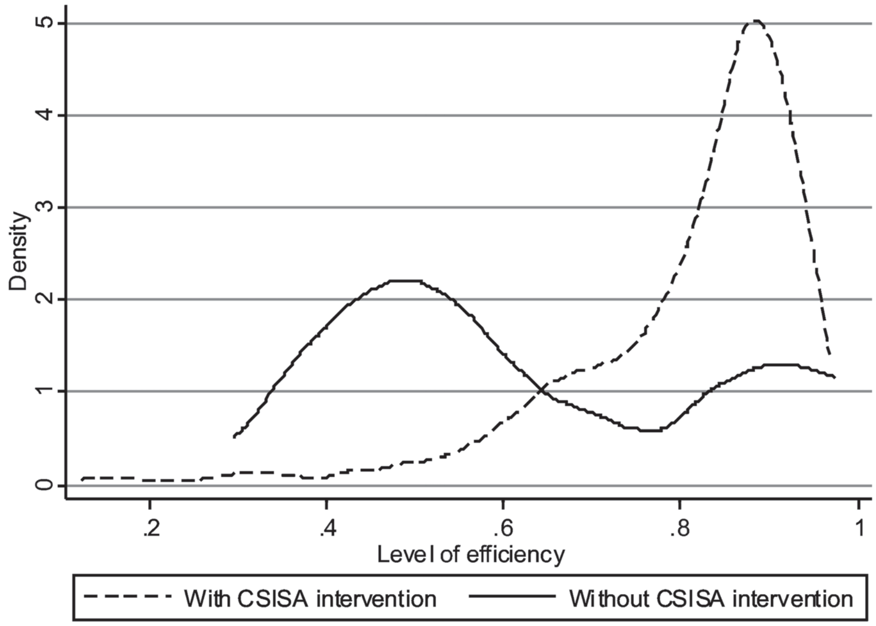

Figure 3. Distribution of technical efficiency level of wheat farmers in *rabi*-2010

The distribution of technical efficiency of with-intervention wheat farmers during *rabi*-2009, depicted in Figure 3, revealed that farmers receiving intervention had a mean value of 80.6 per cent which ranged from 12.2 per cent to 96.8 per cent level of technical efficiency. With-intervention wheat farmers could improve their level of technical efficiency by 19.4 per cent. Almost two-thirds, 62 per cent, of with-intervention wheat farmers had technical efficiency levels that were higher than the mean value. Farmers not receiving intervention were found to have lower levels of technical efficiency than farmers receiving intervention. Only 39 per cent of without-intervention farmers had a level of technical efficiency higher than the mean value. This result shows that without-intervention farmers could improve their technical efficiency in wheat production activities by 36 per cent.

Conclusions

The role of seed subsidies in technical efficiency has been revealed in this study. All farmers who received subsidies have been found to be more technically efficient than those who did not. Potentially, this impact could be related not only to the subsidy alone, but technical efficiency may also be attributed to the varieties of seeds that the farmers receive through intervention. Also, farmers do not receive subsidies through only the CSISA project, but also from other sources.

Rice-wheat cropping systems have been found to be less technically efficient than a more diversified cropping system. This is a potential concern for this region because the agriculture systems are cereal-intensive. It was only in with-intervention wheat farmers that rice-wheat cropping has been found to be more technically efficient. Wheat productivity is expected to increase as a result of the use of CSISA-promoted resource-conserving technologies. As reported by Aslam *et al*. (1993), ZT-wheat after ZT-rice gives equal or improved yields compared to when wheat is planted after conventional tillage rice. Also, based on field experiments, Hobbs *et al.* (2002) have reaffirmed that ZT-wheat, following unpuddled soil is cost-effective, conserves resources and does not reduce yields. The results in technical efficiency have indicated that improvements for the wheat season are already being realised by the farmers receiving CSISA-intervention.

The CSISA project, and ultimately the Indian government, should provide seed subsidies to more farmers to achieve gains in technical efficiency. Gains in technical efficiency could also be obtained by the project if diversified cropping systems were promoted.

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