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Technical Efficiency in Organic and Conventional Wheat Farms: Evidence from a Primary Survey from Two Districts of Ganga River Basin, India

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Abstract— This paper analyses the technical efficiency of wheat farms operating under organic and conventional farming systems. The study is based on a primary survey of 579 farms (294 organic and 285 conventional) conducted in 2021 in two districts located in the Middle Ganga River Basin, India. Technical, managerial, and scale efficiencies of individual farms are estimated by applying Data Envelopment Analysis (DEA). The per hectare value of wheat production is taken as an output variable, and values of seeds, human labour, machine cost, plant nutrients, farm yard manure (FYM), plant protection, and irrigation charges are considered input variables for estimating the farm-level efficiencies. The post-DEA analysis is conducted using the Tobit regression to determine the efficiency factors. The results show that technical efficiency is significantly higher in conventional than organic farming systems due to a higher gap in scale efficiency than managerial efficiency. Further, 9.8% of conventional and only 1.0% of organic farms operate at the Most Productive Scale Size (MPSS), and 99% of organic and 81% of conventional farms at IRS. Organic farms perform well in managerial efficiency, but their technical efficiency is lower than conventional farms, mainly due to their relatively lower scale size. The paper suggests that technical efficiency in organic wheat farms can be increased by upscaling the farm size by incentivizing group/collective farming in clusters.

Keywords— Organic, Conventional, Technical Efficiency, Determinants, DEA, Tobit regression

I. INTRODUCTION

Agriculture is a highly polluting activity responsible for 25-33% of greenhouse gas emissions (Steinfeld, 2006). The conventional way of farming is believed to be responsible for the degradation of soil quality and has adverse environmental effects. One of the ways to reduce its negative externalities is organic farming, as it is believed to be beneficial to the environment (Aldanondo-Ochoa & Almansa-Sáez, 2009; Tuomisto et al., 2012). It was the 1930s and 1940s which saw the beginning of the organic movement, which started as an initiative to reduce the use of chemicals in agriculture (Poudel et al., 2015). Organic farming enables the agroecosystem to have rich biodiversity owing to the decomposition of crop residuals, use of bio-fertilizers, and lower use of nutrients (Hansen et al., 2001).

With all the potential benefits of organic farming, government policies in India are also encouraging organic farming. Comparing conventional and organic farming systems is necessary to understand the costs and benefits of switching to organic farming. Measuring efficiency is crucial to determine the profits that can be attained by improving the agricultural process with the given level of technology (Laha & Kuri, 2011). Comparison of organic and conventional farming systems with respect to efficiency has become a research interest in recent years (Madau, 2007).

Wheat is one of the major food crops in India. It is the second most important crop and is essential for food and nutritional security (Kumar et al., 2014). Along with being a staple food in the northern region of India, it is highly valuable for the country too. India has exported 7,239,366.80 MT of wheat with a value of Rs. 15, 840.31 crores (2,121.72 USD million) in 2021-22 (Government of India, 2022). Hence, it is an important crop from a trade and consumption standpoint. This paper focuses on the technical efficiency of wheat in the middle Ganga river basin and compares the efficiency levels under organic and conventional farming. It also studies the socio-economic factors that might impact its technical efficiency. This analysis will help understand wheat's agricultural performance using the data from the North Indian region and help identify the determining factors of its technical efficiency.

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II. REVIEW OF LITERATURE

Production efficiency is believed to be first discussed by Koopmans (1951) and Shephard (1953). Technical efficiency is said to be 100 percent when there is no possibility of a higher production level unless the production of some other output is reduced or the input in the production process is improved (Koopmans, 1951). The assessment of efficiency began with M.J. Farrell and was continued by Koopmans. Currently, the measures used to assess technical efficiency are parametric or nonparametric. The stochastic frontier approach (parametric) is one of the widely used measures for technical efficiency, which is a contribution by Aigner et al., 1977 and Meeusen & Broeck, 1977. Data Envelopment Analysis (DEA) is another approach (nonparametric) for measuring technical efficiency. Several researchers have conducted technical efficiency analysis using either of these methods (Alemdar & Necat Ören, 2006; Djokoto et al., 2017; Ghaderzadeh & Rahimi, 2008; Madau, 2007; Mirza et al., 2015).

A comparison between technical efficiency under organic farming (OF) and conventional farming (CF) can be made to understand the relative ability of the farmer to make the best possible use of the resources at his/her disposal (Madau, 2007). Researchers have compared technical efficiency between OF and CF and have found different results. Several studies find CF technically more efficient than OF (Charyulu & Biswas, 2010; Djokoto et al., 2017; Kargiannis et al., 2012; Kumbhakar et al., 2009; Larsen & Foster, 2005; Madau, 2007; Wibowo et al., 2019). On the other hand, some literature shows that OF has a higher technical efficiency than CF (Arandia & Aldanondo-Ochoa, 2008; Poudel et al., 2015; Raimondo et al., 2021; Songsrirote & Singhapreecha, 2007; Tzouvelekas et al., 2002). Lower levels of profit in organic farming have been stated as one of the possible reasons for higher technical efficiency in organic farming, as it might have forced the farmer to use the inputs optimally (Tzouvelekas et al., 2002). A low level of scale efficiency (SE) in OF was found responsible for its low technical efficiency (Kargiannis et al., 2012). Wibowo et al. (2019) attribute the low technical efficiency of OF to the low crop yield. The use of a restricted technology by organic farmers has also been found as a possible reason for low technical efficiency in OF (Larsen & Foster, 2005).

Determining factors of technical efficiency have been studied, and various socio-economic factors have been found to affect technical efficiency. Access to credit, household size, and farming experience tend to positively impact the technical efficiency of OF (Poudel et al., 2015). The size of the farms, farmer's education, and capital were also found to positively affect the technical efficiency of OF(Tzouvelekas et al., 2002). Education, location, farm management, agricultural training, and management characteristics have been deduced to be the factors that affect technical efficiency in OF. In contrast, knowledge about agriculture, agricultural training, management characteristics, and location are found to impact technical efficiency in CF (Songsrirote & Singhapreecha, 2007).

Wheat is one of the major cereal crops in the world. Its world trade is bigger than all other crops (Government of India, 2022). Numerous studies have been conducted to assess the technical efficiency of wheat cultivation. In some studies, technical efficiency for wheat cultivation is observed to be low (Al-Feel & AL-Basheer, 2012; Chebil et al., 2016; Croppenstedt, 2005). A panel data analysis to estimate the technical efficiency of wheat farms in Northern India found that the average technical efficiency has been reducing through the years (Goyal & Suhag, 2003). Some techniques like scheduling irrigation water, sowing, timely harvesting, and applying fertilizer have been found to improve technical efficiency (Chebil et al., 2016). Land preparation, timely irrigation, and using improved varieties of wheat seed also improve the technical efficiency of wheat cultivation (Mirza et al., 2015).

Existing literature focuses on the estimation of technical efficiency and its determinants. However, there is a research gap when it comes to the comparison of technical efficiency between OF and CF, particularly for wheat cultivation in the Ganga river basin. This study intends to fill this gap and contributes to the existing literature by estimating technical efficiency for wheat cultivation under OF and CF systems and analyzing the determining factors for the same.

III. DATA & METHODOLOGY

A. *DATA*

To measure the technical efficiency and its determinants in wheat cultivation, a survey was conducted for primary data collection. The study area for the research included two districts, Haridwar from Uttarakhand and Bulandshahr from Uttar Pradesh. Primary data was collected from July 2021 to August 2021 using a pre-tested questionnaire. Two blocks from Haridwar district (Laksar and Narsan) and Bulandshahr district (Dibai and Siyana) were selected randomly for the survey. Following this, five villages were selected from each development block, i.e., 20 villages were selected. Therefore, 30 farmers from each village were selected as the respondents, among which half were organic, and half were conventional. Since all farmers were not found growing wheat in our sample households, the sample size was reduced from 600 to 579 wheat farmers (294 organic farms and 285 conventional farms).

B. *METHODOLOGY*

B 1. DATA ENVELOPMENT ANALYSIS

DEA methodology is applied to measure the technical efficiency in wheat cultivation under OF and CF systems. DEA can consider multiple outputs and inputs without assumptions in data distribution, making it an ideal choice for efficiency measurement in case of multiple inputs and outputs. The following output and input variables are taken to measure technical, managerial, and scale efficiencies under OF and CF systems.

Output variable: The main output and its by-product

Input Variables

1. Seeds: The values of farm-grown seeds and purchased seeds are included in this variable. The value of the farm-grown seeds has been imputed, and the market value of the purchased seeds is used.
2. Human Labour: The value of hired labour using the prevailing wage rate and the imputed value of family labour based on the wage rate are included in this variable.
3. Machine Cost: This variable includes the imputed cost of owned machinery and the cost of the hired machinery.
4. Cost of Plant Nutrients: The value of the chemical fertilizers in the case of conventional farming and the value of the bio-fertilizers in the case of organic farming is included in this variable.
5. Value of FYM and Vermicompost: The value of farmyard manure and vermicompost is included using this variable.
6. Plant Protection Cost: In the case of conventional farming, the value of chemical pesticides is included, and in the case of organic farming, the value of bio-insecticides and bio-pesticides is included.
7. Irrigation charges: These include the cost of irrigation using owned or hired facilities.

Rupees per hectare is the unit used for all variables.

B2. TOBIT MODEL

The factors affecting the efficiency have been studied using the Tobit model as it is a censored regression model and is appropriate for the data used in this study.

Standard Tobit Model is given as:

$y^* = x_i \beta + \varepsilon_i$, where y is the dependent variable and i= 1,2,3,4,5,....N and ε_i is the error term

$y = y^*$ if $y^*>0$

$y = 0$ if $y^* \leq 0$

Here, the error term is assumed to be NID $(0, \sigma^2)$ and independent of the independent variables.

Description of Variables

The following table elaborates on the variables used for Tobit regression. The values for the dependent variables (efficiency scores) range have an upper limit (one) and a lower limit (zero).

Variables	Description	Hypothesized Sign
Farming practices	conventional=0, organic=1	+ve
Region	Haridwar = 0, Bulandshahr = 1	+ve
Gender	Female=0, male =1	+ve
Farming experience	In years	+ve
Education	Illiterate = 0, Primary = 1, Middle =2, Metric = 3, Inter = 4, Higher = 5	+ve
Farm size	In hectares	+ve
KCC	If a farmer has KCC (Yes = 1, No =0)	+ve
Smartphone	If a farmer has Smartphone (Yes = 1, No =0)	+ve
Membership	If a farmer is a member of any organization (Yes = 1, No =0)	+ve
Soil testing	If soil testing done (Yes = 1, No =0)	+ve
Dist. from the market	In km	-ve
Dist. from KVK	In km.	-ve

IV. RESULTS & DISCUSSION

IV.1 Descriptive Statistics

Table 2 presents the values of inputs and output in wheat cultivation. The mean value of production (VOP) under wheat cultivation is Rs. 105501 per ha, with a standard deviation of Rs. 13153. A high standard deviation (SD) for the VOP shows a variance in production value across all the farms. The input variables also have a high SD which also points towards the variation in seeds, labour, machine cost, fertilizer, pesticide, and irrigation across farms. The labour cost has the maximum share in the input cost, followed by machine cost, irrigation cost, fertilizers, seeds, and pesticides.

Table 2: Summary Statistics for Inputs and Output Variables (Wheat)

Statistics	*Seed*	*Lab*	*Machine*	*FER*	*PEST*	*IRR*	*VOP*
Mean	4766	17676	7662	5110	355	5383	105501
Median	4615	17820	6200	4894	360	3500	106440
SD	688	1017	2924	1348	88	3981	13153
Min	3000	15255	3200	1515	150	0	78200
Max	6560	19935	14000	7641	758	17000	131892
Count	579	579	579	579	579	579	579

Source: Author's estimation

IV.2 Technical Efficiency

If all the available inputs are used in a production process, and the maximum possible output is produced, it can be said that the process is technically efficient. The technical efficiency of a process can be enhanced by reducing the gap between the maximum possible output and actual output (Shenggen, 2000). The efficiency scores, overall technical efficiency (OTE), pure technical efficiency (PTE), and scale efficiency (SE) for OF and CF systems in wheat cultivation are presented in Table 3, which shows that wheat farmers, who practice CF have better OTE, PTE and SE than their OF counterparts. OTE under OF is 0.736, while that of CF is 0.898. If an average conventional farmer reduces the inputs by 10.2%, the production process can be technically efficient, while for the organic farmer, the inputs have to be reduced by 26.4%.

Table 3: OTE, PTE, and SE Scores under OF and CF Systems in wheat cultivation

Efficiency Score	Wheat	
	OF	CF
OTE	0.736	0.898
PTE	0.901	0.956
SE	0.817	0.940

Source: Author's estimation from the field survey data

The OTE is lower for OF because of low SE. The efficiency scores for wheat show that the scale inefficiency of 18.3% is higher than the managerial inefficiency (9.9%) for organic farmers. Similarly, under CF, the scale inefficiency is higher at 6% than managerial inefficiency at 4.4%. As scale inefficiencies have a bigger role in the lower levels of OTE, it would help to devote more land to wheat cultivation and improve scale efficiency.

Table 4: Crop-wise Number of Farms with 100 percent OTE, PTE, and SE under OF and CF Systems

Efficiency	Number of Farms with 100% efficiency scores		
	OF	CF	Total
OTE	3 (1.0)	28 (9.8)	31 (5.4)
PTE	16 (5.4)	59 (20.7)	75 (13)
SE	3 (1.0)	34 (11.9)	37 (6.4)
No. of Sample Farms	294	285	579

Note: Figures in the parenthesis show the percentage of farms with 100% efficiency scores

Table 4 shows the number of farms with efficiency scores equal to one operating at the most productive scale sizes (MPSS). Under the CRS assumption, 28 conventional farms, which make up 9.8% of the total conventional farms, operate at MPSS. In contrast, only three organic farms operate at MPSS, which make up only 1% of the total organic farms. In the case of PTE and SE, a higher percentage of conventional farms are efficient. This analysis finds that practicing conventional farming enables more farms to achieve scale and pure technical efficiency; therefore, 100% OTE is achieved by more conventional farmers than organic farmers.

IV.2.1 Efficiency Analysis by Farm Size

With the majority of the landholdings in India being small and marginal, it is often debated whether the farm size affects agricultural performance or not. Continuing the analysis in our study area, we study the efficiency scores for different sizes of farms under organic and conventional farming systems. Similar to the figures for the country, farm sizes in the study area were also found to be mostly small and marginal, making it difficult for the farmers to avail the benefits of economies of scale.

The smaller farms under organic farming in wheat cultivation seem more efficient than the medium and large ones as they have a higher average OTE score. On the other hand, PTE and SE scores do not behave in a similar way across farm sizes. The managerial efficiency (PTE) is more or less the same for various farm sizes. Small and marginal farms have a better OTE score than medium and large farms for conventional farmers. As the same pattern is seen in organic farms, it can be said that an inverse relationship is seen between farm size and overall technical efficiency. Conventional farmers face a similar PTE across farm sizes, and in the case of SE, no specific pattern can be seen across farm sizes. Still, the lowest SE score is under large farms, which means that farmers are unable to tap into the economies of scale even after having large farm sizes.

Table 6: Technical and Scale Efficiencies by Farm Size under OF and CF Systems

Land Holding	Efficiency	Wheat	
		OF	CF
Marginal(<1)	OTE	0.751	0.902
	PTE	0.905	0.956
	SE	0.828	0.943
Small (1-2)	OTE	0.733	0.891
	PTE	0.902	0.957
	SE	0.812	0.931
Medium (2-4)	OTE	0.713	0.894
	PTE	0.890	0.945
	SE	0.800	0.945
Large (>4)	OTE	0.709	0.836
	PTE	0.893	0.913
	SE	0.794	0.916

IV.2.2 Returns to Scale

A farm operating at increasing returns to scale (IRS) implies that a better OTE can be achieved by increasing the farm size. Efficiency can be improved by decreasing the farm size if the farm is operating at decreasing returns to scale. As most of the farms under OF and CF were found to be operating at increasing returns to scale (IRS), we can say that if the size of farms under cultivation is increased, there would be an improvement in the level of technical efficiency in around 90% of the total farms. About 99% of the organic farms operate at IRS, which is higher than the percentage of CF at IRS, implying that lower levels of efficiency in OF are because of small farm sizes.

Table 7: Classification of Farms by Returns to Scale under OF and CF Systems

Returns to Scale	OF	Non-OF	Total farms
IRS	291 (99.0)	231 (81.1)	522 (90.2)
DRS	0 (0)	26 (9.1)	26 (4.5)
CRS	3 (1.0)	28 (9.8)	31 (5.1)

Note: Figures in Parentheses are a percentage of the respective total.

None of the organic farms operate at decreasing returns to scale, which means that bigger land sizes are not a problem in organic farming, although 9.1% of conventional farms can improve their technical efficiency by reducing the farm size. The SE of organic farms can be concluded to be lower owing to the smaller farms.

IV.3 Factors Affecting the Technical Efficiency of Wheat

Technical efficiency in wheat cultivation under OF and CF systems has been analyzed. This section will assess the impact of various socio-economic factors on technical efficiency in wheat cultivation. The Tobit regression model is used to study how factors like farming experience and education of the farmers affect technical efficiency. This model is well-suited for censored data. As the efficiency scores are censored, we use Tobit regression for this study. Table 8 shows the results of the Tobit regression. Dependent variables for this analysis are the efficiency scores, viz., OTE, PTE, and SE. Independent variables are given in the first column of the table. The coefficient of each independent variable depicts its impact on the dependent variables, and the sign of the coefficient indicates whether the impact is negative or positive.

The variable 'farming practices' shows whether the farmer practices organic or conventional farming. The negative coefficient for the variable shows that practicing organic farming negatively impacts technical efficiency. If organic farming is practiced, OTE decreases by 0.138, PTE decreases by 0.0543, and SE decreases by 0.1007. The region from which the farmer belongs also has a significant impact on technical efficiency. However, it is quite small. If the farmer belongs to Bulandshahr (Uttar Pradesh), efficiency scores would be higher than those of the farmer from Haridwar (Uttarakhand). The gender of the farmer does not seem to significantly impact the efficiency scores; similarly, farming experience and education also have no significant impact on OTE, PTE, and SE.

Table 8: Tobit Regression Coefficients for OTE, PTE, and SE of Wheat Farms

Dependent variable = Efficiency score (OTE, PTE, SE)

	OTE		PTE		SE	
Predictor (s)	Coefficients	Std. Error	Coefficients	Std. Error	Coefficients	Std. Error
Farming practices	-0.1389*	0.0121	-0.0543*	0.0070	-0.1007*	0.010
Region	0.0511*	0.0098	0.0185*	0.0057	0.0394*	0.008
Gender	0.0080	0.0153	0.0104	0.0089	0.0014	0.0126
Experience	-0.0003	0.0003	-0.0002	0.0001	-0.0002	0.0003
Education						
Primary	-0.0032	0.0148	-0.0054	0.0085	-0.0003	0.0121
Middle	0.0109	0.1190	-0.0005	0.0069	0.0109	0.0098
Metric	0.0052	0.0122	-0.0054	0.0071	0.0097	0.0101
Inter	0.0123	0.0123	0.0001	0.0071	0.0123	0.0102
Higher	0.0010	0.0150	-0.0048	0.0087	0.0039	0.0124
Farm size	-0.0042	0.0037	-0.0035*	0.0021	-0.0013	0.0031
KCC	-0.0169**	0.0069	-0.0064	0.0039	-0.0135**	0.0057
Smart-phone	-0.0047	0.0079	-0.0011	0.0045	-0.0046	0.0065
Dist. KVK	-0.0009*	0.0003	-0.0010*	0.0002	-0.0001	0.0003
Dist. market	-0.0014*	0.0004	-0.0016*	0.0003	0.0002	0.0003
Membership	-0.0118	0.0111	0.0014	0.0065	-0.0148	0.0092
Soil testing	-0.0098	0.0089	0.009***	0.005	-0.0185**	0.0073
Constant	0.9097*	0.0223	0.9772*	0.0131	0.9378*	0.0185
Log-likelihood	588.75		778.57		698.82	
Chi^2	462.15		254.73		423.65	
No. of farms	579		579		579	

Note: *. ** and *** indicate significance at 1%, 5%, and 10% significance levels, respectively.

Source: Authors' estimation from field survey data

The farm size was found to have a negative and significant impact on the PTE score and not on the OTE and SE score, implying that managerial efficiency decreases with the farm size. Possession of a Kisan (farmer) Credit Card (KCC) reduces the OTE score by 0.0169 and SE by 0.0135 but did not significantly impact PTE. Possession of a smartphone and membership in a community-based organization had no significant impact on the technical efficiency of wheat cultivation. Distance to the KVK (Agriculture Science Centre) and the market has a statistically significant negative impact on the OTE and PTE score but did not significantly impact the scale efficiency. The results imply that technical and managerial efficiencies in wheat farms are inversely related to the district of farms from the market and agricultural science centres (KVKs).

V. CONCLUSION & POLICY IMPLICATION

DEA reveals that farmers practicing CF have a higher level of technical efficiency than OF. It does not imply that organic farming is not technically efficient, as the efficiency scores for OF are good but not better than CF. A higher number and higher percentage of conventional farms are found to be operating at the MPSS. However, the total percentage of farms that lie at the CRS technology frontier is not high, which implies that there is still a need to improve technical efficiency across all the farms under wheat cultivation. Efficiency analysis by the farm size shows that the lower levels of OTE in OF are mainly due to low SE. Low-scale efficiency can be attributed to the small farm sizes under OF.

Tobit regression reveals that the gender of the farmer, farming experience, education, possession of a smartphone, and membership in a community-based organization had no significant impact on the efficiency scores for wheat cultivation. Practicing organic farming is found to have a negative impact on technical efficiency, which aligns with the results of the technical efficiency analysis of this study. If the farmer belongs to Bulandshahr in Uttar Pradesh, the technical efficiency is higher than if the farmer belongs to Haridwar in Uttarakhand. Farm size affects managerial efficiency negatively. Holding a KCC also has a significant negative impact on OTE and SE scores. Farm distances from KVK and the market negatively impact the OTE and PTE but do not impact the SE.

Lower SE calls for a policy intervention for the farm size. If farms are consolidated and the size of the farms is increased, technical efficiency is likely to improve. As most of the farms operate at IRS, better technical efficiency can be achieved by increasing the farm sizes. Group farming can be encouraged as it can help the farmers in realizing economies of scale. Organic farmers would benefit more from group farming as the low SE scores for OF have a major role in low OTE for OF. More land should be brought under organic farming in clusters to improve scale efficiency. The field survey reveals that organic farmers have devoted only a part of their total land to OF and are still practicing CF on some parts of their land. If government policies enable the farmers to convert their whole land to OF and increase farm sizes via clustering, it can improve technical efficiency in OF.

As community-based organizations are supposed to help the farmers improve their agricultural efficiency, it needs to be explored why these CBOs do not significantly impact technical efficiency. Soil testing significantly impacts PTE, which implies that the managerial efficiency of wheat farms can be improved by encouraging farmers to get their soil tested and use the recommended doses of plant nutrients to reduce costs and conserve resources.

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