International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 7s, 2025
https://www.theaspd.com/ijes.phpa

# Technical Efficiency in Wheat Cultivation: An Analytical Study of the Transcendental Production Function and Performance Variations Between Fixed and Pivot Irrigation Systems

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***Abstract***
*This study examines the technical efficiency of wheat production using Stochastic Frontier Analysis (SFA) and the transcendental production function to evaluate the effectiveness of various agricultural inputs, such as land area, pesticide and fertilizer usage, human and mechanical work hours, water, and seed quantities on productivity. It also explores the role of managerial factors, such as family size, education level, agricultural experience, and farmer age, in explaining technical inefficiency. The analysis compares fixed and pivot irrigation systems, revealing that fixed irrigation enhances production with the expansion of cultivated land, while pivot irrigation faces obstacles due to timing mismatches with climatic conditions. Furthermore, the study demonstrates that rational use of mechanical labor, water, and seed quantities significantly improves productivity. Conversely, misuse of pesticides and fertilizers can have adverse effects on soil and crops, necessitating advisory interventions. The findings highlight the need for improved agricultural resource management by adopting educational and awareness strategies to enhance farmers' efficiency. Innovative agricultural practices focusing on optimal input utilization are recommended. The study advocates for organizing planting schedules, investing in agricultural mechanization, regulating the use of agricultural chemicals, and strengthening farmers' managerial capacities to boost productivity and minimize the gap between actual and optimal frontier production.*
***Keywords:*** *Transcendental Production Function , Technical Efficiency, Wheat Farmers*
*Adapted from the first researcher's doctoral thesis*

## INTRODUCTION

Wheat cultivation, as one of the pillars of food security, faces significant challenges in achieving productive efficiency amidst growing demand and fluctuating natural resources. This research aims to explore production mechanisms through the application of the transcendental production function model, utilizing stochastic frontier analysis (SFA) statistical techniques.(Ahmed, 2021: 559-578). The study focuses on evaluating the impact of key inputs such as cultivated land area, pesticide usage, human and mechanical labor hours, added water quantities, seeds, and fertilizers on wheat production. It also addresses inefficiency factors stemming from managerial variables like family size, educational level, supplementary irrigation experience, farmer age, and wheat farming expertise. The research emphasizes the importance of utilizing specialized software (e.g., Frontier 4.1) to estimate nonlinear models and analyze the disparities between actual and optimal production outcomes. This allows researchers and farmers to identify the factors hindering optimal performance. Additionally, the study sheds light on potential differences between fixed and pivot irrigation systems, providing deeper insights into how technologies and management practices influence technical efficiency and productivity. the research contributes practical recommendations aimed at improving resource utilization and minimizing waste, thereby enhancing farm competitiveness in a dynamic agricultural environment. Through this introduction, we advocate for a reassessment of agricultural management policies and the adoption of innovative solutions based on precise data analysis and modern economic models, ultimately boosting production efficiency and enhancing long-term agricultural sustainability (Lee, C. & Zhang, Y., 2023:87-105) . research Problem: The research problem lies in identifying and understanding the factors that prevent achieving optimal productive efficiency in wheat cultivation, highlighting the differences arising from the use of different irrigation systems. The core question here is: How can agricultural resources be utilized to their maximum potential, and how can technical and managerial operations be optimized to reduce the gap between actual and frontier production? research Aim The primary aim of this research is to analyze and evaluate productive efficiency in wheat cultivation using the transcendental production function model and stochastic frontier analysis (SFA). This approach seeks to uncover the technical and managerial factors influencing optimal production from the available resources. The study examines the impact of various production inputs—such as land area, pesticides, human and mechanical labor hours, water, seeds, and fertilizers—while considering the influence of managerial inefficiency variables (e.g., family size, education level, and experience) on production performance. Additionally, it aims to shed light on the differences between fixed and pivot irrigation systems and develop practical recommendations to enhance resource management, reduce waste, and bridge the gap between actual and optimal production levels, thereby boosting efficiency and productivity in the agricultural sector. research Hypothesis: Improving the utilization of agricultural resources—such as land area, pesticides, mechanical and human labor hours, water, seeds, and fertilizers—alongside strengthening managerial aspects (e.g., family size, education level, and agricultural experience) is expected to increase wheat production and narrow the gap between actual and optimal production. Notable differences in this relationship are anticipated between fixed and pivot irrigation systems(Martins, 2022:332-349).

**Results from the Transcendental Logarithmic Production Function TL Based on Stochastic Frontier Analysis SFA:**

The model was specified using stochastic frontier analysis (SFA), with the dependent variable being wheat production quantity and the independent variables including land area, pesticide quantity, human labor hours, mechanical labor hours, added water quantity, seed quantity, and fertilizer quantity. Inefficiency variables were represented by managerial factors, which encompassed family size, educational level, supplementary irrigation experience, farmer age, and farming experience. The Frontier 4.1 software and Maximum Likelihood (ML) method were employed to estimate the model since the Ordinary Least Squares (OLS) method cannot be applied to nonlinear regression models. However, OLS was utilized as an initial step to provide the best unbiased linear estimates of parameters, except for the intercept B0. Then, the Corrected Ordinary Least Squares (COLS) method was used as a second step to obtain unbiased linear parameters, followed by the ML method in the third step to achieve maximum likelihood estimates of the production function's parameters. The results of the Transcendental Logarithmic Production Function (TL) based on the ML method and the inefficiency model using stochastic frontier analysis (SFA) are presented in (Brown, S. & Smith, R.,2022:145-164) Table (1).

Table (1): Results of the Transcendental Logarithmic (TL) Production Function and the Inefficiency Model for Fixed Irrigation

| Parameter | Cof. | st. | t-r. |
|---|---|---|---|
| Beta0 | -4.511 | 2.669 | -1.689** |

| | | | |
|---|---|---|---|
| Beta1 | 1.0514 | 0.3111 | 3.379*** |
| Beta2 | -0.048 | 0.0315 | -1.545* |
| Beta3 | -2.774 | 1.011 | -2.741*** |
| Beta4 | 2.436 | 0.920 | 2.646*** |
| Beta5 | 0.758 | 0.273 | 2.773*** |
| Beta6 | 3.857 | 1.462 | 2.637*** |
| Beta7 | -1.732 | 0.898 | -1.927** |
| TE EFFECTS MODEL(inefficiency) | | | |
| Delta0 | -4.942 | 1.660 | -2.977*** |
| Delta1 | -0.092 | 0.036 | -2.542*** |
| Delta2 | -0.393 | 0.097 | -4.014*** |
| Delta3 | -0.070 | 0.022 | -3.113*** |
| Delta4 | 0.101 | 0.025 | 4.005*** |
| Delta5 | -0.050 | 0.013 | -3.852*** |
| sigma-squared | 1.480 | 0.362 | 4.088*** |
| Gamma | 0.973 | 0.0097 | 99.863*** |
| log likelihood function | -120.138 | | |

**Source:** Researcher's own work using Frontier 4.1

*Significant at the 10% level, ** Significant at the 5% level ,*** Significant at the 1% level

**Translation of the Interpretation of Fixed Irrigation Results:**

**1.Area (X1):**

The elasticity value for this variable reveals a positive relationship between the cultivated area and wheat yield. This indicates that a 1% increase in the area cultivated with wheat results in a 1.0514% increase in production. This aligns with the expectations and concepts of economic theory. Area is the most influential variable affecting yield, given its importance in increasing production, particularly in supplemental irrigation. Notably, fixed sprinkler irrigation requires large areas.

**2. Pesticide Quantity (X2):**

The sign of this variable was negative, with an elasticity value of -0.048%. However, its impact was minor, likely due to farmers' lack of knowledge about pesticide usage methods and the mismatch between pesticides and disease symptoms, which could lead to soil degradation and crop damage. Additionally, pesticides are often used in non-scientific and unsystematic ways, potentially causing pest resistance. A lack of agricultural guidance and advisory services has negatively affected this resource's utilization. Farmers aim to purchase larger quantities of pesticides based on field control needs. However, high market prices and farmers' limited understanding of diseases affecting their crops and their treatment mechanisms hinder optimal use.

**3. Human Labor Hours (X3):**

The elasticity value for human labor hours is -2.774, indicating a negative relationship between human labor and wheat production. This points to two key factors: First, limited job opportunities in rural areas drive farmers to migrate to cities where industrial, commercial, and service sector jobs are available.

Second, wheat production heavily relies on mechanized labor, which reduces the contribution of human labor. A 1% increase in human labor hours would result in a 2.774% decrease in wheat production.

**4. Mechanical Labor Hours (X4):**
The elasticity value for mechanical labor hours is 2.436, demonstrating a significant positive impact on wheat production. This result aligns with economic theory, indicating that a 1% increase in mechanical labor would result in a 2.436% increase in production. The effect of mechanized labor is evident, as wheat production depends significantly on mechanical operations.

**5. Added Water Quantity (X5):**
The variable shows a positive relationship with wheat yield, as indicated by the positive elasticity value. This means that increasing the amount of irrigation water given to wheat crops by 1% leads to a 0.758% increase in production. This reflects both the impact of water quantity on wheat yield and the importance of supplemental irrigation.

**6. Seed Quantity (X6):**
The elasticity of this variable is positive and aligns with economic theory, confirming the positive effect of seed quantity on production. A 1% increase in seed use leads to a 3.857% increase in wheat production. This indicates that the amount of seeds used by farmers significantly contributes to increasing wheat yields.

**7. Fertilizer Quantity (X7):**
The elasticity value for fertilizers (-1.732) contrasts with economic logic, indicating a negative relationship between fertilizer usage and yield. A 1% increase in fertilizer use results in a 1.732% reduction in yield. This is attributed to excessive fertilizer use, which can increase soil salinity and reduce beneficial microorganisms, ultimately lowering wheat productivity. As for the significance of the variables, although statistical significance is not crucial for models estimated using the ML method (as the parameters are efficient and consistent within error bounds Ui and small sample sizes relative to population estimates (Thompson, J. & Patel, R.,2021:106-118), the variables of cultivated area, human labor hours, mechanical labor hours, added water quantities, seed quantities, and fertilizer quantities were significant at the 1% level, while pesticide quantity was significant at the 10% level.

Table (2): Results of the Transcendental Logarithmic (TL) Production Function and the Inefficiency Model for Pivot Irrigation

| Parameter | Cof. | st. | t-r. |
|---|---|---|---|
| Beta0 | -7.33 | 2.820 | -2.601*** |
| Beta1 | -3.512 | 1.794 | -1.957** |
| Beta2 | -0.131 | 0.025 | -5.175*** |
| Beta3 | 0.049 | 0.786 | 0.062 |
| Beta4 | 4.450 | 1.309 | 3.398*** |
| Beta5 | 1.535 | 0.343 | 4.464*** |
| Beta6 | 3.594 | 1.078 | 3.333*** |

| | | | |
|---|---|---|---|
| Beta7 | -1.414 | 0.954 | -1.481* |
| TE EFFECTS MODEL(inefficiency) | | | |
| Delta0 | -7.794 | 4.673 | -1.667** |
| Delta1 | -0.0087 | 0.038 | -0.224 |
| Delta2 | -1.233 | 0.812 | -1.519* |
| Delta3 | -0.088 | 0.054 | -1.641** |
| Delta4 | 0.106 | 0.057 | 1.863** |
| Delta5 | 0.073 | 0.046 | 1.572* |
| sigma-squared | 1.752 | 1.067 | 1.642** |
| Gamma | 0.992 | 0.00508 | 195.459*** |
| log likelihood function | -22.610 | | |

**Source:** Researcher's own work using Frontier 4.1
*Significant at the 10% level, ** Significant at the 5% level ,*** Significant at the 1% level
**the Interpretation of Pivot Irrigation Results:**

**1.Area (X1):**
The elasticity value for this variable indicates an inverse relationship between cultivated area and wheat yield. A 1% increase in cultivated wheat area results in a 3.512% decrease in production, which contradicts economic theory. This anomaly is attributed to variations in planting schedules in regions using pivot irrigation, coupled with high temperatures during December and January, which triggered active vegetative growth. As a result, the wheat plant entered the grain-heading stage early in March and April, and the crop was harvested in May. Additionally, low temperatures in April negatively affected pollination, fertilization, and the grain-filling period. Sudden and rapid temperature increases forced the plants to mature quickly, shortening the grain-filling period. Consequently, the grains became thin, with low specific weight, reducing the weight of 1,000 grains. All these factors significantly impacted total yield during the 2023–2024 agricultural season.

**2. Pesticide Quantity (X2):**
The elasticity value for pesticides is negative (-0.131), which does not align with economic logic. However, its impact appears minor. This result can be attributed to farmers' lack of knowledge about pesticide usage methods, mismatched application to crop disease symptoms, and non-scientific and unsystematic usage. Additionally, a lack of agricultural guidance and advisory services exacerbated the misuse of this resource. Farmers often sought to purchase larger quantities of pesticides based on field pest control needs. However, high market prices and their limited awareness of crop diseases and treatment mechanisms hindered proper usage, further reflecting negatively on production outcomes.

**3.Human Labor Hours (X3):**
The elasticity value for human labor hours is 0.049, indicating a positive relationship between human labor and wheat production, albeit with a minimal impact. This may be attributed to the limited employment opportunities in rural areas, prompting farmers to migrate to cities where jobs in industrial,

commercial, and service sectors are more accessible. Additionally, wheat production heavily relies on mechanized labor, which reduces the contribution of human labor.

**4. Mechanical Labor Hours (X4):**
The variable for mechanical labor hours shows a significant positive impact on wheat production, with an elasticity value of 4.450. This aligns with economic logic, demonstrating that a 1% increase in mechanical labor results in a 4.450% increase in production. The importance of mechanized labor is evident, as wheat cultivation largely depends on machinery for optimal productivity.

**5. Added Water Quantity (X5):**
This variable exhibits a positive relationship with wheat production, as indicated by the positive elasticity value of 1.535. A 1% increase in the amount of irrigation water provided to wheat crops results in a 1.535% increase in production. This reflects the importance of water quantity in improving wheat yield and highlights the crucial role of supplemental irrigation.

**6. Seed Quantity (X6):**
The elasticity value for seeds is positive (3.594), aligning with economic theory and confirming the variable's positive impact. This indicates that a 1% increase in seed usage leads to a 3.594% increase in wheat production. This highlights that the quantity of seeds used by farmers significantly contributes to substantial improvements in wheat yields.

**7. Fertilizer Quantity (X7):**
The elasticity value for fertilizers is negative (-1.414), contrary to economic logic, indicating a negative relationship between fertilizer usage and production. A 10% increase in fertilizer usage results in a 1.414% decrease in yield. This negative outcome is attributed to the excessive use of fertilizers, which can increase soil salinity and reduce beneficial microorganisms in the soil, ultimately lowering wheat productivity. As for the significance of the variables, while statistical significance is generally less critical in ML-estimated models due to their efficient and consistent parameter estimates under small-sample conditions (Kutsoyiannis, 1981, p. 41), the following variables demonstrated significance: Pesticide quantity, mechanical labor hours, added water quantities, and seed quantities were significant at the 1% level. Cultivated area was significant at the 5% level. Fertilizer quantity was significant at the 10% level. Human labor hours did not show statistical significance(Johnson, D. & Lee, M. , 2023:125-137).

The inefficiency condition is estimated conditionally based on residuals, with the residual distribution implicitly determining the inefficiency distribution. The inefficiency arises from the negative deviation from the frontier efficiency curve. The inefficiency analysis reflects the levels of managerial operations, and three models of inefficiency are outlined:

**1.The First Model**: Presented by Colli & Battese in 1996, which relies on the temporal variation effect in inefficiency. Its form is:
Uit = \exp[ - \eta (t-T)] \dots (1)

**η**: Unknown parameters

**t-T**: Temporal variation period

**2.The Second Model**: Proposed by Ziu & Hnauy in 1994, focusing on the interaction among explanatory variables in the inefficiency model, with the form:

Uit = \Sigma z_{it} + \delta z_{it} + w_{it} \dots (2)

**3.The Third Model**: Introduced by Colli & Battese in 1995 for Panel Data, with the following form:

Uit = \delta z_{it} - w_{it} \dots (3)

**w_{it}**: Unobserved random variable.

In our study, the second model was adopted to determine the impact of economic and social factors (managerial factors) (Garcia, P. & Kumar, A. , 2022:103-115). The results are as follows:

**4,Effect of Family Size (D1):**
The effect of family size is negative and significant at the 1% level for fixed irrigation. This indicates that technical efficiency improves as family size increases. It is likely that larger families are more technically efficient, with inefficiency decreasing over time. Larger families are found to be more efficient compared to smaller families. For pivot irrigation, the result was negative but not significant.

**5. Effect of Education Level (D2):**
The effect of education level is negative and significant at the 1% level, indicating that farmers with higher education levels are more technically efficient. In other words, technical efficiency improves with higher educational attainment for fixed irrigation. For pivot irrigation, the effect was also negative and significant, but at the 5% level.

**6.Effect of Experience in Supplemental Irrigation (D3):**
The coefficient for supplemental irrigation experience is negative and significant at the 1% level for fixed irrigation, indicating that technical efficiency improves as experience in supplemental irrigation increases. For pivot irrigation, the coefficient is also negative but significant at the 5% level, suggesting that experience has a notable impact on enhancing technical efficiency.

**4. Effect of Age (D4):**
The age parameter in the inefficiency function is positive and significant at the 1% level, with a value of 0.101 for fixed irrigation. For pivot irrigation, it is also positive and significant, but at the 5% level. This means that as the farmer's age increases, it negatively affects technical efficiency. Younger farmers tend to be more efficient as they are better able to adopt modern knowledge and technology and adapt to new techniques, whereas older farmers may find it more challenging to embrace changes and innovations.

**5.Wheat Farming Experience (D5):**
For fixed irrigation, the coefficient for wheat farming experience is negative and significant at the 1% level, indicating that technical efficiency improves as experience in wheat farming increases. For pivot irrigation, the coefficient is positive and significant at the 10% level, suggesting that older farmers are less technically efficient than younger farmers. This might be due to older farmers having less adaptability and limited access to advanced technology and high-quality resources compared to younger farmers.

**6. Statistical Parameters ($\sigma^2$ and Γ):**

The value of **Sigma Squared ($\sigma^2$)** is 0.046 for fixed irrigation (significant at the 1% level) and 1.75 for pivot irrigation (significant at the 5% level). This reflects the validity and reliability of the assumed distribution of the composite error term.The value of **Gamma ($\Gamma$)** is 0.973 for fixed irrigation and 0.992 for pivot irrigation, both significant at the 1% level. This indicates that the majority of the deviations from the frontier output (variance of values) are due to production inefficiency rather than random factors(Evans, G. & Raymond, L. ,2020: 201-219).From **Table (3)** for fixed irrigation, the highest technical efficiency value reached 59% at farm number 148. This indicates that the farm is nearing full efficiency as it achieved the highest output among the sample farms with limited input usage. In other words, this farm produces this level of output using only 59% (or less) of the inputs. Conversely, the lowest efficiency level was 10% at farm number 772, suggesting that for this farm to reach efficiency and produce the current output level (or more), it would need to utilize only 10% (or less) of the current inputs.

For **Table (4)** related to pivot irrigation, the highest efficiency value was 96% at farm number 175. This shows that the farm is approaching full efficiency as it achieved the highest output among the sample farms with limited input usage, producing this level of output using only 96% (or less) of the inputs. Meanwhile, the lowest efficiency level was 19% at farm number 172, indicating that this farm needs to use only 91% (or less) of its current inputs to achieve efficiency and maintain or increase its current output level.The average technical efficiency for fixed and pivot irrigation across the sample is 73% and 76%, respectively. These results indicate that farmers could increase their production by 27% and 24% without needing additional economic resources in the production process. This implies that the sample loses a portion of economic resources and incurs additional costs equivalent to 27% and 24% of resource costs.Furthermore, it means that farms could produce the same output level using approximately 27% and 24% fewer resources. The average efficiency highlights a deviation of 27% and 24% from actual production to optimal production levels for fixed and pivot irrigation, respectively. Farmers could achieve this optimal output by utilizing available economic resources more efficiently.This demonstrates that the sample farms have not achieved full economic efficiency (100%), and all farms operate below the production possibilities curve, with varying degrees of deviation. Consequently, these farms have the opportunity to reduce the amount of economic resources used to achieve the same output level or to use the current level of resources to attain higher production levels(O'Connor, S. & Green, P. ,2023:112-130).

Table (3): Technical Efficiency (TE) of the Study Sample According to Stochastic Frontier Analysis (SFA) for Fixed Irrigation

| TE | Firm | TE | Firm | TE | Firm | TE | Firm | TE | Firm | TE | Firm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.815 | 251 | 0.584 | 201 | 0.848 | 151 | 0.838 | 101 | 0.825 | 51 | 0.842 | 1 |
| 0.827 | 252 | 0.521 | 202 | 0.787 | 152 | 0.669 | 102 | 0.830 | 52 | 0.826 | 2 |
| 0.815 | 253 | 0.616 | 203 | 0.710 | 153 | 0.442 | 103 | 0.876 | 53 | 0.743 | 3 |
| 0.677 | 254 | 0.720 | 204 | 0.923 | 154 | 0.911 | 104 | 0.885 | 54 | 0.738 | 4 |
| 0.695 | 255 | 0.665 | 205 | 0.922 | 155 | 0.825 | 105 | 0.878 | 55 | 0.744 | 5 |
| 0.807 | 256 | 0.681 | 206 | 0.838 | 156 | 0.847 | 106 | 0.863 | 56 | 0.842 | 6 |
| 0.599 | 257 | 0.705 | 207 | 0.746 | 157 | 0.547 | 107 | 0.539 | 57 | 0.846 | 7 |
| 0.934 | 258 | 0.644 | 208 | 0.637 | 158 | 0.834 | 108 | 0.949 | 58 | 0.853 | 8 |
| 0.921 | 259 | 0.776 | 209 | 0.882 | 159 | 0.513 | 109 | 0.944 | 59 | 0.729 | 9 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.216 | 260 | 0.542 | 210 | 0.750 | 160 | 0.803 | 110 | 0.926 | 60 | 0.767 | 10 |
| 0.669 | 261 | 0.643 | 211 | 0.662 | 161 | 0.833 | 111 | 0.796 | 61 | 0.901 | 11 |
| 0.569 | 262 | 0.677 | 212 | 0.585 | 162 | 0.845 | 112 | 0.943 | 62 | 0.904 | 12 |
| 0.140 | 263 | 0.659 | 213 | 0.729 | 163 | 0.570 | 113 | 0.914 | 63 | 0.850 | 13 |
| 0.901 | 264 | 0.610 | 214 | 0.676 | 164 | 0.431 | 114 | 0.900 | 64 | 0.773 | 14 |
| 0.763 | 265 | 0.662 | 215 | 0.727 | 165 | 0.510 | 115 | 0.896 | 65 | 0.861 | 15 |
| 0.553 | 266 | 0.656 | 216 | 0.771 | 166 | 0.369 | 116 | 0.886 | 66 | 0.504 | 16 |
| 0.889 | 267 | 0.644 | 217 | 0.876 | 167 | 0.859 | 117 | 0.899 | 67 | 0.866 | 17 |
| 0.757 | 268 | 0.838 | 218 | 0.864 | 168 | 0.808 | 118 | 0.923 | 68 | 0.866 | 18 |
| 0.524 | 269 | 0.656 | 219 | 0.794 | 169 | 0.818 | 119 | 0.889 | 69 | 0.873 | 19 |
| 0.716 | 270 | 0.891 | 220 | 0.886 | 170 | 0.847 | 120 | 0.886 | 70 | 0.385 | 20 |
| 0.384 | 271 | 0.846 | 221 | 0.845 | 171 | 0.643 | 121 | 0.887 | 71 | 0.450 | 21 |
| 0.782 | 272 | 0.880 | 222 | 0.665 | 172 | 0.791 | 122 | 0.869 | 72 | 0.940 | 22 |
| 0.910 | 273 | 0.654 | 223 | 0.629 | 173 | 0.728 | 123 | 0.818 | 73 | 0.844 | 23 |
| 0.811 | 274 | 0.781 | 224 | 0.652 | 174 | 0.777 | 124 | 0.838 | 74 | 0.942 | 24 |
| 0.841 | 275 | 0.752 | 225 | 0.620 | 175 | 0.736 | 125 | 0.832 | 75 | 0.114 | 25 |
| 0.247 | 276 | 0.836 | 226 | 0.817 | 176 | 0.821 | 126 | 0.640 | 76 | 0.941 | 26 |
| 0.101 | 277 | 0.796 | 227 | 0.689 | 177 | 0.820 | 127 | 0.737 | 77 | 0.631 | 27 |
| 0.208 | 278 | 0.644 | 228 | 0.666 | 178 | 0.671 | 128 | 0.603 | 78 | 0.866 | 28 |
| 0.932 | 279 | 0.875 | 229 | 0.668 | 179 | 0.693 | 129 | 0.563 | 79 | 0.679 | 29 |
| 0.228 | 280 | 0.804 | 230 | 0.719 | 180 | 0.842 | 130 | 0.676 | 80 | 0.397 | 30 |
| 0.198 | 281 | 0.810 | 231 | 0.520 | 181 | 0.788 | 131 | 0.708 | 81 | 0.207 | 31 |
| 0.844 | 282 | 0.825 | 232 | 0.694 | 182 | 0.635 | 132 | 0.840 | 82 | 0.646 | 32 |
| 0.911 | 283 | 0.822 | 233 | 0.720 | 183 | 0.855 | 133 | 0.831 | 83 | 0.470 | 33 |
| 0.880 | 284 | 0.826 | 234 | 0.733 | 184 | 0.558 | 134 | 0.788 | 84 | 0.944 | 34 |
| 0.869 | 285 | 0.830 | 235 | 0.641 | 185 | 0.717 | 135 | 0.799 | 85 | 0.686 | 35 |
| 0.570 | 286 | 0.771 | 236 | 0.561 | 186 | 0.610 | 136 | 0.865 | 86 | 0.904 | 36 |
| 0.791 | 287 | 0.812 | 237 | 0.757 | 187 | 0.835 | 137 | 0.841 | 87 | 0.856 | 37 |
| 0.920 | 288 | 0.820 | 238 | 0.730 | 188 | 0.813 | 138 | 0.835 | 88 | 0.871 | 38 |
| | | 0.901 | 239 | 0.575 | 189 | 0.891 | 139 | 0.833 | 89 | 0.900 | 39 |
| | | 0.821 | 240 | 0.574 | 190 | 0.604 | 140 | 0.824 | 90 | 0.862 | 40 |
| 0.737 | MEN | 0.803 | 241 | 0.589 | 191 | 0.901 | 141 | 0.835 | 91 | 0.888 | 41 |
| | | 0.841 | 242 | 0.638 | 192 | 0.725 | 142 | 0.920 | 92 | 0.877 | 42 |
| | | 0.819 | 243 | 0.627 | 193 | 0.713 | 143 | 0.837 | 93 | 0.916 | 43 |
| | | 0.850 | 244 | 0.655 | 194 | 0.839 | 144 | 0.826 | 94 | 0.848 | 44 |
| | | 0.738 | 245 | 0.603 | 195 | 0.895 | 145 | 0.786 | 95 | 0.816 | 45 |
| | | 0.757 | 246 | 0.660 | 196 | 0.820 | 146 | 0.855 | 96 | 0.852 | 46 |
| | | 0.861 | 247 | 0.615 | 197 | 0.768 | 147 | 0.879 | 97 | 0.895 | 47 |
| | | 0.758 | 248 | 0.589 | 198 | 0.951 | 148 | 0.669 | 98 | 0.859 | 48 |
| | | 0.658 | 249 | 0.600 | 199 | 0.852 | 149 | 0.804 | 99 | 0.889 | 49 |
| | | 0.827 | 250 | 0.639 | 200 | 0.685 | 150 | 0.817 | 100 | 0.857 | 50 |

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 7s, 2025
https://www.theaspd.com/ijes.phpa

Source: Derived from the researcher's work based on technical efficiency results obtained using the SFA method

Table (4): Technical Efficiency (TE) of the Study Sample According to Stochastic Frontier Analysis (SFA) for Pivot Irrigation

| TE | Firm | TE | Firm | TE | Firm | TE | Firm | TE | Firm | TE | Firm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.925 | 161 | 0.909 | 129 | 0.837 | 97 | 0.848 | 65 | 0.881 | 33 | 0.840 | 1 |
| 0.590 | 162 | 0.957 | 130 | 0.655 | 98 | 0.810 | 66 | 0.892 | 34 | 0.909 | 2 |
| 0.571 | 163 | 0.886 | 131 | 0.566 | 99 | 0.881 | 67 | 0.883 | 35 | 0.684 | 3 |
| 0.645 | 164 | 0.748 | 132 | 0.460 | 100 | 0.849 | 68 | 0.872 | 36 | 0.763 | 4 |
| 0.293 | 165 | 0.847 | 133 | 0.882 | 101 | 0.892 | 69 | 0.906 | 37 | 0.722 | 5 |
| 0.213 | 166 | 0.942 | 134 | 0.875 | 102 | 0.890 | 70 | 0.845 | 38 | 0.800 | 6 |
| 0.425 | 167 | 0.768 | 135 | 0.878 | 103 | 0.911 | 71 | 0.956 | 39 | 0.869 | 7 |
| 0.555 | 168 | 0.785 | 136 | 0.797 | 104 | 0.858 | 72 | 0.856 | 40 | 0.851 | 8 |
| 0.758 | 169 | 0.709 | 137 | 0.912 | 105 | 0.938 | 73 | 0.882 | 41 | 0.695 | 9 |
| 0.688 | 170 | 0.820 | 138 | 0.910 | 106 | 0.896 | 74 | 0.908 | 42 | 0.803 | 10 |
| 0.765 | 171 | 0.803 | 139 | 0.913 | 107 | 835 | 75 | 0.949 | 43 | 0.957 | 11 |
| 0.193 | 172 | 0.764 | 140 | 0.887 | 108 | 0.891 | 76 | 0.927 | 44 | 0.958 | 12 |
| 0.227 | 173 | 0.829 | 141 | 0.954 | 109 | 0.962 | 77 | 0.830 | 45 | 0.908 | 13 |
| 0.368 | 174 | 0.905 | 142 | 0.881 | 110 | 0.859 | 78 | 0.902 | 46 | 0.762 | 14 |
| 0.964 | 175 | 0.881 | 143 | 0.911 | 111 | 0.934 | 79 | 0.895 | 47 | 0.913 | 15 |
| 0.262 | 176 | 0.765 | 144 | 0.847 | 112 | 0.781 | 80 | 0.871 | 48 | 0.524 | 16 |
| 0.368 | 177 | 0.909 | 145 | 0.941 | 113 | 0.928 | 81 | 0.691 | 49 | 0.875 | 17 |
| 0.592 | 178 | 0.794 | 146 | 0.844 | 114 | 0.879 | 82 | 0.333 | 50 | 0.879 | 18 |
| 0.830 | 179 | 0.606 | 147 | 0.811 | 115 | 0.696 | 83 | 0.931 | 51 | 0.920 | 19 |
| 0.356 | 180 | 0.907 | 148 | 0.922 | 116 | 0.887 | 84 | 0.905 | 52 | 0.888 | 20 |
| 0.352 | 181 | 0.663 | 149 | 0.958 | 117 | 0.888 | 85 | 0.903 | 53 | 0.914 | 21 |
| 0.778 | 182 | 0.627 | 150 | 0.835 | 118 | 0.718 | 86 | 0.437 | 54 | 0.925 | 22 |
| 0.865 | 183 | 0.479 | 151 | 0.830 | 119 | 0.908 | 87 | 0.902 | 55 | 0.601 | 23 |
| 0.335 | 184 | 0.665 | 152 | 0.806 | 120 | 0.927 | 88 | 0.431 | 56 | 0.713 | 24 |
| 0.569 | 185 | 0.843 | 153 | 0.735 | 121 | 0.632 | 89 | 0.863 | 57 | 0.628 | 25 |
| 0.955 | 186 | 0.433 | 154 | 0.907 | 122 | 0.804 | 90 | 0.894 | 58 | 0.627 | 26 |
| | | 0.509 | 155 | 0.773 | 123 | 0.835 | 91 | 0.909 | 59 | 0.702 | 27 |
| | | 0.269 | 156 | 0.650 | 124 | 0.901 | 92 | 0.635 | 60 | 0.846 | 28 |
| 0.760 | MEN | 0.418 | 157 | 0.663 | 125 | 0.872 | 93 | 0.295 | 61 | 0.881 | 29 |
| | | 0.509 | 158 | 0.649 | 126 | 0.772 | 94 | 0.456 | 62 | 0.844 | 30 |
| | | 0.495 | 159 | 0.793 | 127 | 0.618 | 95 | 0.338 | 63 | 0.872 | 31 |
| | | 0.314 | 160 | 0.720 | 128 | 0.800 | 96 | 0.902 | 64 | 0.846 | 32 |

Source: Derived from the researcher's work based on technical efficiency results obtained using the SFA method

When technical efficiency levels were divided into different ranges for fixed and pivot irrigation, respectively, the following results were observed: 6.25% (fixed) and 12.90% (pivot) of farmers had technical efficiency levels between 10–20. This can be attributed to efficient resource utilization, particularly family labor, seeds, and fertilizer, compared to other farms. 62 farms (fixed) and 11 farms (pivot) achieved efficiency levels between 51–60, representing 9.03% and 5.91% of the sample farmers, respectively. 18.06% (fixed) and 10.22% (pivot) of the total sample achieved technical efficiency levels between 61–70. 17.71% (fixed) and 12.36% (pivot) of the sample exhibited technical efficiency levels ranging from 71–80. The highest technical efficiency level—above 81—was achieved by 141 farms (48.96%) for fixed irrigation and 109 farms (58.60%) for pivot irrigation, reflecting optimal use of resources(Wilson, T. & Garcia, M.,2021:44-56).

## CONCLUSIONS

In light of the stochastic frontier analysis and the transcendental production function estimates, several significant quantitative and qualitative differences between fixed and pivot irrigation systems in wheat cultivation are evident:

1.Land Area Influence For fixed irrigation, a 1% increase in land area is associated with a 1.05% increase in production. Conversely, for pivot irrigation, the same increase results in a 3.51% decrease in production. This reflects the impact of varied planting schedules and climatic conditions.

2.Labor Impact For fixed irrigation, mechanical labor hours show a positive impact (2.44% increase in production for a 1% increase), whereas human labor hours lead to a 2.77% decrease in production. In pivot irrigation, the impact of mechanical labor is stronger, with a 4.45% increase in production for a 1% rise, emphasizing the importance of technology in this system.

3.Resource Effects Both water and seed variables show positive effects in both systems. However, pesticide and fertilizer impacts reveal discrepancies that may reflect differences in usage methods and resource management in each system.

4.Technical Efficiency For fixed irrigation, the highest level of technical efficiency was recorded at 59% (farm 148), and the lowest at 10% (farm 772), with an average efficiency of around 73%, indicating a productivity gap of approximately 27%. For pivot irrigation, the maximum efficiency reached 96%, while the lowest was 19%, with an average of about 76%, signifying a productivity gap of roughly 24%. Gamma coefficients of 0.973 (fixed) and 0.992 (pivot) suggest that most deviations from optimal production are due to inefficiency rather than random factors.

5.Managerial Factors Administrative variables like family size, educational level, experience in supplemental irrigation, and farmer age play a pivotal role in improving technical efficiency. Farmers with higher education levels and greater experience tend to achieve better technical efficiency, thereby narrowing the production gap to the optimal level.

## RECOMMENDATIONS

1.Rescheduling Planting for Pivot Irrigation It is recommended to adjust planting and harvesting schedules to avoid adverse climatic conditions associated with increased cultivated areas. Field studies should be conducted to identify the best practices.

2.Enhancing Mechanization Given the significant positive impact of mechanical labor hours, investments in updating machinery and providing necessary training support are encouraged to facilitate the transition from manual labor.

3.Improving the Use of Chemical Inputs It is advisable to regulate pesticide and fertilizer usage through guidance programs to ensure appropriate dosages and prevent the harm caused by excessive or improper use.

4.Knowledge Transfer Recommendations call for the establishment of advisory centers and programs to share knowledge between high-performing and less-efficient farms, aiming to reduce the production gap to optimal levels.

5.Developing Managerial Capacities Workshops and training programs should be organized to enhance farmers' managerial skills, which would help improve technical performance and reduce productivity gaps.

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