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# Effect of Irrigation Water on Production and Cost Technical Efficiency of Rice: Empirical evidence from Egypt

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**Abstract:** This research employs stochastic frontier analysis (SFA) for analyzing technical and cost efficiency as well as, estimation factors that Influence the Production and cost of rice, considering the types of irrigation water as an input in rice production. Using cross-sectional data were obtained from 392 rice rural farmers selected using a multistage random sampling technique. representing Al- Hamoul Center, Kafr El-Sheikh Governorate. The empirical results were showed empirical results showed that most rice farmers who use freshwater have higher mean technical efficiency (0.96) than rice farmers who use mixed irrigation and drainage water estimated at 0.91 and 0.82, respectively. While, the cost average of efficiency rice farmers using freshwater, mixed irrigation, and drainage water is estimated at 1.274, 1.384, and 1.442; this implies 27%, 38%, and 1.44 of the cost, respectively, is wasted relative to farms using the best practices and producing the same output. Thus, the results showed that freshwater achieves the highest technical efficiency and cost efficiency, which is, achieves the lowest waste of costs. This indicates that kind of irrigation water used in rice production would have an important role in increasing the total rice production.
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**Keywords**: Kafr El-Sheikh Governorate, Rice crop, Irrigation water, Cost efficiency, production efficiency, stochastic frontier analysis (SFA).

## 1- Introduction

The agricultural sector is one of the essential water-consuming sectors. Globally, 70% of all freshwater withdrawals were utilized for agriculture. (Ritchie, 2017). Low-income countries' average agriculture usage is ranged from 79-90% for middle-income, and about 41% in high incomes countries (Doungmanee, 2016; Gleick, 2012). Considerable efforts have been made to push policies aimed at enhancing water efficiency based on enhanced water management (Scott et al., 2014). Therefore, the United Nations, 2015 Sustainable Development goals aimed at the core of SDG 6.4 – address water-use efficiency and stress (Giupponi et al., 2018; Hellegers et al., 2021; Hoekstra et al., 2017). Egypt's agricultural sector faces a series of main challenges related to water scarcity, food insecurity, climate change, and production patterns with a rising population. Egypt's agricultural sector uses about 61.65 BCM (about 76.82% of the country's water resources) in 2018/2019 (CAPMAS, 2020). In light of conditions of climate change, the required water to irrigate diverse crops is expected about 61.8 BCM in 2025/2024. On the other hand, the UN cautioned that Egypt would most probably run out of water by the year 2030 (UNESCO, 2012). By then, forecasts per capita water supply are expected to drop by 40% (Boretti, 2019). According to Abdelkader et al. (2018) and Beyene et al. (2009), the Nile River water is decreasing due to climate change, therefore agriculture in the Nile Delta will reduce. Therefore, the Action Strategy for Sustainable Agricultural Development (SADS) 2030 includes a target for the efficient utilization of finite agricultural resources; particularly water and land resources among them. Target 3.2.3 aims to improve water use efficiency in agriculture by modifying the SADS cropping pattern. By 2030, Egypt sought to reduce the rice-planted area to 1.3 million fed. to save about 12.40 billion m3/year of water (Karajeh et al., 2013; Osman et al., 2016). In 2018, the Ministry of Water Resources and Irrigation (MWRI) reduced the rice area Cultivated to 724.200 feds across the agricultural directorates of the North Delta region Cultivated area (Atallah, 2019; Elmoghazy et al., 2018). Even though, rice is an appropriate crop for that region, the insufficient water supply for total consumption, leads to restrictions on the cultivated area. Recently, the Egyptian government has imposed some programs and policies for groundwater, non-conventional water resources, and agricultural wastewater. The reuse of drainage in 2020 is about 13.70 BCM/year which represented about 22.10%, and 17% of the total uses of water (80.30 BCM) and (61.70 BCM) of total irrigation water, respectively (CAPMAS, 2020).

Kafr El-Sheikh Governorate suffers from a shortage of irrigation water due to the majority of agricultural land at the ends of irrigation canals. Therefore, agricultural drainage water is reused either officially or unofficially to strike a balance between needs and water resources by combining irrigation water channels with agricultural drainage water leading to the difference in production and cost of rice. It will be leading to a difference in rice production and cost efficiency thus it will affect the farmer's income. Estimation of production and cost efficiency considering the types of irrigation water is important to stakeholders to increase the productivity of the agriculture sector in a developing country like Egypt.

In this context, this research aims to measure the technical and cost efficiency of rice production inputs. In addition, determination Factors Influencing the Production and cost of rice, focusing on the types of irrigation water as an input in rice production.

## 2- Material and Method

### 2.1. Study Area

This research was held at three associations in Al- Hamoul Center, Kafr El-Sheikh Governorate, during the summer growing season of 2020/2021 Kafr El Sheikh is located in the Northern Nile Delta, which is lying at (31¯ 07° N Latitude, 30¯ 57° E longitude). With an altitude of ~ 6 meters above sea level, moreover connecting the Nile River to the Mediterranean Sea. It includes ten administrative centers (Markaz) (Fi .1, table 1).

**Table 1.** Cultivated area and production of the rice crop in administrative centers (Markaz) at Kafr El-Sheikh governorate (2020/2021).

| administrative centers (Markaz) | Cultivated area (1000 fed.) | % | Productivity (Ton/ fed.) | total production (1000 tons) | % |
|---|---|---|---|---|---|
| AL hamoul | 46.0 | 18.0 | 3.9 | 180.3 | 17.3 |
| Kafr El-Sheikh | 40.1 | 15.7 | 4.2 | 168.2 | 16.1 |
| sayidi salim | 36.8 | 14.4 | 4.0 | 148.5 | 14.2 |
| Desouq | 29.4 | 11.5 | 4.2 | 123.9 | 11.9 |
| Bella | 28.5 | 11.1 | 3.8 | 110.7 | 10.6 |
| Mutubas | 24.5 | 9.6 | 4.0 | 99.3 | 9.5 |
| AL-Riyadh | 22.8 | 8.9 | 4.2 | 97.1 | 9.3 |
| Qiliyn | 13.4 | 5.2 | 4.0 | 54.8 | 5.2 |
| Fuh | 9.6 | 3.7 | 4.1 | 39.9 | 3.8 |
| Baltim | 4.6 | 1.8 | 3.8 | 17.9 | 1.7 |
| total governorate | 256 | 100 | 4.1 | 1041.1 | 100 |

**Source:** Author's calculation from analysis of survey data 2020/2021.

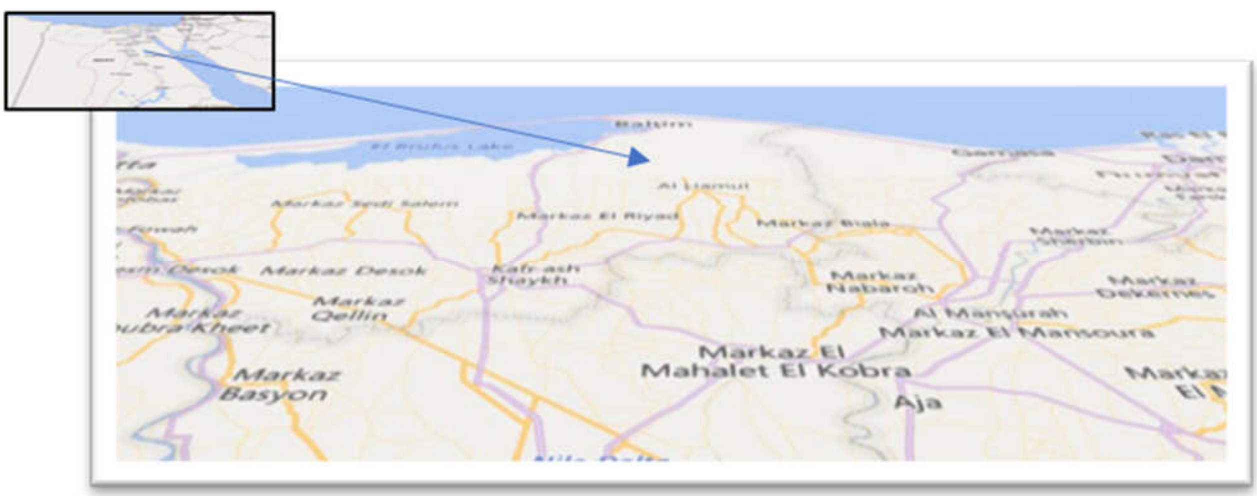


Fig. 1. Map shows the study location of Al- Hamoul Markaz, Kafr El-Sheikh Governorate, Egypt.
**Source:** Author's Compilation, using google mapping.

### 2.2. Sampling Techniques and Data Collection

To select a representative sample for the study, a multistage sampling technique was conducted. In the first stage, Kafr El-Sheikh Governorate was selected purposively due to, major producer of rice, with a production of about 1.023 million tons and rice cultivated area was estimated of about 256 thousand fed. (MALR, 2020). Moreover the difference in the type of water used for irrigation. The second stage, Al-Hamoul Center was selected purposively according to the cultivated area; it represented ~ 18.2% of the total rice area of the governorate. Meanwhile, rice production represented ~ 17.3% of the total rice production of the governorate in 2020/2021. (Table 1). In addition, the different types of water used for irrigation are freshwater, drainage water, and mixing water. In the third stage, three associations namely (Al-Khamseen, Al-Hamoul, and Kom Al-Hajar), were purposively selected due to the different water resources used for irrigation. In the last stage, 392 sample rice-producing farmers were selected through simple random selection from associations (table 2). A sample frame consisting of the list of rice farmers become obtained, from the agriculture Directorate inside the Kafr El-Sheikh Governorate. Finally, the total sample size for the research become determined using Yamane's (1967) (Israel, 1992; Tejada et al., 2012).

**Table 2.** Sample Size Determination and Distribution based on the Kind of Irrigation Water Season 2020/2021

| Region | Kind of Irrigation Water | Cultivated area (feddan) | farmer population | No. of farmers sampled |
|---|---|---|---|---|
| ALkhamsin | Fresh water | 2080 | 950 | 105 |
| AL hamoul | Mixed water | 2080 | 1850 | 147 |
| kum alhajar | Drainage water | 2471 | 1422 | 140 |
| Total | | 6631 | 4222 | 392 |

**Source:** Author's calculation from analysis of survey data 2020/2021.

### 2.3. Theoretical Framework

The techniques used in this research is the production (TE) and cost efficiency (CE) using estimating the stochastic frontier analysis (SFA) of each model. Farrell et al. (1962) D. J. Aigner et al. (1968) translated Farrell's frontier estimated a stochastic frontier function Farrell et al. (1962) and later, D. Aigner et al. (1977); (Farrell et al., 1962); Meeusen et al. (1977) George E Battese et al. (1977) and suggested the stochastic frontier approach. Further, this approach develops by Kalirajan (1981); Russell (1985); Kumbhakar et al. (1991); George Edward Battese et al. (1995); Tim J Coelli (1996); Sakano et al. (1997); Bauer et al. (1998); T. Coelli et al. (1999); (Timothy J Coelli et al., 2005); Kumbhakar et al. (2005); Cullinane et al. (2006); Ghosh et al. (2010); (Varasani et al., 2016); Adeyemi et al. (2017); Banker et al. (2019); Zhichkin et al. (2019) and Siagian et al. (2020). The SFA assumes a functional relationship between outputs and inputs addition utilizes statistical approach to analysis the function.

The basic model of the stochastic frontier used in this research, as follows:

$$Y_i = f(X_{ij}; \beta) + \varepsilon_i \quad (1)$$

$$\ln y_i = \beta_0 + \beta_i \ln X_i + (V - U_i) \quad (2)$$

$$C_i = f(X_{ij}; P_{ij}; Y_i) + \varepsilon_i \quad (3)$$

$$\ln(C_i) = \beta_0 + \beta_i \ln p_{ij} + \beta_i \ln y_i + (V - U_i) \quad (4)$$

Where $Y_i$ is a output of the *i* farms, $X_i$ is a vector of the output of the $i$ farm's inputs, used by farm I, $C_{ij}$ is a total production cost, $P_{ij}$ is a vector of price, and $\varepsilon_i$ is a "composed" error term. The error term $\varepsilon_i$ = v, + $u_i$. The terms a two-sided $(-\infty < v_i < \infty)$ normally distributed random error $(v \sim N[0, \sigma_v^2])$ that represents the stochastic effects outside the farmer's control, measurement errors, and other statistical noise. The term $u_i$ is a non-negative random variable that represents the technical inefficiency of the farm. Equation (3 and 5) estimated by the maximum likelihood estimation (MLE) creates consistent estimators for $\beta$, $\lambda$, and $\sigma$, where $\beta$ is a vector of unknown parameters, $\lambda = \sigma_u/\sigma_v$, and $\sigma^2 = \sigma_u{}^2 + \sigma_v{}^2$. Assume that $v_i$ and $u_i$ are independent of each other, the conditional mean of $u_i$ given $\varepsilon$ is estimated by:

$$E(u_i \mid \varepsilon_i) = \sigma^{\cdot}\left[\frac{f^*\left(\frac{\varepsilon_i\lambda}{\sigma}\right)}{1-F^*\left(\frac{\varepsilon_i\lambda}{\sigma}\right)} - \frac{\varepsilon_i\lambda}{\sigma}\right] \quad (5)$$

Where $\sigma^{*2} = \sigma_u^2\sigma_1^2/\sigma^2, f^2$ the standard normal density is function, and $F^*$ is the distribution function.

The TE of farm will be estimated by using the following equation:

$$TE_i = \frac{y_i}{\exp(x_i\beta+v_i)} = \frac{\exp(x_i\beta+v_f-u_i)}{\exp(x_i\beta+v_i)} = \exp(-\hat{u}_i) = \exp\left(-E(u_i \mid \varepsilon_i)\right) \quad (6)$$

Where $TE_i$ takes values on the interval (0, 1), where $TE_i$ = 1 indicates a fully efficient farm system and $TE_i$ = 0 a fully inefficient farm system.

The measurement of cost efficiency explain by the equation (7).

$$CE_i = \frac{C(I_i, P_i; \beta)\exp\{U_i\}}{C_i} \quad (7)$$

Where, $CE_i$ is the possible minimum cost ratio with a specific inefficiency level toward the actual total cost. When, the $CE_i = C(P_iY_i\beta).\exp\ (U_i)$. The $CE_i$ will equal one, meaning the farm system is in full efficiency condition in time $i$. On the other hand, when the actual cost is bigger than the minimum estimated cost, the farming system is inefficient.

### 2.4 Empirical Model

The empirical model utilized in this research is Cobb-Douglas stochastic frontier model. The production and cost stochastic frontier function will be defined by equations 8 and 9. Both production and cost stochastic frontier models are estimated by using Frontier 4.1

$$\ln\ Y_i = \beta_0 + \beta_1 \ln\ X_{1i} + \beta_2 \ln\ X_{2i} + \cdots + \beta_8 \ln\ X_{gi} + (V_i - U_i) \quad (8)$$

Where,

| | | | |
|---|---|---|---|
| $Y_i$: | Rice production ( ton/fad.) | $\beta_0$: | Intercept |
| $\beta$: | Regression coefficient | $X_1$: | Seed ( kg/fad.) |
| $X_2$: | Labor (working hours/day /fad.) | $X_3$: | Machine labor (working hours/day /fad.) |
| $X_4$: | Animal labor (working hours/day /fad.) | $X_5$: | Fertilizer $P$ ( kg/fad. ) |
| $X_6$: | Fertilizer K ( kg/fad. ) | $X_7$: | Fertilizer N( kg/fad. ) |
| $X_8$: | Pesticide (liter /fad.) | $V_i$: | Errors due to random sampling |
| $U_i$: | Effect of technical inefficiency | | |

$$\ln(C_i) = a_0 + a_1 \ln(P_{1i}) + \cdots + a_8 \ln(P_{8i}) + a_9 \ln\ Y_i + (V_i + U_i) \quad (9)$$

Where,

| | | | |
|---|---|---|---|
| $C_i$: | Total production cost (EGP) | $\alpha_0$: | Intercept |
| a | Regression coefficient | $P_1$: | Seed cost (EGP) |
| $P_2$: | Labor cost (EGP/working hours/day) | $P_3$: | Machinery cost (EGP/working hours/day) |
| $P_4$: | animal labor cost (EGP/working hours/day) | $P_5$ : | Cost of fertilizer $P$ (EGP/kg) |
| $P_6$: | Cost of fertilizer K (EGP/kg) | $P_7$: | Cost of fertilizer N(EGP/kg) |
| $P_8$: | Cost of pesticide (EGP /liter) | Y: | Rice production ( ton/fad.) |
| $V_i$: | Errors due to random sampling | $U_i$: | Effect of technical inefficiency |

## 3- Empirical Results:

### 3.1 Descriptive statistics:

Summary statistics of the variables included in the model are illustrated in Table 3. The descriptive statistics are calculated based on the kind of irrigation water 2020/2021 basis. A standard deviation of the sample indicates the output, input quantity, and input cost disparity among the farmers.

**Table 3.** Summary Statistics of variables used in Stochastic Production and Cost Function Analysis

| Variables | Freshwater | | | Mixing waters | | | Drainage water | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | Mean | Std. Dev. | N | Mean | Std. Dev | N | Mean | Std. Dev |
| Rice production ( ton/fad. ) | 105 | 4.3 | 0.5 | 147 | 4.1 | 0.5 | 140 | 3.8 | 0.7 |
| Seed ( kg ) | 105 | 68.7 | 8.2 | 147 | 68.3 | 9.0 | 140 | 64.8 | 8.9 |
| Labor (working hours/day ) | 105 | 51.6 | 4.3 | 147 | 54.5 | 5.9 | 140 | 54.1 | 5.8 |
| Machine work (working hours/day ) | 105 | 11.9 | 2.5 | 147 | 12.9 | 2.6 | 140 | 14.7 | 2.6 |
| Animal work (working hours/day ) | 105 | 3.4 | 0.9 | 147 | 3.8 | 1.3 | 140 | 3.6 | 1.2 |
| Fertilizer *P* ( kg/fad. ) | 105 | 22.9 | 8.1 | 147 | 24.8 | 7.7 | 140 | 24.2 | 7.5 |
| Fertilizer K ( kg/fad. ) | 105 | 17.9 | 9.7 | 147 | 22.5 | 10.9 | 140 | 21.8 | 10.8 |
| Fertilizer N( kg/fad. ) | 105 | 58.2 | 14.6 | 147 | 60.8 | 13.8 | 140 | 66.3 | 13.1 |
| Pesticide(liter /fad.) | 105 | 2.0 | 0.8 | 147 | 1.7 | 0.8 | 140 | 1.7 | 0.8 |
| Total production cost EGP | 105 | 4.7 | 0.5 | 147 | 4.1 | 1.0 | 140 | 3.9 | 0.9 |
| Cost of labor (EGP /day) | 105 | 89.7 | 11.0 | 147 | 94.8 | 12.7 | 140 | 91.8 | 12.2 |
| Cost of machine work (EGP /day) | 105 | 105.0 | 8.5 | 147 | 107.5 | 8.3 | 140 | 116.1 | 8.2 |
| Cost of animal work (EGP /day) | 105 | 69.6 | 5.6 | 147 | 69.5 | 4.8 | 140 | 67.5 | 4.9 |
| Cost of fertilizer *P* (EGP/kg) | 105 | 71.8 | 6.0 | 147 | 104.9 | 52.9 | 140 | 99.9 | 49.3 |
| Cost of fertilizer K (EGP/kg) | 105 | 286.6 | 99.8 | 147 | 280.0 | 85.3 | 140 | 280.0 | 87.7 |
| Cost of fertilizer (EGP/kg) | 105 | 172.7 | 10.8 | 147 | 198.1 | 41.7 | 140 | 194.0 | 38.6 |
| Cost of pesticide (EGP/liter) | 105 | 112.8 | 11.2 | 147 | 116.1 | 13.7 | 140 | 117.6 | 10.8 |
| Total production cost (EGP) | 105 | 7763.9 | 1347.5 | 147 | 8751.3 | 2009.3 | 140 | 8821.8 | 1896.5 |

Source: Author's calculation from analysis of survey data 2020/2021.

### 3.2 Factors Influencing Rice Production

The maximum likelihood estimates (MLE) of parameters in the stochastic production defined by equation (8) are presented in Table 4. Based on the analysis of the effect of the difference in types of irrigation water on rice production. **In the case of freshwater**, the result of parameter estimates for the seed variable shows a positive sign and significant effect on rice production with a coefficient value of 0.41; this implies that increasing the amount of seed by 1% would increase the total productivity by 0.41%. The coefficients of animal work and pesticides variables are negative signs (0.08, 0.22) at a 1% level of significance, respectively, which means that an increase in the use of animal work and pesticides in the production process by 1% would decrease the rice production by 0.08%, and 0.22 % respectively. The variables of labor, machine work, fertilizer P, and fertilizer N affect a significant and positive relationship on rice production with coefficient values are 0.13, 0.11, 0.18, and 0.25, respectively, which is, denote the increase of those variables by 1% would increase the total the rice production per fed. to 0.13%, 0.11%, 0.18%, and 0.25% respectively. The variable of fertilizer K is not significant. Meanwhile, the gamma value (γ) is equal to 0.99 and significant at the level of 1%. It indicates that 99% of the variation in rice production was due to differences in technical inefficiencies among farmers (ui), and 1% of the variations were outside the farmers' control or measurement error (vi).

While, **In the case of mixed irrigation,** the result of the parameters estimated for seed, labor, fertilizer P, fertilizer N, and pesticides show a positive and statistically significant coefficient, which means that, indicates the increase in those variables has a positive impact on the rice production per fed. The coefficient values of seed, labor, fertilizer P, fertilizer N, and pesticides are 0.25, 0.17, 0.19, 0.21, and 0.23, respectively, indicating that a 1% increase in those variables leads to 0.25%, 0.17%, 0.19%, 0.21%, and 0.23% increase in the rice production per fed. In addition, the variables of machinery and animal work are significant at the level of 1% and negative sign, with coefficients values of 0.13 and 0.06, respectively. This implies that an increase in the use of machinery and animal work in the production process by 1% will decrease rice production by 0.13% and 0.06% respectively. Whereas, the variable of fertilizer K is not significant. The gamma value (γ) is 0.93, which measures the variability of the two sources of error. This implied that 93% of the variation in rice production was due to differences in technical inefficiencies among farmers (ui), and 7% of the variations were related to stochastic random error (vi).

On the Other hand, **In the case of drainage water:** somewhat similar to the results of mixed irrigation. The seed, labor, fertilizer N, and fertilizer K variables show a positive sign and significant effect on rice productivity at the level of 1%. With a coefficient value of 0.57, 0.46, 0.26, and 0.21, this implies that increasing the amount of those variables by 1% would increase the productivity by 0.57%, 0.46%, 0.22%, and 0.21% respectively, while fertilizer P has a positive sign (0.17) at a 5% level of significance. The coefficients of machinery and pesticides variables are negative signs (0.28, 0.23) at a 1% level of significance, which means that an increase in the use of machinery and pesticides in the production process by 1% would decrease the rice production by 0.28%, and 0.23 % respectively. The variable of animal work do not affect the production function. The gamma value (γ) is equal to 0.92 and significant at 1%; it indicates that 92% of production variations were caused by inefficiencies (ui), and 8% of the variations were outside the farmers' control or measurement error (vi).

**Table 4.** Estimation Result of Production Function Stochastic Frontier of Rice

| Variable | Parameter | Freshwater | | Mixing waters | | Drainage water | |
|---|---|---|---|---|---|---|---|
| | | Coefficient | t-value | Coefficient | t-value | Coefficient | t-value |
| Constant | $\beta_0$ | 0.59** | 7.75 | -0.52** | -2.92 | 0.56 $^{NS}$ | 0.95 |
| seed | $\beta_1$ | 0.41* | 2.3 | 0.25** | 9.51 | 0.57** | 4.4 |
| labor | $\beta_2$ | 0.13** | 6.04 | 0.17** | 4.06 | 0.46** | 7.18 |
| machinery | $\beta_3$ | 0.11** | 8.66 | -0.13** | -5.41 | -0.28** | -4.17 |
| animal work | $\beta_4$ | -0.08** | -10.05 | -0. 06** | -4.23 | -0.14 $^{NS}$ | -0.91 |
| fertilizer P | $\beta_5$ | 0.18* | 2.46 | 0.19** | 2.9 | 0.17* | 2.34 |
| fertilizer K | $\beta_6$ | 0.15 $^{NS}$ | 1.63 | 0.10$^{NS}$ | 0.02 | 0.21** | 3.03 |
| fertilizer N | $\beta_7$ | 0.25** | 5.61 | 0.21** | 4.53 | 0.26** | 4.05 |
| pesticides | $\beta_8$ | -0.22** | -3.41 | 0.23** | 5.02 | -0.23** | -3.14 |
| Sigma-squared | δ2 | 0.29** | | 0.16** | | 0.38** | |
| Gamma | γ | 0.99** | | 0.93** | | 0.92** | |

** Significance at 5%, * Significance at 1%, NS = not significant.
Source: Author's calculation from analysis of survey data 2020/2021.

### 3.3 Factors Influencing Rice Production Cost

The results of the maximum likelihood analyses of the stochastic cost frontier are given in Table 5. Based on the analysis of the effect of the difference in types of irrigation water on rice production cost

**In the case of freshwater**, the result reveals that the variables of labor Cost, fertilizer P Cost, fertilizer N Cost, Pesticides Cost, and rice production have a positive sign and significance at the level of 1% with coefficient values of 0.16, 0.11, 0.35, 0.24, and 0.25. This implies that increasing those variables by 1% would increase the total cost production by 0.16%, 0.11%, 0.35%, 0.24%, and 0.25% respectively. While seed cost and animal work cost has a positive sign with coefficient values of 0.31, 0.12, respectively, at a 5% level of significance. The coefficient of the machinery cost variable is negative signs (0.26) at a 5% level of significance, which means that an increase in the use of machinery in the production process by 1% would decrease the production cost by 0.26%. The variable of fertilizer K is not significant. The gamma value (γ) is equal to 0.90 and significant at the level of 1%. It indicates that 90% of production variations were caused by inefficiencies (ui), and 10% of the variations were outside the farmers' control or measurement error (vi).

Whilst, **In the case of mixed irrigation,** Results indicate that labor cost, machinery cost, fertilizer P cost, fertilizer K cost, fertilizer N cost, have a significant value at a 1% level of significance. With coefficient values of 0.19, 0.32, 0.17, 0.10, and 0.11 this implies that increasing those variables by 1% would increase the total cost production by 0.19%, 0.32%, 0.17%, 0.10%, and 0.11% respectively. Whereas seed costs and animal work costs, have positive signs (0.25, 0.32) at a 5% level of significance. The variable of pesticide cost and Rice production is not significant. Meanwhile, the gamma value (γ) is equal to 0.88 and significant at the level of 1%. It indicates that 88% of production variations were caused by cost inefficiencies (ui), and 12% of the variations were outside the farmers' control or measurement error (vi).

Finally, **In the case of drainage water,** The analysis showed that the coefficient of the seed cost, labor cost, machinery cost, fertilizer P cost, fertilizer K cost, and rice production variable are positive signs of 0.26, 0.17, 0.32, 0.15, 0.09, and 0.25 at a 1% level of significance. This implies that increasing those variables by 1% would increase the total cost production by 0.26%, 0.17%, 0.32%, 0.15%, 0.09%, and 0.25% respectively. Fertilizer N cost and pesticide cost variables are negative signs of 0.19 and 0.32 at a 1% level of significance; this indicates that increasing those variables by 1% would decrease the total cost production by 0.19% and 0.32% respectively. The gamma value (γ) is equal to 0.85 and significant at the level of 1%. It indicates that 85% of production variations were caused by cost inefficiencies (ui), and 15% of the variations were outside the farmers' control or measurement error (vi).

**Table 5.** Estimation Result of Cost Function Stochastic Frontier of Rice

| Variable | Parameter | Freshwater | | Mixing waters | | Drainage water | |
|---|---|---|---|---|---|---|---|
| | | Coefficient | t-value | Coefficient | t-value | Coefficient | t-value |
| Constant | $a_0$ | 1.68* | 2.03 NS | 0.48 NS | 1.23 | 0.67** | 4.52 |
| Seed Cost | $a_1$ | 0.31* | 2.2 | 0.25* | 2.27 | 0.26** | 2.63 |
| Labor Cost | $a_2$ | 0.16** | 3.64 | 0.19** | 5.83 | 0.17** | 4.73 |
| Machinery Cost | $a_3$ | -0.26* | -2.01 | 0.32** | 4.15 | 0.32** | 4.84 |
| animal work Cost | $a_4$ | 0.12* | 2.02 | 0.32* | 2.30 | 0.17 NS | 0.36 |
| fertilizer P Cost | $a_5$ | 0.11** | 11.81 | 0.17** | 6.49 | 0.15** | 8.91 |
| fertilizer K Cost | $a_6$ | -0.14 NS | -0.98 | 0.10** | 3.15 | 0.09** | 3.36 |
| fertilizer N Cost | $a_7$ | 0.35** | 7.02 | 0.11** | 2.57 | -0.19** | -2.82 |
| Pesticides Cost | $a_8$ | 0.24** | 4.68 NS | -0.23 | -0.92 | -0.32** | -3.85 |
| Rice production | $a_9$ | 0.25** | 4.77 NS | -0.12 | -0.93 | 0.25** | 2.99 |
| Sigma-squared | δ2 | 0.39** | | 0.21** | | 0.14** | |
| Gamma | γ | 0.90** | | 0.88** | | 0.85** | |

** Significance at 5%, * Significance at 1%, NS = not significant.

**Source:** Author's calculation from analysis of survey data 2020/2021.

### 3.4 Frequency Distribution of the Technical Efficiency

The frequency distribution of the technical efficiency (TE) of the rice farmers is laid in Table 6.

**In the case of freshwater,** the predicted technical efficiency range is among 0.675 and 1.00, with a mean of 0.963. TE of 4.8% (5 out of 105) of farmers is between 0.71 and 0.80. In addition, 24.8% (26 out of 105) of the farmers have efficiency scores between 0.81 and 0.90. Further, most of the farms (72 out of 105) have efficiency scores between 0.91 and 1.00, and only 2 of the farmers have efficiency scores between 0.61 and 0.70; This denotes that the rice farmers were efficient in deriving maximum output from the input, given the available resources.

On the other hand, **In the case of mixed irrigation,** the results also indicated that the TE range is between 0.556 and 0.999, with a mean of 909. The percentage of TE is equal to 1.4% (2 out of 147) of farmers is between 0.51 and 0.60, and only 3.4% (5 out of 147) of farmers is between 0.61 and 0.70. Further, it is equal to 4.1% (6 out of 147) of farmers is between 0.71 and 0.80. While most of the farmers (84 out of 147) have efficiency scores between 0.91 and 1.00, this denotes that the farmers were efficient in obtaining maximum output from the input, dependent on available resources.

Finally, **In the case of drainage water,** the results revealed that the TE range is between 0.513 and 0.998, with a mean of 0.852. The percentage of technical efficiency is equal to 5% (7 out of 140) of farmers is between 0.51 and 0.60, while 13.6% (19 out of 140) of farmers is between 0.61 and 0.70. Further, it is equal to 12.9% (18 out of 140) is between 0.71 and 0.80. While most of the farmers (59 out of 140) have efficiency scores between 0.91 and 1.00, this denotes that the farmers were reasonably efficient in obtaining maximum output from the input, dependent on available resources.

**Table 6**. Distribution of farmers by production efficiency

| Efficiency Score Range | Freshwater | | Mixing waters | | Drainage water | |
|---|---|---|---|---|---|---|
| | Frequency | % | Frequency | % | Frequency | % |
| 0.51 – 0.60 | 0 | 0 | 2 | 1.4 | 7 | 5.0 |
| 0.61 – 0.70 | 2 | 1.9 | 5 | 3.4 | 19 | 13.6 |
| 0.71 – 0.80 | 5 | 4.8 | 6 | 4.1 | 18 | 12.9 |
| 0.81 – 0.90 | 26 | 24.8 | 50 | 34.0 | 37 | 26.4 |
| 0.91 - 1 | 72 | 68.6 | 84 | 57.1 | 59 | 42.1 |
| **Total** | 105 | 100.0 | 147 | 100.0 | 140 | 100.0 |

**Source:** Author's calculation from analysis of survey data 2020/2021.

### 3.5 Frequency Distribution of the Cost Efficiency

Cost Efficiency (CE) derived from the stochastic frontier model is approached in Table 7.

**In the case of freshwater,** according to the findings, it could be observed that the predicted cost efficiency range is between 1.907 and 1.021, with a mean of 1.274; this indicates that rice farmers have costs that are about 27% above the minimum defined by the frontier. This implies 27% of the cost is wasted relative to farms using the best practices and producing the same output. The percentage of cost efficiency is equal to 62.9% (66 out of 105) of farmers is between 1 and 1.2. Moreover, 29.5% (31 out of 105) of farmers are between 1.3 and 1.5 while, 4.8% (5 out of 105) of farmers are between 1.9 and 2.1. This indicates that the majority of farmers use cost-minimizing input ratios to produce at a given level of output, which represents their propensity to reduce resource waste associated with the production process from a cost standpoint.

Where, **In the case of mixed irrigation,** the results in the same table showed that the range is between 1.023 and 2.005 with a mean CE of 1.384, which means that rice farmers have a cost about 38% above the minimum defined by the frontier. This may mean that 38% of the cost is wasted relative to farms using the best practices and producing the same output. The percentage of cost efficiency is equal to 39.5% (58 out of 147) of farmers between 1 and 1.2. In addition, 38.8% (57 out of 147) of farmers are between 1.3 and 1.5 whilst, 6.8% (10 out of 147) of farmers are between 1.9 and 2.1. This means that the majority of farmers use cost-minimizing input ratios to produce at a given level of output, which represents their propensity to reduce resource waste associated with the production process from a cost perspective.

Finally, **In the case of drainage water,** table 7 it could be noticed that it could be observed that the predicted cost efficiency range is between 1.009 and 2.064, with a mean of 1.442; this implies that rice farmers have costs that are about 44% above the minimum defined by the frontier. This may mean that 44% of the cost is wasted relative to farms using the best practices and producing the same output. The percentage of cost efficiency is equal to 31.4% (44 out of 140) of farmers between 1 and 1.2. As well, 26.4% (37 out of 140) of farmers are between 1.3 and 1.5 whilst, 15% (21 out of 140) of farmers are between 1.9 and 2.1. This implies that the majority of farmers use cost-minimizing input ratios to produce at a given level of output, which represents their propensity to reduce resource waste associated with the production process from a cost perspective.

**Table 7**. Distribution of cost efficiency of rice farmers in Kafr El-Sheikh Governorate, Egypt

| Efficiency Score Range | Freshwater | | Mixing waters | | Drainage water | |
|---|---|---|---|---|---|---|
| | Frequency | % | Frequency | % | Frequency | % |
| 1 – 1.2 | 66 | 62.9 | 58 | 39.5 | 44 | 31.4 |
| 1.3 – 1.5 | 31 | 29.5 | 57 | 38.8 | 37 | 26.4 |
| 1.6 – 1.8 | 3 | 2.9 | 22 | 15.0 | 38 | 27.1 |
| 1.9 – 2.1 | 5 | 4.8 | 10 | 6.8 | 21 | 15.0 |
| **Total** | 105 | 100.0 | 147 | 100.0 | 140 | 100.0 |

Source: Author's calculation from analysis of survey data 2020/2021.

**Conclusions and Recommendations:**

- This research employs stochastic frontier analysis (SFA) correcting for analyzing technical and cost efficiency as well as estimation factors that Influence the Production and cost of rice considering the types of irrigation water as an input in rice production. Using cross-sectional data were collected from 392 rice farmers selected using a multistage random sampling technique representing Al- Hamoul Center, Kafr El-Sheikh Governorate. The data were estimated by using stochastic frontier production function Maximum Likelihood Estimation method with software frontier 4.1. Estimation of production and cost efficiency considering the types of irrigation water is important to stakeholders to increase the productivity of the agriculture sector in a developing country like Egypt. The results of this study can be summarized as follows:
- Freshwater achieved the highest productivity, reaching about 4.3 tons/fed, while mixed water and agricultural drainage water achieved productivity of about 4.1 tons/fed and 3.8 tons/fed, respectively.
- In terms of cost, freshwater bears the lowest cost, estimated at about 7763 L.E, while mixed water and wastewater bear a cost estimated at 8751 L.E, 8821 L.E.
- According to Stochastic Production Function analysis, gamma value (γ) is equal to 0.99, 0.93 0.92, and significant at the level of 1%. It indicates that 99%, 0.93%, and 0.92% of the variation in rice production was due to differences in technical inefficiencies among farmers.
- According to stochastic cost function analysis, the gamma value (γ) is equal to 0.90, 0.88 0.85, and significant at the level of 1%. It indicates that 99%, 0.88%, and 0.85% of the variation in the total cost of production among the sampled farmers was due to the differences in their cost efficiencies
- Most rice farmers who use freshwater have higher mean technical efficiency (0.96) than rice farmers who use mixed irrigation and drainage water estimated at 0.91 and 0.82, respectively this indicates an opportunity to improve technical efficiency among the farmers.
- The average cost efficiency for rice farmers using freshwater, mixed irrigation, and drainage water is estimated at 1.274, 1.384, and 1.442; this implies 27%, 38%, and 1.44 of the cost respectively. This indicates rice farmers who use fresh water have a higher propensity to reduce resource waste associated with the production process from a cost perspective than rice farmers who use mixed irrigation and drainage water

Based on the findings, results the study recommends:

- Preserving water resources from depletion, not by reducing rice areas, but by changing crop irrigation systems.
- In addition to applying modern technologies to raise water use efficiency.
- Expansion of investment in irrigation and drainage development projects. Improving water quality and conducting more chemical analyzes to mitigate these effects.

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