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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Economic Efficiency of Fertilizer Use in Paddy, Canola, and Cotton Production: Evidence from Türkiye

Çeltik, Kanola ve Pamuk Üretimde Kimyevi Gübre Kullanım Etkinliği: Türkiye Örneği

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Abstract

This study analyzes the economic efficiency of fertilizer use in the production of paddy, canola, and cotton in Türkiye. The sampling methods used were; simple random sampling for cotton, stratified sampling for rice, and a complete enumeration method for canola. Primary data were collected from 74 paddy, 83 canola, and 136 cotton producers. The data used in the research pertain to the 2016 production season for cotton and the 2018 production season for rice and canola. Production functions were estimated based on the main input variables for each crop. In paddy production, the coefficient of determination (R^2) was found to be 0.972, the sum of input elasticities (Σbi) was 1.002, and the elasticity coefficient of the fertilizer input was 0.243. The marginal efficiency of fertilizer use in paddy was calculated as 13.67. For canola production, the R^2 value was 0.919, the fertilizer elasticity coefficient was 0.662, and the total input elasticity (Σbi) was 1.004. The marginal efficiency coefficient of fertilizer in canola was found to be 9.39. In the cotton model, the coefficient of determination was 0.915, the elasticity of fertilizer input was 0.263, and the total input elasticity was 0.976. The marginal efficiency of fertilizer in cotton production was calculated as 4.18. In all three models, the fertilizer variable was statistically significant at the 5% level. Additionally, the high R^2 values and statistically significant F-statistics indicate the reliability of the estimated production functions. The results show that fertilizer is not used at an economically optimal level in the examined enterprises for any of the three crops. These findings imply that there is potential to increase both yield per unit area and farm income through improved fertilizer use. In conclusion, increasing the amount of fertilizer applied per unit area in paddy, canola, and cotton production can be considered an important strategy to enhance agricultural productivity and producer profitability.

Keywords: Paddy, Cotton, Canola, Chemical fertilizer, Efficiency, Türkiye

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Öz

Bu çalışma, Türkiye'de çeltik, kanola ve pamuk üretiminde gübre kullanımının ekonomik etkinliğini analiz etmektedir. Yürütülen araştırmada örnekleme yöntemi olarak pamukta basit tesadüfi örnekleme, çeltikte tabakalı örnekleme, kanolada ise tam sayım yöntemi kullanılmıştır. Analizlerde 74 çeltik, 83 kanola ve 136 pamuk üreticisine ait birincil veriler kullanılmıştır. Araştırmada kullanılan veriler pamukta 2016 yılı, çeltik ve kanolada 2018 yılı üretim dönemine aittir. Üretim fonksiyonları, ilgili üretim girdilerine göre tahmin edilmiştir. Çeltik üretimi için oluşturulan modelde belirleme katsayısı (R^2) 0.972, üretim faktörlerine ait esneklik katsayıları toplamı (Σbi) 1.002 ve gübre girdisinin esneklik katsayısı 0.243 olarak hesaplanmıştır. Gübre kullanımının marjinal etkinlik katsayısı ise 13.67 olarak belirlenmiştir. Kanola üretimi için elde edilen sonuçlara göre, belirleme katsayısı 0.919, gübre girdisinin esneklik katsayısı 0.662 ve toplam esneklik değeri 1.004'tür. Gübre faktörünün marjinal etkinlik katsayısı bu ürün için 9.39 olarak hesaplanmıştır. Pamuk üretimi için oluşturulan modelde ise R^2 değeri 0.915, gübre esnekliği 0.263 ve toplam esneklik değeri 0.976'dır. Bu üründe gübrenin marjinal etkinlik katsayısı 4.18 olarak bulunmuştur. Üç ürün özelinde yapılan analizlerde, gübre girdisinin %5 anlamlılık düzeyinde istatistiksel olarak anlamlı olduğu görülmüştür. Ayrıca tahmin edilen üretim fonksiyonlarının yüksek R^2 değerlerine ve anlamlı F istatistiklerine sahip olması, modellerin güvenilirliğini desteklemektedir. Bu çalışma kapsamında ürünler için hesaplanan marjinal etkinlik katsayıları, incelenen işletmelerde çeltik, kanola ve pamuk üretiminde gübre faktörünün etkin bir şekilde kullanılmadığını göstermektedir. Bu durum, işletmelerin birim alandan elde ettiği verimi ve gelir düzeyini artırma potansiyelinin bulunduğunu işaret etmektedir. Sonuç olarak, çeltik, kanola ve pamuk üretiminde gübre kullanım düzeyinin artırılması hem tarımsal verimliliği hem de üretici kârlılığını artırmak açısından önemli bir strateji olarak değerlendirilmektedir.

Anahtar Kelimeler: Çeltik, Pamuk, Kanola, Gübre, Etkinlik, Türkiye

1. Introduction

The global population has been increasing rapidly in recent decades, with projections indicating it will reach 8.5 billion by 2030 and 9.7 billion by 2050. This unprecedented growth presents a substantial challenge to global food security. To meet the rising nutritional demands, it is essential to either expand agricultural production areas and livestock numbers or, more critically, enhance productivity per unit of land or animal.

One of the most effective strategies to achieve higher yields in crop production has been the use of chemical fertilizers. These inputs play a crucial role in supplying essential nutrients that enhance plant growth and increase productivity. However, the steady decline in available arable land due to urbanization, land degradation, and climate change further amplifies the need for higher productivity from existing agricultural areas. This pressure often leads to the increased use of chemical fertilizers, as they offer the fastest and most direct means of improving yield. Nevertheless, while fertilizers contribute significantly to agricultural output, their excessive or improper use can result in serious environmental issues including; soil degradation, water contamination, and reduced biodiversity. Therefore, the efficient and balanced use of fertilizers is essential not only to ensure long-term soil health and sustainability but also to maintain economic viability in agricultural enterprises. Recent years have witnessed a surge in the use of chemical fertilizers, driven by the need to maximize agricultural output amid shrinking arable lands. While chemical fertilizers have contributed significantly to yield increases, their misuse and overuse can result in serious environmental damage, including soil degradation and water pollution (Bulut & Erdal, 2023; Kashem & Singh, 2002). Garai et al. (2020) emphasized that the adoption of high-yielding crop varieties, combined with increased use of fertilizers and other agrochemicals, has played a vital role in enhancing productivity. In contemporary agricultural production, not only the low-cost production of crops but also the relationship between input use and environmental impact has started to play a significant role. In recent years, considerable research has been conducted to determine the energy use efficiency and greenhouse gas emissions associated with the inputs used in the production of rice, cotton, and canola. These studies have also provided detailed information on the quantities of fertilizers applied in the cultivation of these crops (Baran et al., 2021; Özpınar, 2023; Hacıoğlu et al., 2024).

Fertilization, defined as the application of organic or inorganic compounds containing essential plant nutrients to the soil or directly to the plant, aims to enhance plant growth by improving the chemical, physical, and biological properties of the soil. Artificial fertilizers, although effective in increasing crop yields, come with high production costs and can strain the purchasing power of small and medium-scale farmers.

A wide range of studies in agricultural economics have examined fertilizer use and efficiency in crop production by employing production functions and econometric models such as Cobb-Douglas, Translog, and Stochastic Frontier approaches. These studies consistently emphasize the importance of fertilizer inputs in enhancing crop yields and economic returns, while also assessing cost shares, elasticity, and marginal efficiency.

Many researchers included multiple input factors in their models, with fertilizer often showing a significant positive elasticity coefficient. For example, studies on paddy production have frequently found that fertilizer contributes substantially to output increases, though efficiency varies. Suresh and Reddy (2006), and Sikdar et al. (2008) demonstrated the significant elasticity of chemical fertilizers in India and Bangladesh. In Ghana, Nimoh et al. (2012) highlighted fertilizer costs' share in the total variable costs, alongside its positive productivity effect. Similar findings were reported by Adedoyin et al. (2016) and Gözener (2016) for Malaysia and Türkiye, respectively. Studies in Indonesia (Pudaka et al., 2018; Ida and Azhar, 2018) confirmed the positive marginal efficiency of fertilizer, with some differentiating fertilizer types, such as urea and NPK (Bakri et al., 2021).

In canola production, researches such as Taheri-Garavand et al. (2010) and Mousavi-Avval et al. (2011) in Iran found fertilizer costs to be a modest but essential component of total costs, with significant elasticity effects of nitrogen and potash fertilizers (Amiri et al., 2020; Dolatabadi and Ghahremanzadeh, 2016). Similarly, Wambui and Majiwa (2020) reported the positive influence of fertilizers on canola yield in Kenya.

Cotton production studies also underscore fertilizer's critical role. For instance, Çelik and Bayramoğlu (2007) and Chaudhry and Khan (2009) found fertilizer elasticity and marginal efficiency coefficients to be significant in Türkiye and Pakistan, respectively. Abid et al. (2011) and Babangida (2016) similarly highlighted these findings in Pakistan and Nigeria. Recent Turkish studies by Candemir (2021) and Işgın et al. (2023) further validated the positive effects of fertilizer inputs on cotton yields and efficiency.

Across all crop types, the fertilizer cost shares in the total production costs often range from approximately 5% to over 30%, depending on crop and region (Sarker and Alam, 2016; Taheri-Garavand et al., 2010). The econometric analyses generally confirm that optimized fertilizer use enhances productivity and economic returns, but diminishing marginal returns necessitate efficient management strategies.

These findings provide a robust empirical foundation for understanding fertilizer use and its economic impact in agricultural production, guiding the present study's approach to modeling and analysis.

In this context, understanding the economic efficiency and impact of fertilizer use on crop productivity is vital for policy formulation, resource allocation, and sustainable agricultural development. This study investigates the role of fertilizer use in the production of selected crops in Türkiye; paddy (a warm-climate cereal), cotton (an industrial crop), and canola (an oilseed crop). Specifically, the research analyzes the changes in fertilizer costs and support policies over time, and assesses the contribution of fertilizers to crop yield using a Cobb-Douglas production function framework.

By calculating elasticity coefficients and marginal productivity values, the study evaluates how effectively fertilizers are utilized in these crop systems. The results aim to provide insights that will assist farmers, researchers, and policymakers in enhancing input efficiency, reducing production costs, and improving agricultural sustainability in the face of the growing global food demand.

2. Materials and Methods

2.1. Materials

As the main material of this research, cotton data were obtained from 136 agricultural enterprises in the Hatay province during the production period of 2016, which were determined with a 95% confidence interval and a deviation from the 3% average by using the "Simple Random Sampling Method". Rice data were obtained from 74 agricultural enterprises in the Çanakkale province during the production period of 2018, which were determined with a 99% confidence interval and a deviation from the 5% average by using the "Neyman Method from Stratified Sampling Methods". Canola data were obtained from 83 agricultural enterprises using the "Full Counting Method" in the Çanakkale province during the production period of 2018.

2.2. Methods

2.2.1. Method used in sampling

In order to determine the sample volume, the "Simple Random Sampling Method" was used (Yamane, 1967; Çiçek and Erkan, 1996). In ascertaining the enterprises to be included in the sample, agricultural enterprises producing cotton registered in the Farmer Registration System of Hatay Provincial Directorate of Agriculture and Forestry were considered as the main group.

$$n = \frac{NS^2t^2}{(N-1)d^2+S^2t^2} \quad \text{(Eq. 1)}$$

$$D^2 = \left(\frac{d}{t}\right)^2 \quad \text{(Eq. 2)}$$

According to Formula 1 and 2;

n= Sample Volume

N= Total Unit Number (belonging to sampling frame)

S= Standard Deviation

t= Confidence Limit

d= Acceptable Margin of Error

"Neyman Method being one of the stratified sampling methods" was used for the paddy plant (Yamane, 1967; Çiçek and Erkan, 1996).

$$n = \frac{[\Sigma(\mathrm{Nh} * \mathrm{Sh})]^2}{\mathrm{N}^2 * \mathrm{D}^2 + [\Sigma(\mathrm{Nh} * \mathrm{Sh})]^2} \quad \text{(Eq. 3)}$$

In equation 3; n= sample volume, N_h = number of enterprises in the sampling frame belonging to the h layer, S_h = standard deviation of the data in the h layer, S_h^2 = h the variance of the data in the h layer, t= the table value of t for a certain confidence interval, N= the total number of enterprises to the sampling frame, d= deviation from the average at a certain proportion (%).

Primary data in the canola research have been gained by using the "Complete Count Method".

2.2.2. Method used in econometric analysis

In order to determine the production amount of the goods specified in the study and the factors affecting the production amount, the Cobb-Douglas type production function was used in the functional analysis (Doll and Orazem, 1984; Neill, 2003; Beattie et al., 2009; Gujarati and Porter, 2009). The Cobb-Douglas production function is generally used in many branches of agricultural production (Kamanga et al., 2000; Vural and Turhan, 2011). The Cobb-Douglas production function is preferred since it provides the ease of calculation and enables both the determination of return to scale and statistical tests on production elasticity (Heady and Dillon, 1966). The equation for the function can be seen in Equation 4 (Ulveling and Fletcher, 1970).

$$\mathrm{Y} = \mathrm{aX}_1^{\mathrm{b}_1}\mathrm{X}_2^{\mathrm{b}_2}\mathrm{X}_3^{\mathrm{b}_3} \ldots \mathrm{X}_\mathrm{n}^{\mathrm{b}_\mathrm{n}} \quad \text{(Eq. 4)}$$

Taking the logarithm of the equation to transform the function in the exponential pattern into linear form; is written as below in Equation 5.

$$\log \mathrm{Y} = \log\mathrm{a} + \mathrm{b}_1\log\mathrm{X}_1 + \mathrm{b}_2\log\mathrm{X}_2 + \mathrm{b}_3\log\mathrm{X}_3 + \cdots + \mathrm{b}_\mathrm{n}\log\mathrm{X}_\mathrm{n} + \mathrm{e}^\mathrm{u} \quad \text{(Eq. 5)}$$

The "Y" dependent variable in the function refers to the independent variables. It takes these values and shows production elasticity.

With the help of an appropriate statistical package program; the coefficient of determination of regression equation (R^2), production elasticity of independent variables ($\mathrm{b_i}$), standard errors, significance levels ($\mathrm{tb_i}$), geometric averages of variables, test of the presence of autocorrelation and multicollinearity, standard equation deviation, and significance level (F test) have been analyzed (Green et al., 2000). The details of the tests performed in the econometric analysis and the related statistical issues are given below.

Coefficient of Determination (R^2): This refers to the part of the changes in the dependent variable that is explained by the changes in the independent variables. Whether the statistical significance of the multiple determination coefficient is meaningful or not is tested by using the "F test" (Dawson and Lingard, 1982).

Significance Test (Student-t test) of Partial Regression Coefficients (b_i): This investigates whether each of the independent variables that make up the function is meaningful on its own at a certain level of significance. The notation of the "t-test" is given in Equation 6.

$$\mathrm{t}_{\mathrm{b_i}} = \frac{\mathrm{b_i}}{\mathrm{S}_{\mathrm{b_i}}} \quad \text{(Eq. 6)}$$

Given the representation in equation 6, = the coefficient of the variable, $\mathrm{b_i}$ $\mathrm{S_{b_i}}$= refers to the standard error of the coefficient. If the calculated t value is greater than the t_{table} value at the given degree of freedom, the b_i coefficient is statistically significant at the specified level of significance.

Intrinsic Connection (Autocorrelation): The fact that the dependent variable (Y) is related to the error term of the period t and the error term of the period t_{-1} may create an autocorrelation issue. Additionally, incorrect selection of the mathematical pattern that presents the relationship between variables, failure to include some of the independent variables, and measurement errors in the independent variable, could also cause autocorrelation. In the study, "Durbin-Watson Statistics" was used to test the existence of autocorrelation in error terms.

Multicollinearity Issue: If all or some of the variables in the function are highly correlated with each other and the correlation coefficient is more than 0.80, the multicollinearity issue is encountered. If any of the determined coefficients is greater than 0.80, one of the highly correlated variables is excluded from the function and then the process is continued. The methods used in the interpretation of the estimated production function are as follows.

Production Elasticity: At a given level of production, the percentage change ratio that the percentage change will implement on the production amount (Y) in any one of the production factors is expressed as production elasticity. Due to the nature of the Cobb-Douglas type production function, the coefficients of the independent variables in the function indicate the marginal production elasticity of the production factors with which they are related (Heady and Dillon, 1966). In this case, if the sum of the coefficients of production elasticity is ($\sum \beta i$) >1, there is an increasing return to scale, if ($\sum \beta i$) <1, there is a decreasing return to scale, and if ($\sum \beta_i$) =1, there is a constant return to scale.

Average Yield (AY_{xi}), Marginal Yield (MY_{xi}), and Marginal Income (MR_{xi}): At a given level of production, the amount of production corresponding to the unit production factor is expressed as the average yield. The amount of production obtained from the use of the last unit of a production factor is called marginal efficiency. Due to the nature of the Cobb-Douglas type production function, the process is carried out via geometric averages. The average and marginal yields in the Cobb-Douglas production function are seen in equation 7 and equation 8 (Singh et al., 2004; Mobtaker et al., 2010; Rafiee et al., 2010).

$$\text{Average Yield (AYxi)} = \frac{\bar{Y}}{\bar{X}_i} \quad \text{(Eq. 7)}$$

$$\text{Marginal Yield (MYxi)} = \frac{\bar{Y}}{\bar{X}_i} * b_i \quad \text{(Eq. 8)}$$

$\bar{Y}$, shows the geometric mean of the amount of production; $\bar{X}$, represents the geometric mean of the factor of production; and b_i, is considered to be the coefficient of the corresponding factor of production. Marginal revenue (MR) is obtained by multiplying the marginal yield with the product price. The formula used in calculating marginal income is shown in Equation 9.

$$\text{Marginal Revenue (MRi)} = \text{MYxi} * \text{Fy} \quad \text{(Eq. 9)}$$

Marginal Efficiency Coefficient (MEC): The determination of the extent to which the production factor is used effectively is determined by the efficiency coefficient of its factor. The concept of efficiency refers to the maximum use of factors. Effective use of the factor is possible at the point where the marginal income of the relevant factor is equal to its marginal expense. Within the framework of this equation, the marginal income of the factors must be divided by the factor price (the marginal expense of the factor) in order to calculate the efficiency coefficient of the factor (Equation 10).

$$\text{MEC (Marginal Efficiency of Coefficient)} = \frac{\text{Marginal Revenue of the Input}}{\text{Factor Price (Marginal Cost of the Input)}} \quad \text{(Eq. 10)}$$

Accordingly; if $\text{MEC} = 1$ the factor is used effectively, if $\text{MEC} > 1$the factor is used less and the use should be increased, and if $\text{MEC} < 1$the factor is overused and the use should be reduced. Within the research, the unit price or opportunity cost of the variables in the free market was taken into account in determining the factor prices. However, in product prices, the declarations of the enterprise managers who were surveyed were taken as the basis. In the present study, only the marginal efficiency coefficient of the chemical fertilizer input was taken into account and interpreted for cotton, canola, and rice production.

3. Results and Discussion

In crop production, the cost of the product consists of the sum of varying costs and fixed costs. In this analysis, the costs varying on the basis of products and the share of the monetary value related to the amount of chemical fertilizer used in the product cost are given in *Table 1*.

This research examined the share of chemical fertilizer expenses within variable costs and overall production costs. Although capital, labor, and other input usage levels per unit area differed across crops, it was found that the monetary value of fertilizer use per unit area accounted for between 10.79% (cotton) and 23.32% (canola) of the variable costs. Similarly, the share of fertilizer in total production costs ranged from 7.90% (cotton) to 18.42% (canola) (*Table 1*).

Table 1. The share of fertilizer costs in the costs of products

Product name	Varying costs ($ da^{-1})	Fertilizer costs ($ da^{-1})	Share of fertilizer (%)	*Total cost* ($ da^{-1})	Share of fertilizer (%)
Canola	80.23	18.71	23.32	101.58	18.42
Paddy	208.86	24.98	11.96	290.62	8.59
Cotton	222.43	23.99	10.79	303.83	7.90

In the case of paddy production, the share of fertilizer costs in variable expenses was calculated as 11.96%. This figure is higher than the 8.14% reported by Nimoh et al. (2012), but lower than the 33.57% estimated by Adedoyin et al. (2016).

The share of fertilizer costs in the total production cost of paddy was determined as 8.59%, which is slightly below the estimates provided by Suresh and Reddy (2006) at 8.97%, and Siagian et al. (2019) at 12.38%.

For canola production, fertilizer costs constituted 23.32% of the variable costs, and 18.42% of the total production costs. These values are notably higher than the 5.10% share reported by Taheri-Garavand et al. (2010).

Regarding cotton production, fertilizer expenditures made up 10.79% of the variable costs. This proportion is higher than those reported by Yılmaz et al. (2005) at 8.96%, and Dass et al. (2014) at 9.87%; but remains lower than the 24.56% estimated by Canan and Dansoko (2022).

Furthermore, the share of fertilizer costs in the total cost of cotton production was calculated as 7.90%. This is higher than the shares reported by Yılmaz et al. (2005) (5.31%) and Dass et al. (2014) (5.90%), but lower than those found by Chaudhry and Khan (2009) (11.28%), Ahmad et al. (2016) (13.25%), Zulfiqar and Thapa (2016) [21.05% for Better Cotton and 18.56% for Conventional Cotton], and Sarker and Alam (2016) (23.08%).

3.1. Production functions of the products subject to research

3.1.1. Cotton

In the research carried out, the gross production value (₺ da^{-1}) obtained from cotton per unit area was taken into account as the dependent variable (Y) in the estimation equation for the cotton product. The cotton production value has been calculated by adding product quantities to the farmyard prices and the supports given to cotton production. The independent variables in the equation are as follows:

X_1 = Seed price (₺ da^{-1})

X_2 = Chemical fertilizer cost (₺ da^{-1})

X_3 = Energy consumed for irrigation water (₺ da^{-1})

X_4 = Pesticide costs (₺ da^{-1})

X_5 = Harvest costs (₺ da^{-1})

X_6 = Hoeing costs (₺ da^{-1})

X_7 = Land rental value (₺ da^{-1})

As a result of the analysis of the data obtained from the cotton producing enterprises, the production function of the relationship between the gross production value selected as the dependent variable, and the independent variables consisting of the main production costs (production inputs) is as follows:

$$Y = 422.45 * X_1^{0.293} * X_2^{0.263} * X_3^{0.195} * X_4^{0.004} * X_5^{0.124} * X_6^{-0.065} * X_7^{0.162}$$

(S=0.1025; R= 0.956; R^2 = 0.915; F=195.64)

The hoeing cost variable, which is one of the factors in the estimation equation, has a negative character and affects production negatively. In other words, this input is overutilized in canola production. The sum of the elasticity coefficients of the factors in the equation (Σ_{bi} 0.976) expresses the decreasing return to scale.

3.1.2. Paddy

In the research on paddy products, the amount of goods obtained from the unit area (Y) (kg daa^{-1}) was taken as the dependent variable. The independent variables in the function are given below:

X_1 = Amount of seed (kg da^{-1})

X_2 = Electricity used in paddy irrigation (KW da^{-1})

X_3 = Amount of pure chemical fertilizer (kg da^{-1})

X_4 = Amount of pesticide (lt da^{-1})

X_5 = Amount of diesel fuel used in production (lt da^{-1})

X_6 = Labor used in irrigation (hour da^{-1})

The functional relationship between the dependent variable (Y) and the independent variables (X_i) in paddy production is given below:

$$Y = 8.721 * X_1^{0.284} * X_2^{0.053} * X_3^{0.243} * X_4^{0.119} * X_5^{0.398} * X_6^{-0.095}$$

($S=0.172$; $R= 0.986$; $R^2 = 0.969$; $F=386.39$)

Among the factors in the estimation equation, the labor force variable used in irrigation has a negative character and affects production negatively. However, the specified production factors are excessively utilized in rice production. The sum of the elasticity coefficients of the factors in the equation (Σ_{bi} 1.002) expresses the constant returns to scale.

3.1.3. Canola

Within the study, the production value of the product (₺ da^{-1}) was included as the dependent variable in the canola production function. The independent variables in the canola production function are given below:

X_1 = Chemical fertilizer cost (₺ da^{-1})

X_2 = Pesticide cost (₺ da^{-1})

X_3 = Seed price (₺ da^{-1})

The functional relationship between the dependent variable (Y) and the independent variables (X_i) in canola production is shown below:

$$Y = 1.281 * X_1^{0.662} * X_2^{0.110} * X_3^{0.232}$$

($S=0.131$; $R= 0.922$; $R^2 = 0.919$, $F=312.79$)

All of the factors in the estimation equation are of positive character. The sum of the elasticity coefficients of the factors in the equation (Σ_{bi} 1.004) expresses the constant returning to scale.

3.2. Basic statistics of the production function of the products subject to research

The basic statistical information about the production function prepared in the research, is given in *Table 2*. The coefficients of determination (R^2) of the production functions vary between the values of 0.915 and 0.972. Among the products, it was calculated that the lowest coefficient of determination was for the cotton production function (0.915), and the highest coefficient of determination was for the paddy production function (0.972). The calculated coefficients of determination show that the independent variables which take place in the estimation functions adequately explain the dependent variables, or the changes in the amount of production obtained. In addition, the "F-Statistic" values related to the functions were found to be statistically significant at the level of 1% for all functions.

The determination of the existence of a possible intrinsic correlation (autocorrelation) in the estimation equations was tested with the help of the "Durbin-Watson Statistical Value". It has been determined that there is no internal connection presence due to the fact that DWcalc> DWU for all functions in the research (*Table 2*).

Table 2. Base statistics regarding to functions of the products

Product name	Determination coefficient (R^2)	"F - value"	Significance level	"DW statistical value"
Cotton	0.915	195.640	0.01	$DW_{calc.\ 1.739} > DW_{U(0.05)\ 1.717}$
Paddy	0.972	386.390	0.01	$DW_{calc.\ 1.871} > DW_{U(0.05)\ 1.834}$
Canola	0.919	312.790	0.01	$DW_{calc.\ 1.606} > DW_{U(0.01)\ 1.578}$

3.3. Elasticity coefficients and significance levels related to the fertilizer factor

The elasticity coefficients and the significance levels of the fertilizer factor used in the products examined are given in *Table 3*. When the total values of the elasticity coefficients of the factors on the basis of products are examined; it is understood that there is an increasing return to scale in paddy and canola crops, while there is a decreasing return to scale in cotton. Increasing returns to scale indicate profitable production. Fixed returns to scale show the level at which enterprises cover all their expenses and make sufficient profits. Decreasing returns to scale indicate that the expenses of the enterprises exceed their incomes, resulting in losses.

Table 3. Elasticity coefficients and significance levels of fertilizer factor in products

Product name	"Elasticity coefficient (bi)"	Standard error (SβI)	"T - value"	Significance level	Sum of elasticity coefficients (Σ b_i)
Cotton	0.263	0.098	2.651	0.050	0.976
Paddy	0.243	0.112	2.160	0.050	1.002
Canola	0.662	0.080	7.821	0.050	1.004

Elasticity coefficients show the level of partial productivity of the inputs in question on the produced goods. The total values of the coefficients express the total level of productivity of the factors involved in production. Among the prepared estimation functions, the elasticity coefficient value for fertilizer was calculated as 0.243 for paddy, 0.263 for cotton, and 0.662 for canola (*Table 3*).

In the study, the elasticity coefficient of the fertilizer in cotton, paddy, and canola production functions was found to be statistically significant at the level of 5%. These values show that the fertilizer factor has a significant effect on the amount of output in crop production (*Table 3*).

3.4. Marginal efficiency coefficients of the fertilizer factor

The marginal efficiency coefficient in the products examined is obtained by dividing the marginal product value of the fertilizer by the fertilizer price. The marginal coefficient of effectiveness refers to the ratio of the marginal product value to the last fertilizer unit used. The marginal product value is obtained by multiplying the product price with the change that the last fertilizer unit has caused in the product amount. In other words, it gives the product value in $ for the $1 paid for the last unit of fertilizer spent (*Table 4*).

Table 4. Marginal product value and efficiency coefficients of fertilizer factor on the basis of products

Product name	Geometric mean ($Y_{product}$)	Geometric mean ($X_{fertilizer}$)	Marginal product value ($)	Factor price ($ kg^{-1})	Marginal efficiency coefficient
Cotton	1024.00	59.05	1.29	0.31	4.18
Paddy	68060.17	3125.85	2.92	0.21	13.67
Canola	22666.25	2885.54	2.01	0.21	9.39

The point where the marginal product value is equal to the marginal product price in the continuation of the activities of agricultural enterprises, could also be expressed by the marginal efficiency coefficient. The findings obtained in the analysis reveal that the fertilizer factor is used less in all products and should be increased. Likewise, for every $1 spent, the product value obtained has a return of over $1. For instance, for every $1 of fertilizer spent in the production of the goods in this research, incomes such as; $4.18 for cotton, $9.39 for canola and $13.67 for paddy, could be gained (*Table 4*). Thus, it is understood that the fertilizer factor is used less than the economic optimum point in all of the products examined. In order to obtain more product and product value from the fertilizer used, the amount of fertilizer use per unit area must be increased.

It is known that fertilizers are not used at the desired level in crop production in Türkiye. In this study, it is revealed that the use of fertilizers is not effective economically in the products examined. In other words, enterprises use fertilizer inputs below the optimum level in order to reach the economically optimum point in the production of goods. The main factor here is that although fertilizer prices did not show a significant change in the 2015-2020 period (when we evaluate the prices according to the $ exchange rate); the fact that both the increase in product prices remained below the inflation level and the fertilizer support given per unit area decreased by nearly 50% in the same period; have significantly affected the amount of fertilizer that should be used per unit area. To conclude, the level of fertilizer consumption in the examined enterprises was not at the desired level due to both internal and external factors.

3.5. Comparison of the findings

3.5.1. Paddy production

In the research by Suresh and Reddy (2006), the coefficient of determination (R^2) for the paddy production function was calculated as 0.863. The elasticity coefficient of the chemical fertilizer variable was found to be 0.17 and statistically significant at the 1% level. The marginal efficiency coefficient of the fertilizer variable was determined as 2.83. The sum of the elasticity coefficients of the variables in the model was 1.394, indicating increasing returns to scale in paddy production.

Sikdar et al. (2008) conducted a study where the elasticity coefficient of the chemical fertilizer variable in the paddy production function was 0.1597 and statistically significant at the 1% level. The total of the elasticity coefficients was 0.908, suggesting decreasing returns to scale.

An examination by Nimoh et al. (2012) identified an R^2 value of 0.6468 and a DW statistic of 2.1137. The elasticity coefficient of chemical fertilizer was 0.1804, significant at the 17% level. The marginal efficiency coefficient was 1.76, and the total elasticity of inputs was 0.5782, indicating decreasing returns to scale.

Gözener (2016) calculated the R^2 value as 0.995. The elasticity of the chemical fertilizer factor was 0.0451, statistically significant at the 5% level. The sum of elasticities was 1.9839, indicating increasing returns to scale.

An inquiry by Adedoyin et al. (2016) found that chemical fertilizer accounted for 33.57% of total variable costs. The R^2 value was 0.897, and the elasticity coefficient of chemical fertilizer was 0.5033, significant at 1%. The marginal efficiency coefficient was 0.06, suggesting excessive fertilizer use. The sum of elasticities was 1.072, indicating increasing returns to scale.

Kaka et al. (2016) reported an elasticity coefficient of 0.8963 for chemical fertilizer, significant at 10%. The total elasticity was 1.4909, indicating increasing returns to scale.

In an investigation by Kanthilanka and Weerahewa (2016), the elasticity of urea fertilizer was 0.229, significant at 5%. However, triple super phosphate (-0.075) and potash (0.030) were not statistically significant. The total elasticity was 0.762, indicating decreasing returns to scale.

Yumnam et al. (2016) discovered R^2 values of 0.6016 and 0.6759 for small and large-scale farms in Himachal Pradesh. The elasticity coefficients for fertilizer were 0.1344 (significant at 5%) and 0.1442 (not significant). In Manipur, small-scale enterprises had an R^2 of 0.7327 and elasticity of 0.1488 (not significant); while large-scale enterprises had an R^2 of 0.7281 and elasticity of 0.3616 (significant at 1%). The corresponding sums of elasticities were 0.5342, 0.4765, 1.6200, and 1.1623, respectively.

Sonawane et al. (2017) calculated an R^2 of 0.65. Fertilizer elasticity coefficients were 0.0302 (N), -0.045 (P), and 0.0199 (K), none of which were statistically significant. However, the elasticity of manure was 0.0251, significant at 10%. The total elasticity was 0.4902, indicating decreasing returns to scale.

A report by Pudaka et al. (2018) found an R^2 of 0.9802 and a DW statistic of 1.776. The fertilizer variable was significant at 20%, with a marginal efficiency coefficient of 9.5422, suggesting underuse.

Ida and Azhar (2018) identified an R^2 of 0.867. The elasticity coefficient for fertilizer was -0.288, significant at 1%. The marginal efficiency coefficient was 17.17, indicating overuse. The sum of elasticities was 1.282, showing increasing returns to scale.

An analysis by Siagian et al. (2019) showed an R^2 of 0.798. None of the seven fertilizer types were statistically significant. The marginal efficiency coefficient was 2.83, indicating insufficient use. The sum of elasticities was 0.971, indicating decreasing returns to scale. The fertilizer cost share was 12.38%.

Bakri et al. (2021) found an R^2 of 0.477. Fertilizers were grouped into urea (0.210), NPK (0.154), Tabas (0.303), and DMA (0.089), none of which were significant. Marginal efficiency coefficients were 7.67, 6.41, 8.80, and 7.18, respectively, indicating underuse. The total elasticity was 1.529, suggesting increasing returns to scale.

In Bangladesh a research by Hoque et al. (2022) observed a fertilizer price index elasticity of 0.260, significant at 5%.

In a recent examination from Türkiye, Yüzbaşıoğlu and Abacı (2023) reported an R^2 of 0.69 and a total elasticity of 0.19. The elasticity of fertilizer per unit area was 0.233, significant at 5%.

In the present study, the R^2 value was 0.972—higher than those found by Suresh and Reddy (2006), Nimoh et al. (2012), Yüzbaşıoğlu and Abacı (2023), Adedoyin et al. (2016), Yumnam et al. (2016), Sonawane et al. (2017), Ida and Azhar (2018), Siagian et al. (2019), and Bakri et al. (2021); but lower than those by Gözener (2016) and Pudaka et al. (2018).

The elasticity coefficient for fertilizer use was 0.243, significant at 5%, and higher than most prior research, including Suresh and Reddy (2006), Sikdar et al. (2008), Nimoh et al. (2012), and others, but lower than values reported by Adedoyin et al. (2016), Kaka et al. (2016), and Hoque et al. (2022).

The sum of the elasticity coefficients was 1.002, indicating constant returns to scale. This value is higher than those reported in some analyses (e.g., Sikdar et al., 2008; Kanthilanka and Weerahewa, 2016), and lower than others (e.g., Suresh and Reddy, 2006; Gözener, 2016; Kaka et al., 2016).

The marginal efficiency coefficient for fertilizer was 13.67, higher than the values in previous studies (e.g., Suresh and Reddy, 2006; Pudaka et al., 2018; Bakri et al., 2021). The closer the marginal efficiency coefficient is to 1, the more optimal the fertilizer use. The findings suggest that in both the present and past inqiries, fertilizer has not been used at its economically optimal level.

3.5.2. Canola production

In the investigation by Mousavi-Avval et al. (2011), the elasticity coefficient of fertilizer use on canola yield was found to be 0.16 and statistically significant at the 5% level. The coefficient of determination (R^2) of the estimation equation was 0.98, and the Durbin-Watson statistic was 2.02. The sum of the elasticity coefficients for canola production was calculated as 0.95, indicating decreasing returns to scale.

In Dolatabadi and Ghahremanzadeh's (2016) research, the elasticity coefficient for nitrogen fertilizer was 0.163 and significant at the 10% level.

Amiri et al. (2020) reported elasticity coefficients of -2.32 for potash fertilizer and -0.32 for organic fertilizer, both significant at the 1% level.

Wambui and Majiwa (2020) found the elasticity coefficient of the fertilizer variable in their production function to be 0.247, also significant at the 1% level.

In this study, factors influencing canola production were analyzed using a production function. The R^2 of the estimation equation was 0.919, which is slightly lower than that reported by Mousavi-Avval et al. (2011) [0.98].

The elasticity coefficient of fertilizer use was estimated at 0.662 and was shown to be statistically significant at the level of 5%. This value is higher than those reported by; Mousavi-Avval et al. (2011) [0.16; 5%], Dolatabadi and Ghahremanzadeh (2016) [0.163; 10%], and Wambui and Majiwa (2020) [0.247; 1%].

The total elasticity of input factors in canola production was calculated as 1.004, suggesting increasing returns to scale. This value is higher than the 0.95 reported by Mousavi-Avval et al. (2011).

The marginal efficiency coefficient of fertilizer use was identified as 9.39, indicating that fertilizer is being used below the economically optimal level. In monetary terms, for every $1 spent on fertilizer, $9.39 in income is generated. The closer this value is to 1, the more efficiently fertilizer is being used. However, due to the lack of comparable studies on this coefficient, no further comparisons could be made.

3.5.3. Cotton production

In an analysis by Gaddi et al. (2002), the elasticity coefficient of fertilizer in cotton production was -0.1002 and not statistically significant. The R^2 value was 0.7696, and the F-statistic was significant at the 1% level.

Çelik and Bayramoğlu (2007) reported an R^2 of 0.847 and a significant F-statistic at the 1% level. The elasticity coefficients for nitrogen and phosphorus fertilizers were -0.0071 and 0.0136, respectively, and both were statistically insignificant.

An investigation by Chaudhry and Khan (2009) involving 100 farmers in Pakistan, found elasticity coefficients of 0.191 for DAP fertilizer (significant at 10%) and 0.158 for urea fertilizer (significant at 5%). The sum of the elasticity coefficients was 1.056, indicating increasing returns to scale. Marginal efficiency coefficients were 4.18 for DAP and 4.092 for urea, suggesting insufficient fertilizer use.

Abid et al. (2011) observed an R^2 of 0.76 (significant at 1%) and a total elasticity coefficient of 1.27, indicating increasing returns to scale. The elasticity coefficient of fertilizer was 0.20 (significant at 10%), and the marginal efficiency coefficient was 1.50, showing fertilizer was underutilized.

The research by Zahedi et al. (2014) calculated an R^2 of 0.94 and a Durbin-Watson statistic of 1.98. The sum of elasticity coefficients was 1.15, also indicating increasing returns to scale. The elasticity coefficient of chemical fertilizer was 0.11 and significant at the 1% level.

In Babangida's (2016) study, the total elasticity coefficient was 0.68 (indicating decreasing returns to scale). The elasticity coefficient for fertilizer was 0.3578, significant at the 1% level.

Ahmad et al. (2016) reported an elasticity coefficient of 0.319 for fertilizer, significant at the level of 1%.

In Pakistan, Wei et al. (2020), identified an R^2 of 0.5941, with the F-statistic significant at the 1% level. The elasticity coefficient of fertilizer cost was 0.019 and not statistically significant. The total elasticity was 0.259, indicating decreasing returns to scale.

Using the Tobit Model in Türkiye, Örük (2020) found elasticity coefficients of 0.0011 for nitrogen, -0.0024 for phosphorus, and 0.0048 for potash fertilizers all significant at the 1% level. The results suggested a negative impact of phosphorus fertilizer on cotton income.

Candemir (2021) observed an R^2 of 0.853, an F-statistic significant at 1%, and a Durbin-Watson statistic of 2.339. The total elasticity was 0.982 (decreasing returns to scale). The elasticity coefficient for fertilizer cost was the highest at 0.606 and significant at 1%. The marginal efficiency coefficient was 1.38, indicating fertilizer was underutilized.

An analysis by Işgın et al. (2023) showed the elasticity coefficient for chemical fertilizer in cotton production to be 0.02476 (statistically insignificant). The total elasticity was 0.96639, again indicating decreasing returns to scale.

In this investigation, the R^2 of the cotton production function was 0.915, which is higher than the values reported by Gaddi et al. (2002) [0.7696], Çelik and Bayramoğlu (2007) [0.847], Abid et al. (2011) [0.76], Wei et al. (2020) [0.5941], and Candemir (2021) [0.853]; but lower than Zahedi et al. (2014) [0.94].

The elasticity coefficient of fertilizer use was estimated at 0.263 and shown to be significant at the 5% level. This value is higher than those reported by several studies (e.g., Gaddi et al. 2002; Wei et al. 2020; Örük 2020), but lower than values reported by Babangida (2016) [0.3578], Ahmad et al. (2016) [0.319], and Candemir (2021) [0.606].

The total elasticity (Σbi) for cotton production was found to be 0.976, indicating decreasing returns to scale. This value is higher than those of Babangida (2016) [0.68], Wei et al. (2020) [0.259], and Işgın et al. (2023) [0.96639]; but lower than Chaudhry and Khan (2009) [1.056], Abid et al. (2011) [1.27], Zahedi et al. (2014) [1.15], and Candemir (2021) [0.982].

The economic efficiency of fertilizer use in cotton production was also examined in this research. Findings revealed that fertilizer is being used below the optimal economic level. The marginal efficiency coefficient was calculated as 4.18, indicating a need to increase fertilizer use. This value was higher than those reported by Abid et al. (2011) [1.50] and Candemir (2021) [1.38], and nearly equal to the values found by Chaudhry and Khan (2009) [DAP: 4.18; Urea: 4.092].

4. Conclusion

This study examined the economic effectiveness of fertilizer use in the production of paddy, canola, and cotton in Türkiye through the Cobb-Douglas production function framework. The findings demonstrate that although chemical fertilizers are a statistically significant input across all three crops, they are not utilized at the economically optimal level in any of the analyzed enterprises.

The marginal efficiency coefficient of 13.67 for paddy, 9.39 for canola, and 4.18 for cotton, indicate a substantial gap between current and optimal fertilizer use, suggesting that yield and income levels could be significantly improved with more efficient input allocation. Furthermore, elasticity coefficients of the fertilizer factor were statistically significant at the 5% level across all crops, reaffirming its critical role in crop productivity.

Despite the increasing importance of fertilizer use in Türkiye's crop production since the 2000s; the heavy reliance on imported raw materials and insufficient financial support mechanisms (such as reduced fertilizer subsidies per hectare), have hindered producers from applying fertilizers at the required levels, especially under high inflation conditions.

The study also revealed varying returns to scale, constant in paddy (Σbi = 1.002), increasing in canola (Σbi = 1.004), and decreasing in cotton production (Σbi = 0.976); which points to structural differences in production efficiency across crops. These findings emphasize the need for targeted policy interventions including; the rationalization of fertilizer subsidies, encouragement of soil analysis-based fertilization, and reduction in import dependency for fertilizer raw materials.

Agricultural production support policies in Türkiye have undergone significant changes over time. However, producers are generally dissatisfied with the agricultural support policies currently in place. This is because, in the case of rice for example, the cost of chemical fertilizer applied per unit area exceeds the fertilizer subsidy provided. Therefore, agricultural subsidies should, in general, be sufficient to cover a certain portion of production costs.

The findings of the study reveal that the use of chemical fertilizers in rice, canola, and cotton production is far from achieving economic optimization. At this stage, increases in chemical fertilizer prices cause producers to apply fertilizer amounts below the economically optimal level. In this context, ensuring that producers have access to chemical fertilizers under more favorable conditions is of critical importance.

In conclusion, improving fertilizer efficiency is not only essential for increasing yields and income but also for ensuring input sustainability in the face of economic volatility. Promoting practices such as soil analysis-based fertilization, revising support mechanisms, and investing in domestic fertilizer production capacity may help close the gap between current and optimal input use ultimately contributing to a more resilient and productive agricultural sector. Ultimately, the results underscore the critical importance of enhancing fertilizer use efficiency to unlock the yield potential and income levels of key agricultural products in Türkiye.

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Ethical Statement

There was no requirement to obtain ethics committee approval in the years of 2017, 2018 and 2019 when the data of this study were collected.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Semerci, A.; Design: Semerci, A.; Data Collection or Processing: Semerci, A., Çelik, A.D.; Statistical Analyses: Semerci, A..; Literature Search: Semerci, A., Çelik, A.D.; Writing, Semerci, A.; Review and Editing: Çelik, A.D.

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