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Assessment of technical efficiency in corn crop farming: Application of stochastic frontier production function

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Abstract

Agricultural expansion, such as the expansion of corn cultivation, is often supported with intensive farming practices and leads to land loss. Optimizing input practises could potentially increase output and income while reducing land area. This study aims to investigate the capacity of inputs, such as land and other factors, to influence production in terms of technical efficiency, and to investigate the best input practices on the technical efficiency of corn. This study uses both primary and secondary data to answer the research objectives. In this study, corn datum was collected for the 2024 planting season. A stratified random sampling method was applied to randomly select 120 farmers as a sample based on the land area. Appropriate qualitative and quantitative data analysis methods were used, differentiated based on their research objectives, using an empirical production function model and a technical efficiency model. The results show that all inputs have an effect on increasing corn yields, and support technical efficiency, which maximises the effect of input use. However, the impact of putting it into use on output appears to be got through other means, but technical efficiency has improved.

Keywords: Best Input Praktices; Corn Farming; Technical Efficiency

1. Introduction

One agricultural commodity that continues to be expanded to improve food security is corn. Specifically, corn is a food crop that is beneficial for both humans and animals. To date, corn remains the second most strategic commodity after rice. From a market perspective, corn marketing potential continues to increase [1]. This is evident in the ever-increasing demand for corn in Indonesia, which is now quite large, amounting to more than 10 million tons of dry corn kernels annually. The largest consumption of corn is for animal feed, as corn accounts for 51% of the raw material for animal feed, especially poultry.

What's more, agriculture plays a significant role in absorbing labour, as most of the population in Jambi province who live in rural areas are still working hard[2]. The problem is that the land area is quite large, narrow, the level of production and productivity of corn fluctuates because the level of soil fertility is quite low and the rainy season is quite short [3]. Consequently, the productivity of corn planting across the country remained low in 2018, with yields in Jambi province at 2.67 tonnes per hectare [4]. One of the corn producing areas in Indonesia is Jambi, which is a province that prioritizes economic development in the agricultural sector, especially in the food crop

Sub-optimal land such as peatland has the potential to be explored as agricultural land, considering its large area spread throughout Indonesia. More than 38 million hectares of sub-optimal land in the tropics, about 8.7 million hectares (22.89%) is cited in Jambi, most of which is still forest and only a small part has been planted as agricultural land. This causes sub-optimal land to have quite potential for the expansion of agricultural areas and at the same time, it can also

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increase the production of crops, such as corn [1]. While corn production has varied relatively well over the past five years, this condition may be rather difficult to occur in the future. Production developments obtained in the corn sub-sector activities in Jambi are designed on the New Order era (1986-1988) and the reform era (1989-2024) from the types of available land typologies. The varying results will illustrate the possibility of uncertainty and risk factors in corn farming. Likewise, the economic crisis and the financial problems faced, have an impact on reducing the input subsidy program [2-3]. In this situation, agricultural policy experts seek to explore the issue of production supply and demand for inputs for corn commodities. The findings of production supply problems such as changes in the use of production factors have been exposed in several papers [4]. However, research on price changes in production supply and input demand remains sparse.

Moreover, Muaro Jambi Regency has a very important role in producing corn and is very productive to improve the regional economy, with an area of 319 hectares, and a harvest of 851.73 tons, so that the average productivity level is 2.67 tons/hectare [4]. Although the development of corn production has achieved results in the past few years, it may be difficult to replicate in the future[5]. In the New Order period (1986-88) and the Reform period (1989-2024), three existing corn land types were divided from the Jambi Province Corn Crop Development Plan, and production data were extracted from them. Different yield levels will reflect the severity of various risk factors in corn cultivation. In addition, due to the economic crisis and financial difficulties have resulted in a reduction in best input practices for corn farming [6].

From this perspective, some agricultural policy experts are very interested in observing the supply and demand response of corn farmers to their inputs. Estimation of supply responses, such as changes in input usage, has been studied in several studies [7-9]. However, few studies have been conducted on input responses related to technological efficiency. Production data divided from a corn crop development programme in Muaro Jambi district, Jambi province, comes from a peatland type that is showing signs of decline. Different yield levels reflect the severity of various risk factors in corn cultivation. In addition, due to the economic crisis and financial difficulties have resulted in a reduction in best input practices for corn farming [6].

Given these conditions, agricultural policy experts are eager to provide the best response to corn farming. Estimates of agreement responses such as changes in input usage have been explained in several studies [8, 10]. However, few people have studied the best input practises for improving technological efficiency. The main problem with corn crops in Muaro Jambi district is that yields remain very low. The factor causing this low productivity is due to the limited ability of farmers to allocate inputs such as seeds, fertilizers, peat land, and appropriate pesticides [1]. This low level of productivity is likely to be come from by best input practices that tend to vary annually, especially the increase in chemical fertilisers and pesticide prices [1].

Technical efficiency is a crucial issue for productivity improvement due to limited inputs and limited opportunities for developing and adopting effective technologies [11-12]. Income can be increased by maximising corn yield through optimising input combinations and improving crop technology efficiency. Hence, increasing technical efficiency can be achieved by improving farmers' management skills. Hence, the research problem can be expressed as follows: What input factors affect the productivity of corn planting? Are the inputs used in corn cultivation effective? What investments affect technical efficiency?

2. Methods

The production function pertains to the allocation of inputs and the resulting output levels [13]. The goal of input allocation is to maximize the amount of output with a given number of inputs used. The production function is a function that describes the mathematical relationship between inputs used to produce a given level of output[14]. The production function can be explored as follows:

$$Q = f(K, L, M, \ldots) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where Q is the output of a specific product in a certain period, K is the capital invested in that period, and L is the labour invested in that period (in hours).Where M represents the amount of raw materials used during that period, and so on.

The levels of capital, labour, and raw material usage can be explained from formula (1). The more appropriate the combination of input factors, the more likely the output is to reach the optimal level. [14] It is pointed out that the production process at the corn planting level generally follows the Cobb-Douglas function relationship model. The Cobb-Douglas function has several advantages, including (1).

Contrasted to other production functions, it is relatively easy and simple because it can be changed into a simple linear form, (2). The ranking coefficient also shows the magnitude of the optimal production elasticity of production factor use, as well as (3). The elasticity of each factor of production is estimated as the product of the business scale (returns to scale) of the factors of production used in an ongoing production process. Disadvantage of using the Cobb-Douglas function as an analysis tool is (1).

Incorrect variable settings can lead to negative production elasticity, or values that are too large or too small, (2). This measurement variable error lies in the validity of the data, that is, whether the data used is correct, or whether it is too high or too low. This measurement error will cause the elasticity to be too high or too low. In practise, management is an important factor in increasing output, but this variable is sometimes difficult to measure and is difficult to use as an independent variable when using the Cobb-Douglas function[14].

2.1. Technical Efficiency Model

In research, technical efficiency analysis [15-16] can be applied through the use of the following equation:

$TE_i = E [\exp(-U_i) / e_i]$ i = 1, 2, 3, ...N .... (2)

TE_i is the technical efficiency of the producer i, and Exp. (- E [Ui | ei]) is (average) value expectation of u_i when using ∑i, so $0 \leq TE \leq 1$. The technical efficiency value is unrelated to the technical inefficiency effect. This effect can also be linked to functions that have a certain amount of output from a certain input (cross-sectional data). When the technical efficiency value is greater than 0.7, the technical efficiency is valued as fairly efficient; when the technical efficiency value is less than or equal to 0.7, the technical efficiency is valued as not efficient.

According [17], the production efficiency theory is an extension of basic economic theory. It uses limited inputs to obtain the highest output, or to obtain a certain level of output at the lowest possible cost. Production efficiency refers to the relative size of an enterprise's capacity to use inputs to obtain a certain number of inputs at a technological level [18]. If the rules are used to agricultural production activities, farmers will strive to achieve a high level of efficiency in applying best practise inputs [19]. If farmers do not apply inputs efficiently, then there is the potential that these inputs have not been used optimally to increase agricultural profits and obtain surplus. Conversely, if farmers invest effectively, then they can make additional contributions to agriculture only by exploring efforts that take into account growth in the field [20].

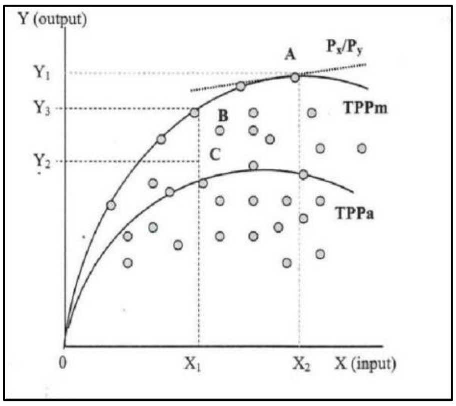

Figure 1 Frontier Production Function

[15, 21] illustrates three types of efficiency in Figure 1. above. The TPP_m curve shows the maximum possible output as X increases, which also shows the frontier production function (frontier production function), and TPP_a shows the average product, which is usually explored using the Ordinary Least Squared (OLS) technique. Every input that successfully produces output is right on the TPP_m production curve (maximum output), then the amount of input usage referred to as production activity reaches maximum output, while the output achieved below the TPP_m curve was called as technical inefficiency.

The criterion for maximising social profit will be satisfied at the optimal level of input into production, for example, if the input level is X_i and the output is Y_1, i.e., point A. At point C, each company that uses input X_2 and produces output Y_2 achieves the dual goals of technical efficiency and configurational efficiency. The level of efficiency achieved is Y_2 /

Y_3. In other words, a company can achieve technical efficiency by using input X_2 to produce Y_2 at point B, but it cannot achieve allocation efficiency. Then, its configuration efficiency is Y_3 / Y_1, and its economic efficiency is Y2 / Y1 [22-24].

This study was explored in the Muaro district of Jambi province, as the area is one of the peatland corn production centres in Jambi province. As well, the Kumpeh sub-district was chosen as the research site. The research site was chosen because it is a corn production centre in the Muaro Jambi district and represents a peatland type. This study was conducted in early 2025. This study is explored in the Kumpeh sub-district of Muaro Jambi district because farmers in this district are more than productive in growing corn, which could help researchers obtain first-hand data. A total of 120 people were randomly used using stratified random sampling. This study used both primary and secondary data. Meanwhile, to see the conditions, almost all the data from the 2024 planting season was used from the central villages and the area was determined purposively because of its location, namely the corn crop centre in Kumpeh sub-district, Muaro Jambi Regency and is the peatland typology.

The selected areas were chosen from corn cultivation, high corn yields, and peatland areas representing large and medium-sized farmers. In estimating the empirical model, the study used the Cobb-Douglas production function. According to [25], this function is applied to observe the input-output relationship in the stochastic frontier function equation. It is operated in two stages. First, the production input coefficients are evaluated using the ordinary least squares (OLS) method. Second, it is explored by applying the Maximum Likelihood Estimation (MLE), A method for estimating all production parameters f_m, intercept f_0, and factor variance using error components vi and ui [26]:

$$Y = \beta 0\, X_1^{\beta 1}\, X_2^{\beta 2}\, X_3^{\beta 3}\, X_4^{\beta 4}\, X_5^{\beta 5}\, X_6^{\beta 6}\, e^{vi-ui.} \quad \ldots\ldots (3)$$

The study applies the trans-log function on an empirical model of the production function.

$$\text{Log } Y = \beta_0 + \beta_1 \text{ Log } X_1 + \beta_2 \text{ Log } X_2 + \beta_3 \text{ Log } X_3 + \beta_4 \text{ Log } X_4 + \beta_5 \text{ Log } X_5 + \beta_6 \text{ Log } X_6 + (v_i - u_i) \quad \ldots\ldots(4)$$

where : variable Y is corn production (kg); X_1 is land area (ha); X_2 is seed (kg); X_3 is urea fertilizer (kg); X_4 is fertilizer NPK (kg); X_5 is pesticides (Litre); X_6 is labour (HOK); and β_0 is an intercept; $\beta_1 - \beta_6$ is a parameter, and v_i - u_i represents the error term.

Estimation of the production function uses a sample using a two-stage method. The chi-square test is used to estimate the production function. The estimation results obtained by using the two-stage method are consistent [22]. To get the level of technical efficiency of corn plants, it can be evaluated by applying the equation:

$$TE_i = exp\ (- E[U_i|e_i].\ i = 1, ..., n \quad \ldots\ldots(5)$$

where [27] TE_i is technical efficiency done by the i-farmer; exp. (- E [U_i | e_i] is expected value of U_i with the 1.

3. Results and Discussion

Data showed that average yield per hectare is about 10,44 tons, the average land use is 2.27 hectares, and it requires 19,8 hours of labour, 101,27 kilograms of urea fertilizer, 75,22 kilograms NPK fertilizer, 2.80 litre pesticide, and 3 activity extension activities. Production function analysis aims to determine how the use of production inputs such as land area, seeds, fertilisers, pesticides, and labour affects production. How is the production response to the use of production factors? Table 2 shows the impact of input factor usage on production.

Table 1 Variable descriptions and summary statistics**.**

Variable	Description	Mean	Std. Dev.	Min	Max
Output Ln(land)	Total yield per hectare Total land used in hectare	10.44 2.27	1.09 3.97	3.5 0.5	24 6.5
Ln(seed)	Quantity of seed applied by hectare in kilograms.	34.16	2.89	10.00	16.00
Ln(fertilizer of urea)	Quantity of fertilizer of urea applied by hectare in kilograms.	101.27	54.92	77	150
Ln(fertilizer of NPK)	Quantity of fertilizer of SP36 applied by hectare in kilograms.	75.22	73.04	50	100
Ln (pesticide)	Quantity of pesticide applied by hectare in liter	2.80	1.97	1.20	4.00
Ln (labor)	Total of man-hours per day.	19.8	1.83	1.00	6.00

Table 2 shows the value of Adj. R^2 = 0.8956, this fact means that 89.56 percent of the variation in the dependent variable can be explained at once by independent variables such as land area, seeds, fertilizers, pesticides, and labour, while the remaining 10.44 percent is affected by other factors outside the model. The effect of using production factors together on the yield of corn can be determined using the F test, and the analysis results obtained by F statistics of 73.54 with a probability of 0.0000 < (0.01) shows that the results have a very large effect, meaning that the independent variables contained in the model together had a very significant that the simultaneous use of production factors in area II, which means that each addition to the same input proportion will result in an increasing increase in output, in other words, corn farming is in the production stage of increasing return to scale.

Considering optimal input practises and technical efficiency assessments, the sigma squared value (0.6231) was found to be significant at the 1% level, indicating that the model fits well and the assumptions about the composite error term are correct. The gamma (γ) value is close to 1, which means that the gap in corn yield in Muaro Jambi is due to inefficiency in technology. According to [26] and [27], this means that the random component of the inefficiency effect makes a significant contribution to the analysis of agricultural production. It got information about the availability of the one-sided error factor in the model and thus, the traditional OLS model is an inadequate representation of the data.

Table 2 Corn estimation production function

Variable	Coefficient	Std Error	t-statistics	Probability
Ln Land	0.201	0.039	5.154	0.000
Ln Seed	0.083	0.111	0.748	0.613
Ln Fertilizer of Urea	0.218	0.068	3.206	0.014
Ln Fertilizer of NPK	0.194	0.056	3.464	0.010
Ln Pesticide	0.153	0.066	2.318	0.046
Ln Labor	0.138	0.043	3.209	0.013
Constanta	102.73			
Adj. R-squared	0.8956			
Σ squared(v)	0.0072			
Σ squared(u)	0.6231			
Mean efficiency	0.742			

The average technical efficiency level at the study site was 74.2% (0.742). This fact means that, given current inputs and existing technology, producers' efficiency could potentially increase by 25.8%. Data shows that the lowest level of technical efficiency is between 0.67 and 0.91. Before evaluating the findings of the inefficiency components, it is good to know that a negative sign on an inefficiency parameter means that the group variable has a positive impact on technical efficiency or a decrease in inefficiency; on the other hand, a positive sign on the inefficiency parameters explains the group variable has impact technical efficiency negatively.

3.1. Estimation of Corn Farming Production Function

Frontier productivity function model estimation is used to analyse agricultural productivity functions. Productivity variables include seeds, urea fertiliser, NPK fertiliser, pesticides, labour force, and frequency of participation in counselling. The estimation results of the production function in the study area are shown in Table 2. Table 2 shows the value of Adj. R^2 = 0.8956, which means that 89.56% of the dependent variable (output) can be explained by the independent variables, while the remaining 10.44% is affected by other factors outside the model.

The productivity elasticities of variables such as land, seeds, urea fertiliser, NPK fertiliser, liquid pesticides, and labour are 0.201, 0.083, 0.218, 0.194, 0.153, and 0.138, respectively. If the independent variable is used by 10 percent with the assumption of ceteris paribus, it can increase the productivity of each by 2.01 percent, 0.83 percent, 2.18 percent, 1.94 percent, 1.53 percent, and 1.38 percent respectively. A value of II suggests that the production curve is in the region of diminishing returns to scale, which means that every increase in the proportion of inputs will lead to an increase in productivity, while output will decrease. Factors affecting fertilizer nitrogen, phosphorus, potassium, pesticides, and labour. Seed variables had no significant effect on yield.

3.2. Farming Technical Efficiency

Technical efficiency is a description of the farmer's ability to obtain maximum results from available inputs. In this study, technical efficiency analysis can be evaluated by the following formula: ET = E [exp (-U_i) / U_i that satisfies the condition ET = 0 and ET = 1. The farmer's ET value is called to be quite efficient if > 0.7 and is below as inefficient if 0.7. The results of the technical efficiency analysis of corn planting in the study area are shown in Table 2. Table 2 shows that the average level of technical efficiency of corn farming is 0.742. This fact indicates that the average productivity of corn farmers is approximately 74.2% of the frontier yield.

This means that the level of technical inefficiency is 0.258 (25.8%), or that there is still a potential for production increase of up to 25.8%. The analysis results show that the lowest technical efficiency for farmers is 0.67, while the highest efficiency for corn is 0.91. This indicates that the average corn cultivation at the study site was technically efficient. The results of this study are in line with research by [21] which states that most corn farmers are technically efficient.

This may be due to the use of production inputs that do not meet the recommended standards. This fact reflects that there is a considerable opportunity to improve productivity, because the gap between the highest productivity level achievable through the best management system (best practises) and the actual productivity level is quite large. This means that to significantly increase agricultural productivity, more advanced innovations are needed, and these innovations require technological breakthroughs achieved through research activities.

4. Conclusions

This study determined the level of technical efficiency among corn producers in Muaro Jambi, Indonesia, and explored specific farm factors that influence efficiency. The data was collected directly from farmers in the target area of Jambi province through questionnaires. Evaluate the efficiency of the technology using stochastic frontier models. Optimal input practises show that the coefficient estimates for land, seeds, urea fertiliser, NPK fertiliser, and labour are positive. Indicating that, if any of these inputs were increased, there may be an increase in crop yields, and an increase of returns of capital. The technical efficiency of farmers in the target area is 74.2%. This means that by making better use of existing inputs and technologies, the technical efficiency of corn production can be improved by 74.2% (based on corn yield).

Compliance with ethical standards

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