JEL: O13, P28, Q10, Q12

Saidin Nainggolan, Yanuar Fitri

University of Jambi
Indonesia

ASSESSMENT OF THE EFFICIENCY OF PALM PLANTATIONS USING A STOCHASTIC FRONTIER APPROACH

Purpose. *The purpose of this study is to (1) estimate the effect of inputs use on production with the stochastic frontier production function model approach; (2) assess the potential for increasing productivity through the study of technical, allocative and economic efficiency of palm plantations; (3) determine the optimal inputs use in order to increase productivity of palm plantations so that technical efficiency, allocative efficiency and economic efficiency are beneficial for farmers.*

Methodology / approach. *This study was conducted in Jambi province of Indonesia by taking samples from Muaro Jambi and Tebo districts. For this study, we randomly selected a sample of 120 farmers. Data were obtained through interviews with respondents in 2022. The analytical method was used to estimate technical, allocative and economic efficiency with the stochastic frontier approach.*

Result. *The research results show that farmers are not yet efficient, both technically, allocatively and economically. The average technical efficiency of oil palm farmers is 68.7 %, allocative efficiency is 61.2 %, economic efficiency is 46.3 %. A quantitative assessment of the impact on the productivity of palm plantations of land area, the number of trees per hectare, labor, varieties and different types of fertilisers was carried out. The productivity scale of oil palm plantations is in the second area, namely decreasing return to scale. Opportunities to increase the productivity of oil palm plantations are very large. It indicates that in order to optimally increase the productivity of oil palm plantations, it is necessary to innovate oil palm plantations in an adaptive manner by allocating optimal production inputs as a result of research. Assistance is needed in procuring production facilities so that farmers can buy production inputs in the right amount, time and price.*

Originality / scientific novelty. *This research is the first study to describe the effect of production inputs, especially single fertilisers, on the estimation of the actual production function and frontier production function using the Cobb-Douglas production function model. This research also explains the determinants and impacts of the number of trees and uses a dummy variable for superior seeds in the module used.*

Practical value / implications. *The productivity function, the results of the evaluation of technical, allocative and economic efficiency of production in smallholder oil palm plantations in rural areas can be used by farmers. The government should intervene to optimise village economic institutions, such as village unit cooperatives, in order to provide fertilisers and herbicides in the right quantities, times and prices according to farmers' needs.*

Key words: *technical efficiency, allocative efficiency, economic efficiency, Indonesia.*

1. INTRODUCTION

Palm oil is a plantation commodity that is Indonesia's main export, and has an important influence on the economy. Oil palm plants began to be cultivated in Indonesia commercially in 1911, while the development of oil palm plantations began in 1969, when the government formed the State Plantation Company with initial funding obtained from investment from the World Bank and the Asian Development Bank. The initial growth of oil palm plantations in the 1970s was dominated by large plantations, both private and state ones, which began to be replaced by smallholders plantations (Saragih et al., 2020). Currently the largest export commodity is palm oil with an area of oil palm plantations in Indonesia reaching 16.3 million hectares, involving more than 16 million workers, and producing more than 21.1 million tons of palm oil in 2020 with an export value of USD 22.97 billion, or a growth of 13.6 % from 2019 (Hartanto, 2021).

In 2019, most of the oil palm plantations in Indonesia were managed by large private plantations, namely 54.94 % or an area of 7,942,335 ha, and smallholder plantations took second place in terms of contribution to the total area of Indonesian oil palm plantations, namely 40.79 % or an area of 5,896,755 ha. Meanwhile, the state large plantation occupies the third position with a contribution of 4.27 % or an area of 617,501 ha (Directorate General of Estate Crops, 2020).

The plantation sector is a leading sector for national income and one of the largest contributors to Indonesia's foreign exchange, which can be seen from the export value of plantation commodities. In 2019, the total plantation export value reached USD 25.38 billion or equivalent to Rp. 359.14 trillion (assuming 1 USD = IDR 14,148). The contribution of the plantation sub-sector to the national economy is increasing and it is expected to strengthen sustainable plantation development (Directorate General of Estate Crops, 2020). An overview of the area of land, production and productivity of smallholder oil palm plantations in Jambi province can be seen in the following Figure 1.

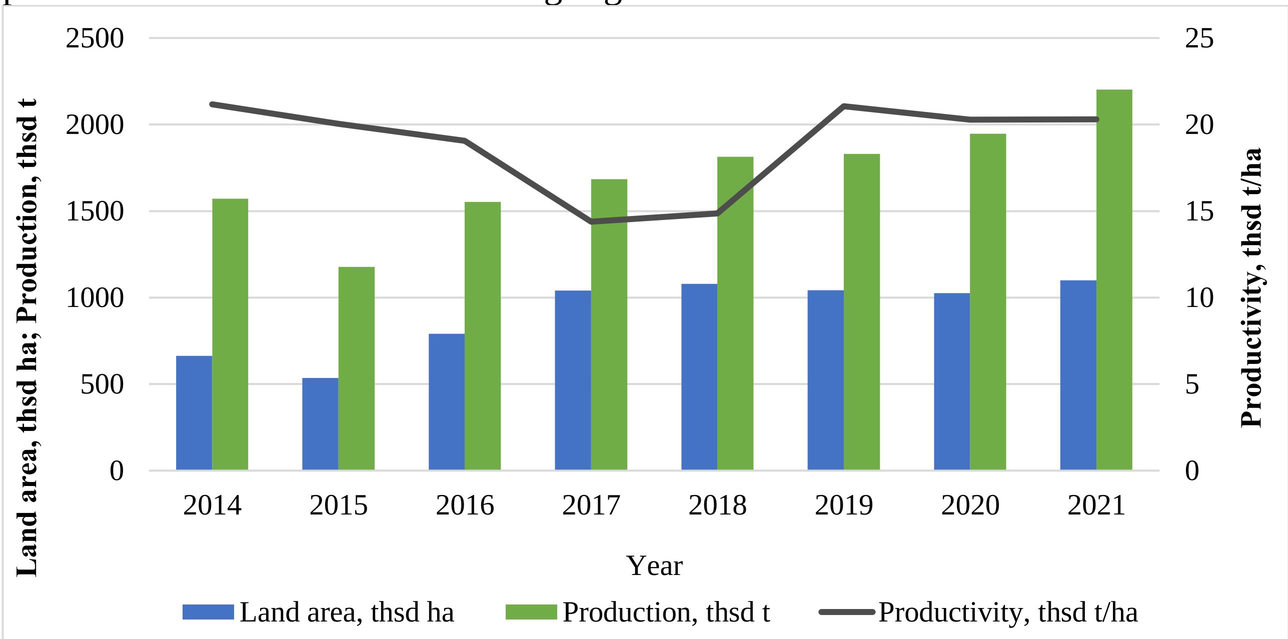

Figure 1. Land area, production and productivity of smallholder oil palm plantations in Jambi province, 2014–2021

Source: built by the authors based on the data of Directorate General of Estate Crops (2020).

Jambi province is among the top ten Indonesian palm oil producing provinces in terms of area and production. Jambi province has a total area of 1,034,804 ha of oil palm plantations with production of 2,884,406 tons in 2019 (Directorate General of Estate Crops, 2020). Based on area and production, Jambi province is the seventh largest palm oil producer in Indonesia. Palm oil commodity is currently one of the leading commodities in Jambi province. Oil palm plantations in Jambi province are dominated by smallholder plantations based on their business status. Smallholder oil palm plantations account for 62.9 %, private large plantations 35.05 % and state large plantations 1.97 %. The productivity of oil palm plantations can reach 24–40 tonnes/ha/year (Pahan, 2018). However, self-help pattern of oil palm plantations (self-help or self-supporting means that the plantation is built on a self-managed basis without credit assistance from the government; in this article, we studied just such farms) in Jambi province only reach 16–25 tonnes/ha/year (Badan Pusat Statistik Jambi, 2022).

This paper aims to (1) estimate the effect of inputs use on production with the stochastic frontier production function model approach; (2) assess the potential for increasing productivity through the study of technical, allocative and economic efficiency of palm plantations; (3) determine the optimal inputs use in order to increase productivity of palm plantations so that technical efficiency, allocative efficiency and economic efficiency are beneficial for farmers.

2. LITERATURE REVIEW

Low productivity can occur because the use of production inputs and cultivation technology is not carried out properly and correctly according to recommendations of Good Agricultural Practices. Soekartawi (2003), Tasman (2008), Wijoyo (2019), Syuhada et al. (2022) note that the use of production inputs affects the productivity of oil palm plantations. If the use of production inputs such as number of oil palm plant, land area, Urea fertiliser (N fertiliser), Triple Super Phosphate (TSP fertiliser), Muriate of Potassium (MOP fertiliser, also known as Potassium Chloride), Dolomite fertiliser, Kieserite fertiliser, and labor is carried out in a good and correct combination, it will result in high production and productivity. Susanto (2021) notes that productivity is considered high if production reaches optimal level. Soekartawi (2003), Jufri & Junaidi (2020) indicate that high productivity describes actual production approaching frontier production. Low productivity constraints require efforts to increase efficiency through the application of technology. Productivity is a comparison of output and input used in the production process (Sakhno et al., 2019).

Tajerin & Noor (2005) argue that studying productivity issues is actually studying technical efficiency issues because productivity measures essentially show how much output can be produced by certain production inputs in oil palm plantations. According to Tasman (2008), the level of technical efficiency is influenced by the combination of use of production inputs in the production process. The ability of farmers to manage and allocate several inputs influences palm oil productivity, and this provides an idea of the level of efficiency achieved by farmers.

According to Bakhsh et al. (2006), there are three possible ways to increase production, namely: increasing land area, developing and adopting new technology and using available resources more efficiently. Increasing palm oil production through extensification is difficult because of the large land area involved, ultimately increasing palm oil production should be done in two possible ways, namely developing and adopting new technology by using available resources more efficiently.

Narala & Zala (2010) stated that the level of production efficiency can increase the achievement of potential production at the farmer level. Increasing farmer efficiency is a potential source of productivity growth and is the main thing for increasing productivity in the future (Bakhsh et al., 2006; Ogundari & Ojo, 2007). Increasing efficiency not only increases supply but can also reduce costs so that it can increase farmer income (Ogundari & Ojo, 2007). The low ability of farmers to produce optimally results in a gap between actual productivity and frontier productivity (Adhiana & Riani, 2019). The determining factor for this productivity gap can occur as a result of the allocation of production input use that is not in accordance with the dosage and timing of fertilisation. Hardiyanti (2017) notes that the level of productivity risk is determined by the optimal allocation of input use. According to Napitupulu et al. (2020), productivity will determine the competitive advantage and competitiveness of oil palm plantations. Productivity analysis is useful as a basis for analysing production efficiency. Farrell (1957), Lau & Yotopoulos (1971), Soekartawi (2003), Tasman (2008) argue that production efficiency is divided into three parts, namely technical, allocative and economic efficiency.

Several studies include Adhiana & Riani (2019), Syuhada et al. (2022), Manik (2022), who conducted technical efficiency studies of oil palm plantations using the stochastic frontier analysis approach, but the variables used were limited to Urea fertiliser, compound fertiliser and labor. The research results show that oil palm plantations in Jambi province are not technically efficient. Furthermore, Rahmawati (2022) conducted research on the technical efficiency of oil palm plantations using the Data Envelopment Analysis (DEA) approach with the variables Urea fertiliser, compound fertiliser and labor, giving results that oil palm plantations in Jambi province were technically efficient. Meanwhile, studies of technical, allocative and economic efficiency in oil palm plantations using the SFA approach with a single fertiliser variable; Urea, TSP, MOP, Dolomite and Kieserite fertilisers; the number of trees and labor are still very scarce according to the author's research. Increasing the technical, allocative and economic efficiency of oil palm plantations is influenced by farmer performance, so it is necessary to study its influence on the production efficiency of oil palm plantations in Jambi province. In this research, the hypothesis proposed is that oil palm plantations are not technically, allocatively and economically efficient.

3. METHODOLOGY

This research was conducted in Jambi province by taking samples from two districts, namely Muaro Jambi District and Tebo District, while the focus of the research was carried out in four villages, namely Bukit Baling Village, Swakpulai, Giri Winangun and Rantau Kembang Village. The data used in this research is cross section. The data period observed is production and production input data for March, July and October 2022. Data was obtained using the interview method with respondents. The instrument used was a questionnaire prepared based on guidelines for the cultivation of mature and imported oil palm plants from the relevant agencies. The sample frame was self-help pattern farmers and the fertiliser used was a single fertiliser. The population of farmer was 2,328 farmers and the sample size used the sloping method $n = N : (1 + Ne^2)$ with a precision level (e) of ± 9 %, so that a sample of 120 farmers was obtained. Simple random sampling is used for sampling.

Stochastic frontier production function analysis. In this study, the estimation of the production function uses the Cobb-Douglas stochastic frontier production function (Coelli et al., 1998; Soekartawi, 2003; Tasman, 2008). The selection of production factor variables in the estimator model is based on economic theory and existing research results. The empirical model of the Cobb-Douglas stochastic frontier production function used in this study is formulated in the following equation:

$$ln\ Y = \beta 0 + \beta 1\ ln\ X_1 + \beta 2\ ln\ X_2 + \beta 3\ ln\ X_3 + \beta 4\ ln\ X_4 + \beta 5\ ln\ X_5 + \\ + \beta 6\ ln\ X_6 + \beta 7\ ln\ X_7 + \beta 8\ D_1 + e(g), \quad (1)$$

where Y – production of fresh fruit bunches, kg;

X_1 – oil palm plantation area, ha;

X_2 – number of oil palm plant, trees;

X_3 – N fertiliser, kg;

X_4 – TSP fertiliser, kg;

X_5 – MOP fertiliser, kg;

X_6 – Dolomite fertiliser, kg;

X_7 – Kieserite fertiliser, kg;

X_8 – labor, working day (HOK);

D_1 – dummy variable for variety (*Var* = 1 if farmers use recommended varieties, *Var* = 0 if farmers do not use recommended varieties);

eg – error, where *eg* = *vi*-*ui*;

vi – a symmetric, normally distributed random error;

ui – a one-sided error term ($ui \leq 0$).

The expected parameter signs are: $\beta 1, \beta 2, \beta 3, \beta 4, \beta 5, \beta 6, \beta 7, \beta 8 > 0$.

Selection of variables in the model: N fertiliser, TSP fertiliser, MOP fertiliser, Dolomite fertiliser, Kieserite fertiliser and labor refer to production inputs that are usually used by farmers and these types of production inputs are recommended by the plantation service. The determination of this variables also refers to Manik (2022) research. Research by Napitupulu et al. (2020) shows that the production factors of number of trees, N fertiliser, TSP fertiliser, MOP fertiliser, Dolomite fertiliser, labor and land area are production factors used in the production function model. Research by Hasan (2022) shows that the production inputs used in the production function model are land area, labor, NPK fertiliser, Urea fertiliser, Kieserite fertiliser, and herbicides. Meanwhile, the reason for using the number of trees is included in the production function model because it is a determining factor in productivity. Thereby also the oil palm variety is used as a dummy variable in the production function model, which according to the author's reference is very rarely included in the model.

After estimating the production function, the next measurement step is measuring production efficiency. Farrell (1957), Tasman (2008), Soekartawi (2003) argue that production efficiency consists of technical, allocative and economic components. Technical efficiency (TE) is useful for determining the ability of a business unit to be able to produce along the Isoquant curve, namely producing the optimal productivity possible with a certain combination of input and technology. Allocative efficiency (AE) is useful for determining the ability of a business unit to use inputs in optimal proportions according to their respective prices and production technology. Measuring economic efficiency is important because it can reduce production costs and make producers more competitive (Alvarez & Aries, 2004).

Technical efficiency analysis. According to Battese & Coelli (1995), technical efficiency is a reflection of a firm's ability to obtain maximum output from a given set of inputs. It is defined as the ratio of the actual production of farmers at the technical level of maximum possible production. In this study, technical efficiency analysis was measured with reference to Lau & Yotopoulus (1971), Jondrow et al. (1982), Ogundari & Ojo (2007), Napitupulu et al. (2020), Syuhada et al. (2022) as follows:

$$TE_i = E\,(exp\,\{-u_i\} : \varepsilon_i);\ i = 1, 2, 3, \dots N, \tag{2}$$

where TE_i is the technical efficiency of the i-th farmer;

$E\,(exp\,\{-u_i\} : \varepsilon_i)$ is the expected value (mean) of u_i provided that ε_i, so $0 \leq \text{TE} \leq 1$.

The technical efficiency value is inversely related to the effect of technical inefficiency and is only used for functions that have a number of outputs and certain input (cross section data). The farmer's TE value is categorised as quite efficient if it is > 0.7 and not yet efficient if it is ≤ 0.7.

Allocative and economic efficiency analysis. In this study, allocative and economic efficiency were analysed using an approach from the input side. Before measuring allocative and economic efficiency, we first derive the dual cost function from the stochastic frontier production function (Coelli, 1996; Soekartawi, 2003; Tasman, 2008; Adhiana & Riani, 2019. The Cobb-Douglas production function used is as follows:

$$Y = \beta_0 X_1^{\beta 1} X_2^{\beta} \dots . X_{2n}^{\beta n}. \tag{3}$$

And the input cost function is as follows:

$$C = P_1 X_1 + P_2 X_2 + \dots P_n X_n, \tag{4}$$

where C – input cost;

P – input production price;

X – production input variable.

The dual cost function can be derived assuming cost minimisation with the constraint $Y = Y_0$. To obtain the dual cost function, one needs to obtain the expansion path, which can be achieved using the Lagrange function as follows:

$$L = P_1 x_i + P_2 x_2 + P_n x_n + P... \lambda\,(Y - \beta_0 x_1^{\beta 1} x_2^{\beta 2})\ ...\ X_{2n}^{\beta n}. \quad (5)$$

To obtain the values of $x_1, x_2 ... x_n$ they can be derived as follows:

$$\frac{\partial L}{\partial x1} = p1 - \lambda\, x_1^{\beta 1\text{-}1} x_2^{\ \beta 2} = 0, \quad (6)$$

$$\frac{\partial L}{\partial x2} = p2 - \lambda x_1^{\beta 1} x_2^{\beta}{}_2^{-1} = 0, \quad (7)$$

$$\frac{\partial L}{\partial x} = Y - \beta_0 x_1^{\beta}{}_1 x_2^{\ \beta}{}_2 = 0. \quad (8)$$

From equations (7) and (8), the values of $X_1, X_2 ... X_n$ expansion path are obtained as follows:

$$X_1 = \frac{p2\ x2}{p1}, \quad (9)$$

$$X_2 = \frac{p1\ x1}{p2}. \quad (10)$$

Then equation (10) is substituted into equation (9) to become:

$$Y = \beta_0 \frac{p2}{p1}^{\beta 1} x_2^{\ \beta 1 + \beta 1}. \quad (11)$$

From equation (11), the input demand function for X_1 and X_2 ... X_n can be determined as follows:

$$x_1^* = \left(\beta_0\, Y P1^{-\beta 2} P2^{-\beta 2}\right)^{\frac{1}{\beta 1 + \beta 2}}, \quad (12)$$

$$x_2^* = \left(\beta_0\, Y P1^{-\beta 1} P2^{-\beta 1}\right)^{\frac{1}{\beta 1 + \beta 2}}. \quad (13)$$

Equations (12) and (13) are then substituted into equation (14) to obtain the dual cost function as follows:

$$C = Y^{\frac{1}{\beta 1 + \beta 2}} \beta 0^{\frac{1}{\beta 1 + \beta 2}} (\beta 1^{-1} \beta 2 p1 + p1)^{\frac{1}{\beta 1 + \beta 2}} (\beta 2^{-1} \beta 1 p2 + p2)^{\frac{1}{\beta 1 + \beta 2}}. \quad (14)$$

In a simpler form, it can also be written as follows:

$$C_i = k \Pi_{j=1}^{i} P x_{ji}^{\ \alpha j} . Y_0{}^r, \quad (15)$$

where $\alpha = r\, \beta 1$;

$r = [\sum j \beta j]^{-1}$;

$k = \frac{1}{r}\left[\beta 0 \prod j \beta j^{bj}\right]^{-r}$;

$\beta j = 1, 2, 3, ..., n$.

The parameter values βj are the results of estimating the stochastic frontier production function. Pxj is the price of the ke-j input production. These prices are obtained from the prevailing input prices in the research area during the study. Y_0 is the observed output level of the respondent farmers. Then the function is expressed in logarithmic form as follows:

$$ln\ C = ln\ K + \alpha_1\ ln\ P_1 + \alpha_2\ ln\ P_2 + ...+ \alpha_6\ ln\ P_6 + r\ ln\ Y_0. \quad (16)$$

Economic efficiency is obtained from the ratio of minimum production costs to total production costs observed, Soekartawi (2003), Ogundari & Ojo (2007), Tasman (2008):

$$EE_i = \frac{C^{\#}}{C} = \frac{E(C_i \mid \mu_i = 0, Y_i, P_i)}{E(C_i \mid \mu_i, Y_i, P_i)} = E[\exp(U_i) \mid \varepsilon_i]. \quad (17)$$

Allocative efficiency per individual oil palm plantation is obtained from technical and economic efficiency as follows:

$$AE = \frac{EE}{TE}. \quad (18)$$

4. RESULTS

4.1. Description of application of cultivation technology. The oil palm land cultivated by farmers is a former forest area, the soil is red and yellow podsolised, the varieties used by farmers are Tenera, Dura and Pesifera varieties. Farmers follow integrated cultivation but do not comply with the recommendations of Good Agricultural Practice. The use of superior clones has an impact on technical efficiency or productivity because superior clones produce better plantations, larger yield size, better quality of produce and a longer productive period of the plant. The government recommends blue label clones, meaning clones that are guaranteed to have productivity and quality marked by providing a guarantee certificate. If the guaranteed result is not fulfilled in accordance with the certificate guarantee, compensation will be given. However, most farmers do not use these seeds because they are very expensive.

Maintenance of oil palm plants that are already producing includes activities such as bushing care, plant plate care, market pickle care, plant fertilisation, weed eradication and fertilisation. For mature plants, farmers make plates from the base of the stem 200 cm. All sample farmers spray using herbicides equivalent to 200 cc/sample or 90 cc/ha of chemicals every year. Spraying is carried out using a knapsack sprayer. Pikul market maintenance is a road in the garden area which is used to make it easier to maintain plants and transport the harvest. The width of the pikul market made by farmers is 1.2 meters. Pikul market maintenance is carried out by controlling weeds (by spraying herbicide once a month). Farmers use plant fertilisation in a quite varied distribution, dosage, application time and rotation. The fertilisers used by farmers are single fertilisers and compound fertilisers. In this study, respondents were those who used a single fertiliser because the farmers believed that the fertiliser would be available at the time, quantity and type of fertiliser needed by the farmers. The application of one type of fertiliser with another type of fertiliser is often too long apart for it to be synergistic. Farmers eradicate weeds or wild plants 3–4 times a year to avoid damaging the main crops, which can reduce production. Farmers eradicate weeds using round up herbicides. Farmers also carry out harvesting, namely removing old or non-productive leaves from oil palm plants. In one year, oil palm plants form 19–25 leaf midribs. However, only 9–22 leaf midribs were found to bear flowers or fruit, while the other midribs did not produce flowers or fruit.

Self-help pattern of oil palm smallholders have an area ranging from 3–9 ha per family with concentrations on a garden area of 4–5 ha. Assuming the average production is 2000 kg/ha and the FFB price is Rp. 1500/kg, the average oil palm farming family in Jambi province has been able to obtain income ranging from Rp. 4.5 to 9.5 million per month. With an average family of 4 dependents, the per capita income ranges from Rp. 1.8 to 2.8 million per month. Increasing income can be achieved by maintaining oil palm plants more intensively, especially from the aspects of right dosage, right method and right time. The use of fertiliser in accordance with the recommended dosage with the correct method and at the correct time of application will increase the productivity of the palm tree. For example, according to Pahan (2018) production can reach 35–48 tons/ha. Meanwhile, the Indonesian Oil Palm Research Institute (2018) said that palm oil production can reach 30–45 tons/ha.

4.2. Input allocation and production of oil palm plantations. The production inputs used by farmers are not as recommended, causing the productivity of oil palm plantations to be not optimal, indicating poor management skills of farmers. The use of production inputs that are not yet optimal reflects that the opportunities for increasing productivity are quite large. The use of production inputs and the production of oil palm plantations can be seen in Table 1.

Table 1

Allocation of production inputs for oil palm plantations in research areas, 2022

Description	Village				Average
	Bukit Baling	Suak Pulai	Giri Winangun	Rantau Kembang	
Number of trees/ha	142	127	122	130	130
N fertiliser (kg/ha)	145.30	110.50	105.15	115.30	119.06
TSP fertiliser (kg/ha)	75.65	70.50	65.30	60.00	67.86
MOP fertiliser (kg/ha)	67.55	60.64	55.33	55.62	59.78
Dolomite fertiliser (kg/ha)	1150.00	855.00	750.00	655.00	852.50
Kieserite fertiliser (kg/ha)	700.00	600.00	500.00	550.00	587.50
Labor (HOK/ha)	60.34	58.62	54.45	56.72	57.53
Land area (ha)	5.80	4.75	5.50	4.70	5.80

Source: primary data processing, 2022.

Table 1 shows an average number of trees of 130 stems/ha. The average volumes of resources were as follows: N fertiliser – 119.06 kg/ha, TSP fertiliser – 67.86 kg/ha, MOP fertiliszer – 60 kg/ha, Dolomite fertiliser – 852.50 kg/ha, Kieserite fertiliser – 587.5 kg/ha, Labor – 57.53 HOK/ha and Land area – 5.18 ha/farmer. The response to oil palm production is greatly influenced by the use of N fertiliser. Kasno & Nurjaya (2020), Fahrudin (2021) note that N fertiliser plays an important role in plant growth, especially stems and leaves, besides that nitrogen is important in the formation of chlorophyll that is very useful in photosynthesis, its function is the formation of proteins, fats and various other compounds. The optimal use of N fertiliser is 337.5 kg/ha (Fauzi et al., 2012), and 275–350 kg/ha (Fahrudin, 2021) per year. Oil palm production is influenced by the use of fertiliser Serikat Petani Kelapa Sawit (2016), Gokomodo (2023), which is useful for stimulating root growth, apart from that it functions to help respiration and accelerate flowering, ripening of seeds and fruit, strengthen the plant's standing and increase resilience against disease. The optimal use of TSP fertiliser is 216 kg/ha (Fauzi et al., 2012) and 200–275 kg/ha (Pahan, 2018) per year. The use of MOP fertiliser is a determining factor in production. According to Fahrudin (2021) and the Indonesian Oil Palm Research Institute (2000), MOP fertiliser is intended for two parts of the plant, namely fruit and stem. MOP functions to strengthen the stem and make it strong and sturdy, while MOP fruit functions to produce fruit with good quality, such as being bigger and heavier. The optimal MOP fertiliser is 270 kg/ha (Fauzi et al., 2012), while according to the Indonesian Oil Palm Research Institute (2018) is 250–325 kg/ha per year. According to Kasno & Nurjaya (2020), Fahrudin (2021), Dolomite fertiliser is useful for providing important nutrients for plants, helps change the soil according to needs, can neutralise excessive substances that can poison plants and plants, increases productivity and soil efficiency for nutrients in the soil. The optimal use of Dolomite fertiliser is 2000 kg/ha (Fauzi et al., 2012) and as much as 1850–2400 kg/ha (Pahan, 2018) per year. Kieserite fertiliser is a production input that has an effect on increasing production (Kasno & Nurjaya, 2020; Indonesian Oil Palm Research Institute, 2020). Kieserite fertiliser can increase the achievement of optimum oil palm growth. Kieserite fertiliser can actually increase plant height, stem diameter, the availability of nutrients needed by plants and the response to fertilisation. The optimal use of Kieserite fertiliser is 1200 kg/ha (Fauzi et al., 2012) and is 1000–1500 kg/ha (Pahan, 2018) per year.

The use of production inputs below the recommendations can have an impact on plant growth, production weight, productivity quality measures and reduced productive life of plants. These four factors will result in low production efficiency. The long-term impact of using production inputs below the recommended dosage will result in low production scale, profitability and farmer income.

4.3. Estimating the production function of oil palm plantations. Analysis of the production function aims to analyse the effect of production input allocation on output, or production response to the use of production inputs. The effect of input allocation on production can be seen in Table 2.

Table 2 shows the adjusted R^2 = 0.8883, this means that the model precision is 88.83 % while the remaining 11.17 % is influenced by other factors outside the model. Production inputs that have a significant effect on production are N fertiliser, TSP fertiliser, MOP fertiliser, Dolomite fertiliser, Kieserite fertiliser, and land area. Test the model using the F-test, from the analysis results obtained F-statistic of 79.57 with a ρ-value 0.0000 < α (0.01), meaning that the variables contained in the model simultaneously have a significant effect on palm oil production. The value of $\sum\beta i = 0.815226 < 1$, means that the production scale is in area II, meaning decreasing return to scale (DRTS).

The land area (X_1) has a positive and significant effect on production (ρ-value = 0.03 < α (0.05)). The land area provides a production elasticity β1 of 0.0812, meaning that an increase in land area of 10 % will increase production by

0.812 %, ceteris paribus. According to a study by Hasibuan et al. (2020) in North Sumatra province, the land area variable has a positive and significant effect on oil palm productivity. Manik (2022), with the same case, conducted research in Muaro Jambi Regency and found that land area had a positive and very significant effect on increasing productivity. The production response to land area is β1 = 0.4683. Meanwhile, Mustar et al. (2020) conducted research in Aceh province and found that land area had a positive but not significant effect towards increasing production.

Table 2

Results of the estimation of the production function of oil palm plantations in research areas, 2022

Variable	Coefficient	Std. error	t-statistic	Prob.
LN_X1	0.081345	0.034066	2.387864	0.0352
LN_X2	0.096212	0.039713	2.422682	0.0097
LN_X3	0.082327	0.056198	1.464945	0.0018
LN_X4	0.109829	0.066238	1.658096	0.0321
LN_X5	0.106628	0.054403	1.959965	0.0000
LN_X6	0.062967	0.020391	3.087979	0.0029
LN_X7	0.098354	0.043123	2.280778	0.0256
LN_X8	0.177564	0.101767	1.744809	0.0387
dV	0.134572	0.062144	2.165486	0.0415
C	5.204995	0.517749	10.05313	0.0000
R-squared	0.899663	Mean dependent var		7.900543
Adjusted R-squared	0.888358	S.D. dependent var		0.387867
S.E. of regression	0.129597	Akaike info criterion		-1.143114
Sum squared resid	1.192481	Schwarz criterion		-0.875136
Log likelihood	54.72455	Hannan-Quinn criterion		-1.035674
F-statistic	79.57732	Durbin-Watson stat.		1.420265
Prob(F-statistic)	0.000000	-		-

Source: primary data processing, 2022.

The number of trees (X_2) has a positive and significant effect on production (ρ-value = 0.0097 < α (0.01)). The number of trees provides a production elasticity of β2 of 0.0962, meaning that an increase in the number of trees by 10 % will increase production by 0.962 %, ceteris paribus. In accordance with Napitupulu et al. (2020), the variable that has a significant effect on productivity at the ∝ = 0.01 level is the number of trees. Ismiasih (2018) in West Kalimantan stated that the variable number of productive trees had a positive and significant effect on the amount of oil palm production. Meanwhile, research by Riati (2016) and Mustar et al. (2020) in Aceh Tamiang Regency shows that the regression coefficient value for the number of trees (X_7) is -0.21, meaning that the number of trees has a negative influence on oil palm productivity. For every 1 % increase in the number of trees, productivity will decrease by 0.213 %.

The N fertiliser (X_3) has a positive and very significant effect on production (ρ-value = 0.0018 < α (0.01)). N fertiliser provides an elasticity of β3 production of 0.0823, meaning that adding N fertiliser by 10 % will increase production by 0.823 %, ceteris paribus. Harefa (2021) states that the N production factor has a positive value and has a significant effect on oil palm farming production at the 5 % level with positive elasticity value.

The TSP fertiliser (X_4) has a positive and significant effect on production (ρ-value = 0.0321 < α (0.05)). TSP fertiliser provides a β4 production elasticity of 0.1098, meaning that adding fertiliser by 10 % will increase production by 1.098 %, ceteris paribus. Meanwhile, research results from Hasibuan et al. (2020) and Manik (2022) show that the use of TSP fertiliser also has a positive but not significant effect on increasing oil palm productivity.

The MOP fertiliser (X_5) has a positive and significant effect on production (ρ-value = 0.000 < α (0.01)). MOP fertiliser provides a β5 production elasticity of 0.1066, meaning that adding fertiliser by 10 % will increase production by 1.066 %, ceteris paribus. According to the results of Arianto (2020) research in West Kalimantan Province, that MOP fertiliser has a positive and significant effect on increasing palm oil production and research by Napitupulu et al. (2020) that MOP fertiliser has an effect on the risk of palm oil productivity.

The Dolomite fertiliser (X_6) has a positive and very significant effect on production (ρ-value = 0.0029 < α (0.01)). Dolomite fertiliser provides a β6 production elasticity of 0.062967, meaning that adding fertiliser by 10 % will increase production by 0.6297 %, ceteris paribus. Napitupulu et al. (2020) states the variable that has a significant effect on productivity at the level of ρ-value = 0.01 is Dolomite fertiliser. Meanwhile, Manik (2022) states that Dolomite fertiliser has a positive but not significant effect on increasing production.

The Kieserite fertiliser (X_7) has a positive and significant effect on production (ρ-value = 0.0256 < α (0.05)). Kieserite fertiliser provides a β7 production elasticity of 0.098354, meaning that adding fertiliser by 10 % will increase production by 0.98354 %, ceteris paribus. In accordance with Pramesti (2023), the elasticity of Kieserite fertiliser on oil palm farming production is 0.150. The probability value of Kieserite fertiliser is 0.027 < α (0.05), which means that the Kieserite fertiliser variable has a partially positive and significant effect on increasing palm oil production. At the same time, the results of research by Napitupulu et al. (2020), suggest that Kieserite fertiliser is a source of inefficiency and has a significant impact on farmers' risk standards.

The labor (X_8) has a positive and significant effect on production (ρ-value = 0.0387 < α (0.05)). Labor provides a production elasticity of β8 of 0.177564, meaning that an increase in labor of 10 % will increase production by 1.77564 %, ceteris paribus. According to research by Apriliyani & Nasution (2022), the regression coefficient on the labor variable is 0.1698 with a t-count value of 3.1964, which is greater than the *t*-table of 2.004, it means that the labor variable has a significant effect on the amount of coconut farming production. smallholder oil palm. If labor is increased by 1 %, it will increase the production of smallholder oil palm farming by 16.98 %. Research by Ismiasih (2018) and Hasan (2022) shows that the response to changes in production to the number of workers is inelastic.

The dummy variable (*dv*) of the superior Tenera variety produces a positive and significant regression coefficient (*ρ*-value = 0.0415 < α (0.05)), meaning that the superior Tenera oil palm variety is better than the Dura and Pisifera varieties for increasing production. Consistent with the Indonesian Oil Palm Research Institute (2018), the Tenera variety has advantages in terms of greater yield weight, better quality and a longer productive period, increased productivity compared to other varieties, therefore, it is necessary to implement the use of this variety if you dare to rejuvenate oil palms.

4.4. Estimation of the productivity function of oil palm plantations. In this section, the input variables used in oil palm plantations will be described and analysed in the frontier productivity function model. Table 3 shows the adjusted value R^2 = 0.7235, meaning that 72.35 % variation in productivity can be explained simultaneously by variables (number of trees, N fertiliser, TSP fertiliser, MOP fertiliser, Dolomite fertiliser, Kieserite fertiliser, and labor) while the remaining 27.65 % are influenced by other factors outside the model. The productivity elasticity value of the variable number of trees, N fertiliser, TSP fertiliser, MOP fertiliser, Dolomite fertiliser, Kieserite fertiliser and labor respectively is 0.158771, 0.193038, 0.092808, 0.141975, 0.113266, 0.178797. If the variable number of trees, N fertiliser, TSP fertiliser, MOP fertiliser, Dolomite fertiliser, Kieserite fertiliser and labor are added by 10 %, ceteris paribus, the productivity can be increased by 1.58, 1.93, 0.92, 1.41, 1.11, 1.78, and 0.81 % respectively.

Table 3

Results of estimating the productivity function of the frontier oil palm plantation in research areas using the MLE method, 2022

Variable	Coefficient	Std. error	t-statistic	Prob.
Ln_X1	0.158771	0.029203	5.436804	0.0442
Ln_X2	0.193038	0.094774	2.036824	0.0000
Ln_X3	0.092808	0.045451	2.041954	0.0412
Ln_X4	0.141975	0.063354	2.240979	0.0376
Ln_X5	0.113266	0.055634	2.035913	0.0001
Ln_X6	0.178797	0.021616	8.271511	0.0003
Ln_X7	0.081693	0.041109	1.987229	0.4407
dP	0.956612	0.374653	2.553328	0.0000
C	4.057535	0.360591	11.25246	0.0000
	Variance equation			
C	0.025756	0.007980	3.227787	0.0012
RESID(-1)^2	-0.131142	0.229243	-0.572065	0.5673
R-squared	0.748034	Mean dependent var		8.716163
Adjusted R-squared	0.723538	S.D. dependent var		0.305432
S.E. of regression	0.160595	Akaike info criterion		-0.705496
Sum squared resid	1.856943	Schwarz criterion		-0.407743
Log likelihood	38.21984	Hannan-Quinn criterion		-0.586118
Durbin-Watson stat.	1.796891	-		-

Source: primary data processing, 2022.

The determinant factors for the high and low productivity of oil palm plantations are the variables N, Dolomite, Kieserite fertilisers, and superior Tenera varieties used at the α level of 0.01. The variables number of trees, TSP fertiliser, and MOP fertiliser have a significant effect on oil palm productivity at the α level of 0.05. Meanwhile, labor does not have a significant effect on productivity. According to Panjaitan et al. (2020), Pasaribu et al. (2016), it was found that N, P, MOP fertilisers has a significant effect on production. Meanwhile, labor has no significant effect on productivity.

The value of $\Sigma \beta i = 0.960348 < 1$, meaning that every additional use of production inputs simultaneously in the same proportion by 10 % will increase productivity which is decreasing by 9.603 % by using superior Tenera seed varieties. In other words, the production scale is in area II or the production scale of oil palm plantations is experiencing decreasing return to scale.

4.5. Palm oil plantation technical efficiency. Measuring technical efficiency is important because it can reduce production costs and make farmers more competitive. Technical efficiency can be seen in terms of minimising input and increasing output. A technically efficient farmer can produce the same amount of output using at least one of the fewer inputs or can use the same input to produce more output. Technically, a farmer is said to be more efficient than other farmers if using the same type and amount of resources produces a greater physical output. Tasman (2008) that high technical efficiency reflects the achievement of farmers in managerial skills which is quite high and reflects opportunities to increase productivity. The results of the analysis of technical efficiency of oil palm plantations can be seen in Table 4.

Table 4

Technical efficiency of oil palm plantations in research areas, 2022

Technical efficiency	Number of farmers	Percentage, %
0.50 – < 0.60	21	17.5
0.60 – < 0.70	56	47.0
0.70 – < 0.80	23	19.2
0.80 – < 0.90	13	10.8
0.90 – < 1.00	2	1.7
Total	120	100.0
Lowest technical efficiency	0.505	-
Highest technical efficiency	0.902	-
Average technical efficiency	0.687	-

Source: primary data processing, 2022.

Table 4 shows the technical efficiency value of palm oil production estimated using the SFA method. The average technical efficiency is 0.687 or 68.7%. This indicates that farmers can reduce production input by 31.3 % to produce the same output or it can be interpreted that at the same level of input and technology, palm oil production can be increased by 31.3% with fixed input and technology and without additional costs. Technical efficiency range 0.505–0.902 or 50.5–90.2 %. This means that at the existing level of input and technology the average production of palm oil has the opportunity to be increased by 9.8–49.5 % or an average of 31.3 %. This indicates that there are opportunities to improve technology and management for oil palm farmers so that they can increase palm oil production and increase farmers' income.

The results of this research show that by traditional plant care, farmers did not apply fertilisers properly and correctly as recommended. This factor is the cause of low productivity. In this case, Puruhito et al. (2019) states that productivity as a measure of the technical efficiency of oil palm is largely determined by the fertilisation aspect in terms of dosage, fertilisation method and fertilisation time. Furthermore Natalia et al. (2016), Sianturi et al. (2021), Nainggolan et al. (2019) point out that low technical efficiency apart from the use production inputs are not as recommended, also due to socio-economic factors and farmer behaviour to avoid production risks. Even though oil palm plantations have low productivity, they have high competitiveness in terms of competitive advantage.

4.6. Oil palm plantation allocative efficiency. Farmers pay less attention to the proportion of input use with input prices and the resulting marginal product. Allocative and economic efficiency in this study was obtained through an analysis of production inputs using input prices that apply at the farm level. The production function used as the basis for the analysis is the stochastic frontier production function. The frontier cost function (isocost frontier) is the result of decreasing the stochastic frontier production function combined with the dummy as follows:

$$\ln C = -15.43453 + 4.6643\ln PX_2 + 5.2453\ln PX_3 + 0.9643\ln PX_4 + \\ + 0.3762\ln PX_5 + 0.9524\ln PX_6 \quad (19)$$

where C – the cost of production per individual farmer, Rp.;
$\ln C$ – the amount of production per hectare, kg/hectare;
PX_1 – the average price of seeds is Rp. 45,000;
PX_2 – the average price of N fertiliser, namely Rp. 2,100;
PX_3 – the average price of TSP fertiliser, namely RP. 2,200;
PX_4 – the average price of MOP fertiliser, which is Rp. 2,200;
PX_5 – the average price of Dolomite fertiliser, which is Rp. 1950;
PX_6 – the average price of Kieserite fertiliser, which is Rp. 1,900;
PX_7 – the wages for worker outside the family per HOK, which is Rp. 85,000.

The inefficiency of oil palm plantations is assumed to increase with the increase in production costs. Based on the results of decreasing the dual cost function in equation (3) and by using equation (4) it can be calculated the value of allocative and economic efficiency in this study.

The value of farmer's allocative efficiency is categorised as quite efficient if the value is > 0.7 and not yet efficient if the value is ≤ 0.7. The results of the allocative efficiency analysis of oil palm plantations can be seen in Table 5.

Table 5 shows that the average allocative efficiency of oil palm farmers is 61.2 %, which means that farmers do not use minimal production inputs and in general production costs can be reduced by 38.8 % to achieve the same output. There are only 9.18 % of farmers who have an allocative efficiency value greater than 0.70 or it can be said that these farmers are allocatively efficient. The variation in allocative efficiency values varies between 0.428–0.815, where this variation shows that oil palm farmers use production inputs in proportions that are not optimal so that costs are higher, a maximum of about 57.2 %. There are 90.8 % of farmers who have an allocative efficiency below 0.7 or farmers who are not yet efficient in terms of allocative efficiency. Efforts that can be made to increase allocative efficiency lie in to help farmers to select and use good and correct production inputs.

Table 5

Allocative efficiency of oil palm plantations in research areas, 2022

Allocative efficiency	Number of farmers	Percentage, %
0.40 – < 0.50	23	19.16
0.50 – <0.60	58	48.33
0.60 – < 0.70	28	23.33
0.70 – < 0.80	7	5.84
0.80 – < 0.90	4	3.34
Total	120	100.00
Lowest allocative efficiency	0.428	-
Highest allocative efficiency	0.815	-
Average allocative efficiency	0.612	-

Source: primary data processing, 2022.

According to research by Nainggolan et al. (2021), most farmers are not allocatively efficient. This shows that the allocation of costs for production inputs is too large, so it needs to be reduced to maximise profit. The allocative efficiency of oil palm plantations is determined by the variable use of production inputs and the price of fresh fruit bunches (TBS) significantly. Based on the results of observations and primary data, it is known that farmers have not received assistance, fertiliser subsidies and credit. In this relationship, in order to increase allocative efficiency, it is hoped that there will be farmer assistance, fertiliser subsidies, credit and stable product prices that will benefit farmers, so that farmers are motivated to choose and use good and correct production inputs in accordance with timely doses and fertilisation.

4.7. Oil palm plantation economic efficiency. Measuring economic efficiency is important because maximum profit can be achieved by using production inputs optimally to obtain maximum output for a given cost and by minimising costs for a given volume of output. The value of economic efficiency is categorised as quite efficient if $EE > 0.7$ and not yet efficient if $EE \leq 0.7$. The results of the economic efficiency analysis of oil palm plantations can be seen in Table 6.

Table 6 shows that the average economic efficiency of oil palm farmers is 0.463. If farmers do not use an optimal combination of production inputs with minimal costs, production costs can be reduced by 53.7 % to achieve the same output. There are no farmers who have a farmer efficiency value greater than 0.7 or it could be said that none of these farmers are economically efficient. The variation in economic efficiency values varies between 0.36–0.67. Where this variation shows that farmers use production inputs in proportions that are not optimal so that production costs are higher by a maximum of 33–64 %.

Table 6

Economic efficiency of oil palm plantation in research areas, 2022

Economic efficiency	Number of farmers	Percentage, %
0.30 – <-0.40	12	10.00
0.40 – < 0.50	48	40.00
0.50 – < 0.60	53	44.16
0.60 – < 0.70	7	5.83
Total	120	100.00
Lowest economic efficiency	0.360	-
Highest economic efficiency	0.670	-
Average economic efficiency	0.463	-

Source: primary data processing, 2022.

This shows that the average oil palm plantations in Jambi province are still not economically efficient. According to the research by Nainggolan et al. (2019), economic efficiency is classified as low, indicating that most farmers have not reached the expected level of efficiency. Stevan et al. (2015) noted that increasing economic efficiency can be done by increasing access for farmers to sell their production directly to factories (industry) so that farmers get a more profitable market share for farmers. According to Adhiana & Riani (2019), Syuhada et al. (2022), this low economic efficiency will result in low profitability and sustainability of farmers. In this connection, to increase profitability and sustainability, it is necessary to increase productivity to approach frontier production by using an optimal combination of production inputs with minimum possible costs.

4.8. Productivity increase estimation with optimal production input. If it is related to the amount of profit of the farmer with the results of the estimation of the frontier productivity function, it can be determined that the amount of optimal production input use allocation. The estimated frontier productivity function is:

$$Yopt = 4.0575X_1^{0.15781}X_2^{0.193038}X3^{0.092808}X4^{0.141975}X5^{0.113266}X6^{0.178797}X7^{0.081693}. \quad (19)$$

The comparison of actual and optimal production input combinations can be seen in Table 7.

Table 7

Comparison of actual and optimal input allocations for oil palm plantations in the study area, 2022

Input type	Input allocation			
	X_{Actual}	$\bar{x}_{Actual}$	$X_{Optimal}$	$\bar{x}_{Optimal}$
Land area, ha	3.5–8.5	6.0	6.0–8.5	7.25
Number of trees, ha	125–135	130.0	135–155	145
Urea, kg/ha	175–200	187.5	250–350	300
TSP, kg/ha	125–175	150.0	200–300	250
KCl, kg/ha	100–150	175.0	130–180	155
Labor, HOK/ha	50–89	69.5	75–90	82.5
Dolomite, kg/ha	850–950	900.0	1,200–1,700	1,450
Kieserite, kg/ha	600–750	675.0	900–1,500	1,200
Production, kg	16,000–22,000	18,650	24,000–31,480	37,000

Source: primary data processing, 2022.

Table 7 shows that the actual production input allocation is below the optimal production input allocation, therefore to achieve optimal production, farmers need to allocate as much input as $\bar{x}$ optimal. The actual production obtained is 18,650 tons/ha and the optimal production is 37,000 tons/ha or there is an increase in production of 98.3 %. According to Tasman (2008), the optimal input allocation with adaptive technology will significantly increase technical efficiency, and increasing technical efficiency will significantly increase the productivity of oil palm plantations. This means that if farmers want to obtain maximum profits, farmers must allocate inputs with optimal combinations so that production close to frontier production is obtained. Factors that can motivate farmers to use optimal production inputs are fertiliser prices, maintaining product price stability at the farmer level, which is more profitable. For this reason, the government needs to provide assistance to farmers, more intensive education to introduce better and more profitable cultivation technology for farmers, subsidize fertilisers, guarantee the availability of fertiliser at the farmer level and increase farmers' access to factories (industry). According to Alamsyah et al. (2021), the determining factor for farmers' income is the price of fresh fruit bunches, because there is a large difference between prices at the farmer level and factory prices, which results in a farmer share of only 76.1–81.5 %. Table 7 shows that there is a gap in the actual production inputs used by farmers with the optimal production inputs or production inputs that farmers should use. This gap can occur due to farmers' lack of knowledge about good and correct allocation of inputs according to dosage, method and time of use. In accordance with research by Pasaribu et al. (2016), there is a lack of farmer assistance, access to fertiliser procurement, farmer knowledge regarding the optimal combination of production inputs.

5. DISCUSSION

The response of the amount of production to changes in the number of factors of production has a significant effect on farm efficiency. The low level of use of inputs and not optimality due to low farming technology causes low technical efficiency, allocative efficiency and economic efficiency. Increasing the efficiency of agriculture depends on the productivity of farmers in managing their agriculture and the implementation of technology in the use of certain resources. Efficiency can be increased with the help of optimal input of assessment results.

As mentioned, the gap between actual production and frontier production occurs because the use of production inputs is not in accordance with the optimum combination or does not comply with recommendations. A literature review shows mixed results regarding the level of significance of the magnitude of production elasticity for palm oil production. Technical efficiency, allocative and economic efficiency are very dependent on the productivity of oil palm plantations. The determinant factors for palm oil production are all production inputs in the model except labor. According to the results of this study, all coefficients of production elasticity are positive, which indicates that the possibilities of increasing production will be high with the accession in the use of optimal production inputs or in accordance with the recommendations. On the other hand, many studies report that land area, number of stems, Dolomite fertiliser and labor are not significant to productivity (Panjaitan et al., 2020; Mustar et al., 2020; Fahrudin, 2021; Syuhada et al., 2022). However, improvements in produce, allocative and economic efficiency come from the use of compound fertilisers. Syuhada et al. (2022), Manik (2022), Puruhito et al. (2019), Indonesian Oil Palm Research Institute confirm that there are advantages of using compound fertiliser production inputs compared to single fertilisers in increasing productivity. Bakhsh et al. (2006), Ogundari & Ojo (2007), Narala & Zala (2010), Hardiyanti (2017), Napitupulu et al. (2020) state that the level of production efficiency can increase the achievement of potential production at the farmer level. Increasing farmer efficiency is a potential source of productivity growth and is the main driver for productivity growth in the future; efficiency gains not only increase supply, but can also reduce costs to increase farmer income. The low ability of farmers to produce optimal output leads to a gap between actual productivity and frontier productivity. The determining factor for this productivity gap can occur because of the allocation of production input use that is not in accordance with the dosage and timing of fertilisation. The level of productivity risk is determined by the optimal allocation of input use. That productivity will determine the comparative advantages and competitiveness of oil palm plantations. According to Adhiana & Riani (2019), Syuhada et al. (2022), this low technical, allocative and economic efficiency will result in low profitability and sustainability of farmers. In this connection, to increase profitability and sustainability, it is necessary to increase productivity to approach frontier production by using an optimal combination of production inputs with minimum possible costs.

6. CONCLUSIONS

The use of production inputs is still much lower than the recommendations of the plantation service, as well as the optimal amount estimated. At the same time, the production inputs used in the model can very significantly explain the performance of palm oil productivity. The variable number of trees, Dolomite fertiliser, Kieserite fertiliser, and Tenera varieties have a positive and very significant effect on productivity. The use of N, TSP and MOP fertilisers has a positive and significant effect on productivity. Meanwhile, labor elasticity towards productivity is also positive but not significant. The productivity scale of oil palm plantations is in area two, namely diminishing returns to scale. Actual productivity is still below than frontier one. Low productivity occurs because the use of production inputs is not optimal. This low productivity results in low production efficiency. The research results show that farmers are not yet efficient both technically, allocatively and economically. The opportunity to increase productivity is still very large. To increase productivity, intensive consultations are needed by the Plantation Service, because farmers' behaviour in maintaining plants is still traditional. Extension should introduce better cultivation technology, and this needs to be accompanied by incentives to subsidise fertiliser and herbicide prices to motivate farmers to use optimal production inputs.

Some policy suggestions include: the government should intervene to optimise Village Economic Institutions, such as village unit cooperatives, in order to provide fertilisers and herbicides in the right quantities, times and prices according to farmers' needs. Using farmer groups and village unit cooperatives to partner with industry to sell produce so that the farmer-to-farmer share is higher and more stable, especially during peak harvest periods. The government needs to provide assistance in procuring superior varieties with low price incentives when farmers want to rejuvenate. To motivate farmers to use inputs according to the optimal number of input combinations or in accordance with recommendations, it is necessary to provide education on better oil palm cultivation techniques, provide fertiliser subsidies for farmers, and ensure the availability of fertiliser on time, in the right dosage, and at affordable prices for farmers.

7. LIMITATIONS AND FUTURE RESEARCH

A limitation in this research is the collection of primary data because the respondents live scattered and far from oil palm plantations. Local enumerators who have been trained first should carry out primary data collection. Another limitation is determining the sampling frame, because farmers in Jambi province consist of self-supporting pattern farmers and other groups. Some farmers use single fertiliser and some use compound fertiliser. We hope that in the future research we will conduct a comparative study of the stochastic marginal production function of farmers with a self-sustaining fertiliser production scheme using single and compound fertilisers in the same model.

Acknowledgments: we thank colleagues from the Faculty of Agriculture at Jambi University who assisted with funding for the implementation of the research and helped provide cover letters for research permits for district authorities and sample villages used as study areas.

Conflicts of interest: the authors declare no conflict of interest.

REFERENCES

1. Adhiana, & Riani (2019). *Analisis efisiensi ekonomi usahatani: pendekatan stochastic production frontier* [Analysis of economic efficiency of farming: stochastic production frontier approach]. Aceh, Sefa Bumi Persada. Available at: https://repository.unimal.ac.id/4688/1/BUKU%20ANALISIS%20EFISIENSI%20EKONOMI%20%20%20USAHATANI.pdf.

2. Alamsyah, Z., Napitupulu, D., Hamid, E., Yanita, M., & Fauzia, G. (2021). Factors affecting the FFB price of independent smallholder oil palm farmers in Jambi Province. *IOP Conference Series: Earth and Environmental Science*, 782, 032060. https://doi.org/10.1088/1755-1315/782/3/032060.

3. Alvarez, A., & Arias, C. (2004). Technical efficiency and farm size: a conditional analysis. *Agricultural Economics*, 30(3), 241–250.

https://doi.org/10.1016/j.agecon.2003.04.001.

4. Apriliyani, K., & Nasution, M. P. (2022). Efisiensi penggunaan faktor-faktor produksi pada usaha tani kelapa sawit rakyat (Elaeis Guineensis Jacq) (Studi Kasus: Desa Tanjung Medan, Kec. Kampung Rakyat Kab. Labuhanbatu Selatan). *Jurnal Agriuma*, 4(1), 31–39. https://doi.org/10.31289/agri.v4i1.71767.

5. Arianto, G., Rahman, M., & Jamaluddin (2020). Faktor-faktor yang mempengaruhi produktivitas kerja karyawan pemupukan kelapa sawit DI PT. Wira Inova Nusantara Desa susuk dalam kecamatan Sandaran Kabupaten Kutai Timur Provinsi Kalimantan Timur. *Jurnal Agriment*, 5(02), 73–81. https://doi.org/10.51967/jurnalagriment.v5i02.296.

6. Badan Pusat Statistik Jambi (2022). Provinsi Jambi Dalam Angka 2022. BPS Jambi. Available at: https://jambi.bps.go.id/publication/2022/09/26/9191a5e9e11c1e7749e609b1/statistik-daerah-provinsi-jambi-2022.html.

7. Bakhsh, K., Ahmad, B., & Hassan, S. (2006). Food security through increasing technical efficiency. *Asian Journal of Plant Sciences*, 5(6), 970–976. https://doi.org/10.3923/ajps.2006.970.976.

8. Battese, G. E., & Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20, 325–332. Available at: https://pages.stern.nyu.edu/~wgreene/FrontierModeling/Reference-Papers/Battese-Coelli-1995.pdf.

9. Coelli, T. J., Rao, D. S. P., & Battese, G. E. (1998). An introduction to efficiency and productivity analysis, 2nd ed. New York, Springer. https://doi.org/10.1007/b136381.

10. Coelli, T. J. (1996). A guide to frontier version 4.1 a computer program for stochastic frontier production and cost function estimation. *CEPA Working Papers*, 96/07. New England, University of New England. Available at: https://www.scirp.org/reference/referencespapers?referenceid=956598.

11. Directorate General of Estate Crops (2020). Statistical of national leading estate crops commodity. Jakarta. Available at: https://drive.google.com/file/d/1ZpXeZogAQYfClNBOgVLhYi8X_vujJdHx/view.

12. Sianturi, E. N., Nainggolan, S., Elwamendri, E (2021). Analisis daya saing usahatani Kelapa sawit Rakyat di kecamatan Sekernan Kabupaten Muaro Jambi. *Jurnal Ilmiah Sosio-Ekonomika Bisnis*, 24(01), 52–58. https://doi.org/10.22437/jiseb.v24i01.13489.

13. Fahrudin, M. (2021). Tanaman Kelapa Sawit (*Elaieis guineensis Jacq)* di PT Sumur Pandanwangi Hanau. Yogyakarta, Politeknik LPP. Available at: https://repository.polteklpp.ac.id/id/eprint/867/1/Laporan%20PKL%202%20&%203%20Management%20dan%20budidaya%20tanaman%20kelapa%20sawit.pdf.

14. Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society*, 120(3), 253–290. https://doi.org/10.2307/2343100.

15. Fauzi, Y., Widyastuti, Y. E., Satyawibawa, I., & Paeru, R. H. (2012). Kelapa

Sawit. Jakarta, Penebar Swadaya. Available at: https://books.google.co.id/books?id=U8FNCgAAQBAJ&printsec=frontcover#v=onepage&q&f=false.

16. Gokomodo (2023). Mengenal Pupuk MOP, Manfaat dan Penggunaanya dalam Pertanian. Available at: https://gokomodo.com/blog/mengenal-pupuk-mop-manfaat-dan-penggunaannya-dalam-pertanian.

17. Hardiyanti, S. (2017). *Analisis risiko usahatani kelapa sawit di desa Batu Matoru kecamatan Lariang, kabupaten Mamuju Utara* [Risk analysis of oil palm farming in Batu Matoru village, Lariang subdistrict, North Mamuju district]. Makassar, Universitas Hasanudin.

18. Harefa, S. N. (2021). *Analisis pendapatan dan efisiensi teknis usahatani kelapa sawit mandiri di desa Markanding kecamatan Bahar Utara kabupaten Muaro Jambi* [Analysis of income and technical efficiency of mandiri palm oil farming in Markanding village, Bahar Utara district, Muaro district, Jambi]. Jambi, Universitas Batanghari. Available at: http://repository.unbari.ac.id/756.

19. Hartanto, A. (2021). Sustainable palm oil development in Indonesia. Kemenko perekonomian RI, Jakarta. Available at: https://www.ekon.go.id/publikasi/detail/2797/pemerintahdorong-kolaborasi-semua-pihak-untuk-pembangunan-kelapa-sawit-berkelanjutan.

20. Hasan, A. (2022). Pengaruh harga dan produktivitas kelapa sawit terhadap pendapatan petani kelapa sawit (studi kasus di desa cahya negri kec.sukaraja kab.seluma). *Jurnal Ekonomi dan Kebijakan Publik*, 5(2), 111–122. https://doi.org/10.32663/pareto.v5i2.3441.

21. Hasibuan, M., Nurdelila, N., & Rahmat, R. (2020). Determinants of palm oil productivity in North Sumatra province. *Jurnal Ekonomi*, 22(3), 239–249. https://doi.org/10.37721/JE.V22I3.729.

22. Indonesian Oil Palm Research Institute (n.d.). Official website. Available at: https://iopri.co.id.

23. Ismiasih, I. (2018). Technical efficiency of palm oil production in West Kalimantan. *Habitat*, 28(3), 91–98. https://doi.org/10.21776/ub.habitat.2017.028.3.13.

24. Jondrow, J, Knox Lovell, C. A., Materov, I. S., Schmidt, P. (1982). On the estimation of technical inefficiency in the stochastic frontier production function model. *Journal of Econometrics*, 19(2–3), 233–238. https://doi.org/10.1016/0304-4076(82)90004-5.

25. Jufri, F., & Junaidi (2020). Factors that influence the production level of palm oil (Elaeis guineensisJacq.) in Laburan village, Paser Belengkong district, Paser regency. *Rawa Sains: Jurnal Sains STIPER Amuntai*, 10(1), 9–17. https://doi.org/10.36589/rs.v10i1.110.

26. Kasno, A., & Nurjaya, N. (2020). Pengaruh pupuk kiserit terhadap pertumbuhan kelapa sawit dan produktivitas tanah. *Jurnal Penelitian Tanaman Industri*, 17(4), 133. https://doi.org/10.21082/jlittri.v17n4.2011.133-139.

27. Lau, L. J., & Yotopoulos, P. A. (1971). A test for relative efficiency and

application to Indian agriculture. *The American Economic Review*, 61(1), 94–109. https://www.jstor.org/stable/1910544.

28. Manik, M. B. (2022). *Analisis efisiensi teknis usahatani kelapa sawit pola swadaya di kecamatan Sekernan kabupaten Muaro Jambi* [Analysis of the technical efficiency of self-help palm oil farming in Sekernan district, Muaro Jambi regency]. Jambi, Universitas Jambi. Available at: https://repository.unja.ac.id/44981/1/Full%20Skripsi%20Monika.pdf.

29. Nainggolan, S., Napitupulu, D. M. T., & Saad, M. (2019). Analysis of technical efficiency, source of inefficiency and risk preferences of farmers and its implications in the efforts to improve productivity of palm oil plantation in Jambi province of Indonesia. *Russian Journal of Agricultural and Socio-Economic Sciences*, 11(95), 83–92. https://doi/10.18551/rjoas.2019-11.11.

30. Nainggolan, S., Yanita, M., & Leonardo, M. (2021). Factors that affect the productivity of palm oil plantations self-help patterns in Jambi province. *Randwick International of Social Science Journal*, 2(4), 404–410. https://doi.org/10.47175/rissj.v2i4.321.

31. Napitupulu, D. M. T., Nainggolan, S., & Murdy, S. (2020). Kajian efisiensi teknis, sumber inefisiensi dan preferensi risiko petani serta implikasinya pada upaya peningkatan produktivitas perkebunan kelapa sawit di provinsi Jambi. *Journal of Agribusiness and Local Wisdom*, 3(2). https://doi.org/10.22437/jalow.v3i2.11614.

32. Narala, A., & Zala, Y. C. 2010. Technical efficiency of rice farms under irrigated conditions in Central Gujarat. *Agricultural Economics Research Review*, 23, 375–381. Available at: https://core.ac.uk/download/pdf/6455744.pdf.

33. Natalia, M. C., Aisyah, S. I., & Supijatno (2016). Fertilization management on mature plant oil palm in Kebun Tanjung Jati. *Buletin Agrohorti*, 4(2), 132–137. https://doi.org/10.29244/agrob.v4i2.15009.

34. Ogundari, K., & Ojo, S. O. (2007). An examination of technical, economic and allocative efficiency of small farms: the case study of cassava farmers in Osun state of Nigeria. *Bulgarian Journal of Agricultural Science*, 13, 185–195. Available at: https://www.agrojournal.org/13/02-05-07.pdf.

35. Pahan, I. (2018). *Panduan teknis budidaya kelapa sawit untuk praktisi perkebunan* [Technical guide to oil palm cultivation for plantation practitioners]. Jakarta, Penebar Swadaya. Available at: https://opac.perpusnas.go.id/DetailOpac.aspx?id=942026#.

36. Panjaitan, E., Paman, U., & Darus (2020). Analysis of the effect of production factorsonproductivity of oil palm farming with Swadaya pattern in Sungai Buluh Village, Kuantan Singingi Hilir district, Kuantan Singingi regency. *Jurnal Dinamika Pertanian Edisi*, 36(1), 61–68. https://doi.org/10.25299/dp.2020.vol36(1).5371.

37. Pasaribu, A., Bakce, D., & Dewi, N. (2016). The efficiency of production analysis of coconut farming in Keritang subdistrict, Indragiri Hilir municipality. *Jurnal Online Mahasiswa*, 3(1). Available at: https://jom.unri.ac.id/index.php/JOMFAPERTA/article/view/9079.

38. Pramesti, W. D. (2023). *Analisis efisiensi teknis, alokatif dan ekonomi usahatani kelapa sawit pola swadaya di kecamatan Pamenang Selatan kabupaten Merangin* [Analysis of technical, allocative and economic efficiency of self-help palm oil farming in Pamenang Selatan district, Merangin regency]. Jambi, Universitas Jambi. Available at: https://repository.unja.ac.id/57239/1/cover.pdf.

39. Puruhito, D. D., Jamhari, J., Hartono, S., & Irham, I. (2019). Determining factors of production in palm oil palm plantation in North Mamuju district. *Jurnal Teknosains*, 9(1), 58. https://doi.org/10.22146/teknosains.38914.

40. Rahmawati, S. E. (2022). *Analisis efisiensi teknis penggunaan pupuk perkebunan kelapa sawit rakyat pola swadaya di kabupaten Muaro Jambi menggunakan metode data envelopment analysis* [Analysis of the technical efficiency of fertilizer use on self-help palm oil plantations in Muaro Jambi regency using the data envelopment analysis method]. Jambi, Universitas Jambi. Available at: https://repository.unja.ac.id/41843.

41. Riati, B. (2016). Efisiensi penggunaan faktor produksi dan pendapatan usahatani kelapa sawit swadaya di kecamatan Kemuning. *Jurnal BiBieT*, 1(2), 95–107. https://doi.org/10.22216/jbbt.vli2.1793

42. Sakhno, A., Hryvkivska, O., Salkova, I., Kucher, L. (2019). Evaluation of the efficiency of enterprises by the method of analysis of functioning environment. *Journal of Environmental Management and Tourism*, X(3), 499–507. https://doi.org/10.14505//jemt.v10.3(35).04.

43. Saragih, I. K., Rachmina, D., & Krisnamurthi, B. (2020). Analisis status keberlanjutan perkebunan kelapa sawit rakyat provinsi Jambi. *Journal of Indonesian Agribusiness*, 8(1), 17–32. https://doi.org/10.29244/jai.2020.8.1.17-32.

44. Serikat Petani Kelapa Sawit (2016). *Standar operasional prosedur manajemen pemupukan* [Standard operational procedures fertilization management]. SOP AGRO-07/03. Available at: https://spks.or.id/file/publikasi/9__SOP_PEMUPUKAN_Fixed-edit1.pdf.

45. Soekartawi (2003). *Teori ekonomi produksi dengan pokok bahasan analisis fungsi Cobb Douglas* [Economic theory of production with the subject of Cobb Douglas function analysis]. Jakarta, Raja Grafindo Persada. Available at: https://lontar.ui.ac.id/detail?id=70319.

46. Stevan, J., Alamsyah, Z., & Naenggolan, S. (2015). Analisis efektivitas pasar lelang karet di kabupaten Bungo provinsi Jambi. *Jurnal Ilmiah Sosio-Ekonomika Bisnis*, 18(1), 32–42. https://doi.org/10.22437/jiseb.v18i1.2814.

47. Susanto, A. (2021). *Konsep produktivitas dan efisiensi teknis dalam dunia pertania* [Concepts of Productivity and Technical Efficiency in the World of Agriculture]. Surabaya, Global Aksara Pers.

48. Syuhada, F. A., Hasnah, H., & Khairati, R. (2022). Oil palm farming technical efficiency analysis: stochastic frontier analysis. *Jurnal Ekonomi Pertanian Dan Agribisnis*, 6(1), 249–255. https://doi.org/10.21776/ub.jepa.2022.006.01.24.

49. Tajerin & Noor, M. (2005). Analisis efisiensi teknis usaha budidaya pembesaran ikan kerapu dalam keramba jaring apung di perairan teluk Lampung:

produktivitas, faktor-faktor yang mempengaruhi dan implikasi kebijakan pengembangan budidayanya. *Jurnal Ekonomi Pembangunan*, 10(1), 95–105. Available at: https://media.neliti.com/media/publications/62197-ID-analisis-efisiensi-teknik-usaha-budidaya.pdf.

50. Tasman, A. (2008). Analisis efisiensi dan produktivitas. Jakarta, Penerbit Chandra Pratama.

51. Wijoyo, B. S. (2019). *Efisiensi penggunaan faktor-faktor produksi pada usahatani kelapa sawit rakyat (studi kasus: desa Lama Baru, kecamatan Sei Lepan, kabupaten Langkat)* [Efficient use of production factors in smallholder oil palm farming (case study: Lama Baru village, Sei Lepan subdistrict, Langkat district)]. Medan, Universitas Muhammadiyah Sumatera Utara. Available at: http://repository.umsu.ac.id/handle/123456789/304.

Citation:

Стиль – ДСТУ:

Nainggolan S., Fitri Y. Assessment of the efficiency of palm plantations using a stochastic frontier approach. *Agricultural and Resource Economics*. 2024. Vol. 10. No. 1. Pp. 203–227. https://doi.org/10.51599/are.2024.10.01.09.

Style – APA:

Nainggolan, S., & Fitri, Y. (2024). Assessment of the efficiency of palm plantations using a stochastic frontier approach. *Agricultural and Resource Economics*, 10(1), 203–227. https://doi.org/10.51599/are.2024.10.01.09.