Research Article

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Production factors, technical, and economic efficiency of soybean (*Glycine max* L. Merr.) farming in Indonesia

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Abstract: Most soybean farming in Indonesia is still performed conventionally. Farmers are less interested in cultivating soybeans because the production yields are relatively small. This research aims to determine the factors influencing production, production inefficiency of soybean, and the technical efficiency (TE) and economic efficiency (EE) level of soybean farming. Primary data were collected using a survey method of soybean farmers in paddy field areas in the Tabanan Regency of Bali Province, Indonesia. Data were analyzed using the stochastic frontier approach using the Frontier 4.1 analysis tool. Factors that positively affected the increasing soybean production were land area, urea and NPK fertilizers, and soybean seeds. The factor positively affecting soybean production inefficiency was a farming experience. The average TE value was 0.77, implying that soybean farming in the study area was efficient. However, the EE value below 0.70 implied that soybean farming was inefficient. Based on soybean farmers' farming experience, TE and EE values were getting lower. The low value of EE was suspected of causing farmers' low interest in cultivating soybean.

Keywords: production efficiency, production inefficiency, soybeans, stochastic frontier approach

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1 Introduction

In Indonesia, soybean is the third most important food crop after rice and maize. Soybean has an important role as an affordable and good protein source, which is predominantly consumed in the form of tempeh and tofu [1], the favorite dishes of most communities in Indonesia. Due to their important role in the Indonesian diet, soybean should be available in sufficient quantities along with the increase in population yearly and soybean demand for food industries' raw materials. Between 2020 and 2024, the national soybean demand ranged from 2.73 to 3.29 million tons. During this period, the consumption level of soybean fluctuates and tends to increase by 1.46% per year. The level was 10.17 kg/capita/year in 2019 and slightly increased to 12.15 kg/capita/year in 2020 [2]. The increase was assumed to be associated with the global pandemic of COVID-19, which led to the decline of the communities' purchasing power for animal protein sources. The consumption pattern then shifted to some affordable vegetable protein sources, such as soybean. Recently, the increase in soybean consumption is also influenced by the communities' awareness of a healthy lifestyle by consuming a vegetarian diet [3].

Soybean is in Indonesia's third household food expenditure rank after rice and chicken meat. Based on a survey by Statistik [4], in 2020, more than 60% of the soybean farming households in Indonesia cultivated soybeans as a secondary crop after rice harvesting in paddy fields, both irrigated and nonirrigated, as a source of farmers' income during the dry season. When the price of soybeans on the market is quite high, farmers also plant soybeans in any season [5]. However, in 2018–2020, the soybean production trend decreased by an average of 6.12% per year, while demand and imports tended to increase linearly with an average of 3.30 and 3.03% per year [6]. The Indonesian Ministry of Agriculture noted that the average soybean productivity in Indonesia in 2014 reached 1.55 t/ha and decreased to 1.44 t/ha in 2018 [7]. This figure was far below the average world soybean productivity in 2016, 2.76 t/ha [8]. The low productivity of soybeans causes the low interest of Indonesian farmers in cultivating soybeans.

Farmers' interest in soybean farming has also declined in Bali Province. It was marked by a decrease in soybean production from 8,504 tons in 2011 to 2,411 tons in 2018 [9,10]. The total area of paddy fields in Bali in 2017 was 78,626 ha, with the highest area in the Tabanan district, 21,089 ha (26.82%) [11]. Soybean production in the Tabanan Regency from 2011 to 2018 tends to decrease. In 2011, soybean production in the Tabanan Regency was 1,033 tons and decreased to 332 tons in 2018. As a result, Tabanan Regency contributed 11.50% to the total decrease in soybean production in Bali Province from 2011 to 2018, reaching 6,093 tons [9,10].

Seeing the problems of soybean farming in Indonesia, particularly in Bali Province, which tends to experience decreased production and low interest of farmers to cultivate soybean, this research aims to determine the factors influencing soybean production, soybean production inefficiency, and the level of technical efficiency (TE) and economic efficiency (EE) of soybean farming in paddy fields in Indonesia with the case study in paddy field areas in the Tabanan Regency, Bali Province. The result of this study is expected to provide policy implications as a reference for the government to increase farmers' soybean production, which impacts increasing soybean farmers' income.

2 Methodology

The research was carried out in December 2021 at the soybean planting site in the paddy fields of Tabanan Regency, Bali Province, Indonesia. The precise research location was in Subak Bengkel at Bengkel Village, Kediri Subdistrict (Figure 1). The location was determined purposively considering that Tabanan Regency has the largest area of paddy fields in Bali Province (26.82%) and has the potential for soybean planting [11].

The quantitative data used in this study were primary data collected from direct interviews with 27 soybean farmer respondents using a questionnaire as guidance. The analytical method used was an econometric model to estimate the relationship between dependent variables of a production function in soybean farming. Several

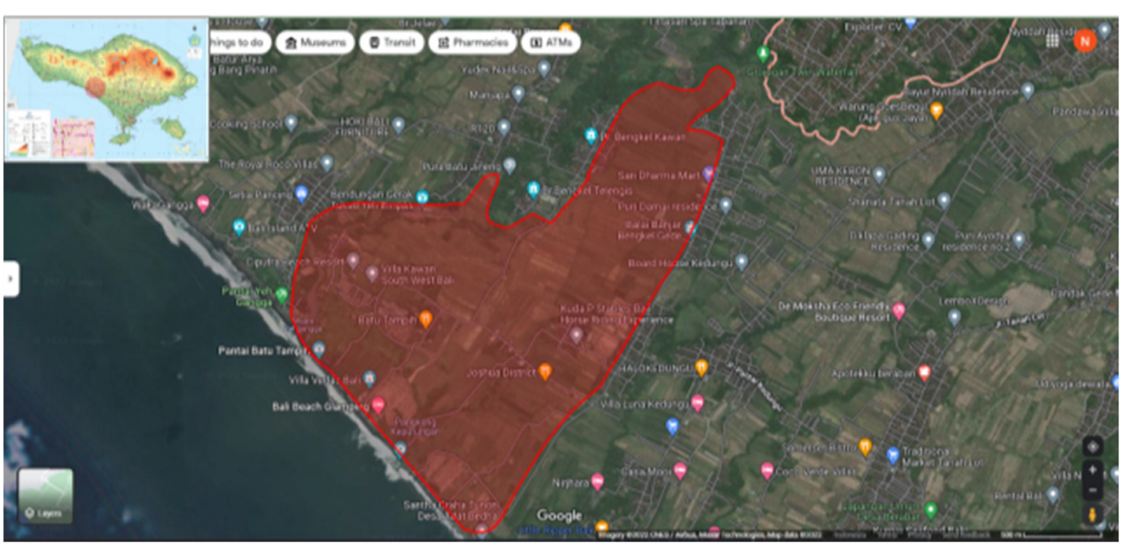

Figure 1: The research location of Subak Bengkel at Bengkel Village, Kediri Subdistrict, Tabanan Regency, Bali Province (GPS coordinate of S 8° 35′ 16.2″, E 115° 5′ 32.7″).

factors underlying the selection of a model were (1) the level of goodness of the fitted model, (2) the appropriateness of the estimated parameters, and (3) the t-test results of the estimated parameters [12,13].

2.1 Production factors

The production factor analysis used the stochastic Frontier Cobb-Douglas production function model. The stochastic frontier model expands the original deterministic model to measure stochastic effects within the production limit [14]. The model of the stochastic frontier production function is as follows:

$$\mathrm{Ln}Y_i = \beta_0 \sum_{i=1}^{n} \beta_j \mathrm{Ln}X_{ji} + \varepsilon_i. \tag{1}$$

Coelli [15] briefly presented the stochastic frontier production function equation as follows:

$$\mathrm{Ln}Y_{it} = \beta x_{it} + (v_{it} - u_{it}), \quad i = 1, 2, 3, \ldots n, \tag{2}$$

where Y_{it} is the production of the ith farmers at the tth time; X_{it} are the variables of input used by the ith farmers at the tth time; β_i are the parameter variables to be estimated; v_{it} are the random variables related to external factors (climate, pests); the distribution is symmetrical and normal ($v_{\mathrm{it}} \sim N(0,\sigma_{\mathrm{v}}^2)$); and u_{it} are the non-negative random variables, assumed to affect the level of technical inefficiency, related to internal factors, and the distribution is half-normal ($u_{\mathrm{it}} \sim |N(0,\sigma_{\mathrm{v}}^2|)$.

The model for estimating the production function in soybean farming is as follows:

$$\begin{aligned}\mathrm{Ln}Y = \mathrm{Ln}\beta_0 + \beta_1\mathrm{Ln}X_1 + \beta_2\mathrm{Ln}X_2 + \beta_3\mathrm{Ln}X_3 + \beta_4\mathrm{Ln}X_4 \\ + \beta_5\mathrm{Ln}X_5 + vi - ui,\end{aligned} \tag{3}$$

where Y represents the production of soybean (kg), β_0 represents the constant, X_1 represents the land area (ha), X_2 represents the seed use (kg), X_3 represents the urea fertilizer (kg), X_4 represents the NPK – nitrogen, phosphor, and potassium fertilizer (kg), X_5 represents labor (days of work), $v_i - u_i$ represents the error term ($\underline{u}_i$), the effect of technical inefficiency of the model; β_i represents the coefficient of estimated parameters, where i = 1, 2, 3, … n.

Expected coefficient values were β_1, β_2, β_3, β_4, β_5, > 0.

Meanwhile, the determinant of the parameter values for the distribution of production inefficiency effects in this research can be built using the following model:

$$ui = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + W_{it}, \tag{4}$$

where u_i represents the production inefficiency effect, δ_0 represents the constant; Z_1 represents the respondent's age (years); Z_2 represents the education level (years); Z_3 represents the soybean farming experience (years); Z_4 represents the number of household members (people); Z_5 represents the dummy of seed certification (0: not certified, 1: certified); w_{it} represents the error term; and δ_i represents the coefficient of estimated parameters, where i = 1, 2, 3, … n.

Expected coefficient values were δ_1, δ_2, δ_3, δ_4, δ_5 < 0.

2.2 TE

TE is the comparison between actual and potential production levels that can be achieved [16]. The TE rate can be measured using a variance ratio as follows [17]:

$$\gamma = \frac{\sigma_{\mathrm{u}}^2}{\sigma^2}, \tag{5}$$

where

$$\sigma^2 = \sigma_{\mathrm{u}}^2 + \sigma_{\mathrm{v}}^2, \text{ and } 0 \le \gamma \le 1. \tag{6}$$

When γ is close to 1, σ_{v}^2 is close to zero, and v_i is the predominant error, it implies technical inefficiency. The difference between the actual and potential productions indicates the inefficiency in production.

Meanwhile, based on Soekartawi [18], TE can be measured with the following equation:

$$\mathrm{TE} = \frac{iY}{i\hat{Y}}, \tag{7}$$

where TE is the technical efficiency level, iY is the ith production (output), and $i\hat{Y}$ is the estimated production in the ith observation obtained from the production function of Frontier Cobb-Douglas.

Measurement of TE from the production input side is the ratio of frontier input or costs to observation input or costs. The general equation of TE achieved by the ith observation at the tth time is defined as follows [19]:

$$\mathrm{TE}_i = \frac{E(Y \mid U_t, X_t)}{E(Y^* \mid U_t = 0, X_t)} = E[\mathrm{Exp}(-U_t)/\varepsilon_t], \tag{8}$$

where $0 < \mathrm{TE}_i < 1$.

2.3 Allocative efficiency (AE)

AE (price efficiency) shows the relationship between cost and output. AE can be achieved if a profit can be maximized by equating the marginal product of each production factor with its price [16]. According to Nicholson [20], price efficiency is achieved when the ratio between the marginal productivity value of each input (NPMx) and the input price (Px) or ki equals 1. This condition requires that NPMx equals Px or can be written as follows:

$$\mathrm{NPM}x = \mathrm{P}x \tag{9}$$

or

$$\frac{\mathrm{NPM}x}{\mathrm{P}x} = 1. \tag{10}$$

In fact, NPMx is not always the same as Px, but according to Sukartawi [16]:

a. (NPMx/Px) > 1 means that X input is inefficient; input X needs to be added to be efficient.

b. (NPMx/Px) < 1 means that input X is inefficient; input X needs to be reduced to be efficient.

c. NPMx/Px = 1 means that input X is efficient and maximum profit is obtained.

2.4 EE

EE is the multiplication of TE and AE (price efficiency). Therefore, EE can be written as follows:

$$\mathrm{EE} = \mathrm{TE} \times \mathrm{AE}, \tag{11}$$

where EE is the economic efficiency, TE is the technical efficiency, and AE is the allocative efficiency.

EE is defined as the ratio of the total minimum production costs (C^*) observed to the actual total production costs (C) [21].

$$\mathrm{EE} = \frac{C^*}{C} = \frac{E(C_i \mid U_i, =0, Y_i, P_i)}{E(C_i \mid U_i, Y_i, P_i)} = E[\mathrm{Exp}(-U_i/\varepsilon)], \tag{12}$$

where 0 < EE < 1.

3 Results and discussion

3.1 Factors affecting soybean production

The results of stochastic frontier model estimation described the best performance of farmers as respondents at the level of existing technology. Estimation was carried out using the maximum-likelihood estimate (MLE) method. Variables significantly influencing soybean production were land area and the use of urea fertilizer at α-level of 1%, NPK fertilizer at α-level of 5%, and seeds at α-level of 10%. The use of labor had no significant effect on soybean production (Table 1).

Table 1: Production function estimation using the MLE method for soybean farming in Bali Province, Indonesia, in 2020

Parameter	Variable	Coefficient	Standard error	t-ratio	
β_0	Constant	2.91	0.21	13.83	
β_1	Land area	0.83	0.06	14.92	***
β_2	Seeds	0.11	0.08	1.43	*
β_3	Urea fertilizer	0.02	0.00	4.40	***
β_4	NPK fertilizer	0.01	0.01	2.30	**
β_5	Labor	0.04	0.06	0.73	

* significant effect at α-level of 10%; ** significant effect at α-level of 5%; *** significant effect at α-level of 1%.

Land area and use of urea fertilizer had positive signs and significant effects on soybean production at a 99% confidence level (α-level of 1%) (Table 1). A coefficient value of 0.83 indicated that an additional 1% of land area for soybean farming (where other inputs remain the same) could increase soybean production by an additional 0.83%. It implies that if farmers want to increase soybean production, the land area cultivated by farmers must be extended. This finding follows previous research stating that increasing the land area would positively affect soybean productivity and production [22–27]. Furthermore, a study in China showed that the land area per capita parameter positively affected TE [28].

A coefficient value of urea fertilizer of 0.02 indicated that an additional 1% of urea fertilizer (where other inputs remain the same) could increase soybean production by an additional 0.02%. It implied that urea fertilizer should be increased to enhance soybean production. This result concurs with the previous studies in Ghana and China [25,28]. Moreover, previous studies [29,30] found that using fertilizer positively affected the EE of soybean farming in Nigeria and Myanmar.

The use of NPK fertilizer significantly affected soybean production at a 95% confidence level (α-level of 5%) and had a positive sign. A coefficient value of 0.01 indicated that an additional 1% NPK fertilizer could increase soybean production by 0.01%. The implication is that NPK fertilizer should be increased to enhance soybean production. NPK fertilizer contains nitrogen, phosphate, and potassium. Phosphate is important for strengthening plant tissue, especially stems, to prevent plants from falling and speeding up the process of seeds ripening [5], while potassium is important for plant growth and development [31] and produces higher seed quality [32].

Using soybean seeds significantly affected soybean production at a 90% confidence level (α-level of 10%). The positive sign with a coefficient value of 0.11 implied that every 1% additional seed could increase soybean production by an additional 0.11%. Previous studies [22,28,30,33–35] found that an increase in the number of seeds significantly and positively affected productivity and soybean production. Therefore, if farmers want to increase soybean production, the input of soybean seeds must be increased according to the needs of the soybean planting area.

3.2 Soybean production inefficiency

A variable that at a 90% confidence level had a significant effect and positive sign on the soybean production inefficiency was the soybean farming experience. The farmer's age, educational level, number of household members, and dummy types of seeds did not significantly affect the inefficiency of soybean production. This finding contrasts with the previous study [36], which stated that the older the farmer and the higher the educational level, the soybean production tends to become more inefficient. Furthermore, Asodina et al. [22] found that the high involvement of young people in soybean production could affect the sustainability of soybean cultivation. The number of household members and dummy types of seed variables with negative signs indicated a tendency that the greater number of household members and the use of certified seed types, the more efficient the soybean production. The average efficiency result was 77.05% (Table 2). The value was categorized as efficient because it was greater than 0.70, the limit of efficiency [15].

The experience in soybean farming had a positive coefficient value of 0.022, meaning that the more experienced farmers in soybean farming, the more production inefficiency increased. It is presumably because the longer farmers experience soybean farming, the more difficult it is for them to accept new technology. It could be because farmers feel that they are already experts in soybean farming and more comfortable with the existing farming system that has been implemented [33]. This finding is in contrast with the previous studies [22,33,37,38], which found that the experience of farmers in soybean production greatly influences production efficiency, and conversely, the low experience of farmers can be a challenge in soybean production. The study by Mariyono [5] stated that increasing farmers' capacity has enhanced soybean production. Therefore, social interaction and providing information when promoting technology are indispensable [39]. The other study revealed that the role of extension in disseminating varieties and technology positively impacts technology adoption at the farm level [37] and further influences the TE of soybean farming [40].

3.3 TE of soybean farming

The more experienced a farmer in soybean farming, the less efficient the soybean production was (Table 2). Farmers with 1–5 years of experience in soybean farming had the highest average TE score of 99.07%, while soybean farmers with experience of 6–10 years and 11–15 years, respectively,

Table 2: Estimation of soybean production inefficiency function using stochastic Frontier approach for soybean farming in Bali Province, Indonesia, in 2020

Parameter	Variable	Coefficient	Standard error	*t*-ratio
δ_0	Constant	−0.21994	0.20122	−1.09304
δ_1	Farmer's age	0.00377	0.00313	1.20448
δ_2	Education level	0.00558	0.00818	0.68248
δ_3	Farmer's experience in soybean farming	0.02171	0.01463	1.48445*
δ_4	Number of household members	−0.00595	0.02259	−0.26334
δ_5	Dummy types of seeds	−0.02948	0.12379	−0.23815
Sigma-square		0.01134	0.00260	4.36954
Gamma		0.99999	0.09564	10.4559
Log-likelihood function			23.92305	
LR test of the one-side error			9.66465	
Mean efficiency			0.77048	

* significant effect at α-level of 10%; ** significant effect at α-level of 5%; *** significant effect at α-level of 1%.

Table 3: Distribution of farmers according to the level of efficiency based on soybean farming experience in Bali Province, Indonesia, in 2020

Level of efficiency	Classification of soybean farming experience					
	1–5 years (people)	Percentage (%)	6–10 years (people)	Percentage (%)	11–15 years (people)	Percentage (%)
<0.50	0	—	0	—	0	—
0.50–0.69	0	—	4	20.00	3	50.00
0.70–0.90	0	—	13	65.00	3	50.00
>0.90	1	100.00	3	15.00	0	—
Total	1	100.00	20	100.00	6	100.00
Average efficiency		0.9907		0.7739		0.7225

Level of efficiency: <0.50 – very low (inefficient); 0.50–0.69 – low (inefficient); 0.70–0.90 – high (efficient); >0.90 – very high (efficient).

had an average TE score of 77.38% and 72.25% (Table 3). However, because the value was greater than 0.70 as the limit of efficiency [15], it can be said that soybean farming in the Tabanan Regency of Bali Province was categorized as technically efficient. This finding aligns with the previous studies [24,41], which revealed that the average TE of soybean farming in Indonesia was 81 and 76.7%, respectively, and in Ethiopia was 72.81% [42].

3.4 AE and EE of soybean farming

AE and EE were obtained by calculating the ratio of input prices to output prices. Soybean farming with farmer experience of 1–5 years resulted in an average value of AE of 0.659. It indicated the inefficient AE of soybean farming. The complete distribution of TE, AE, and EE of soybean farming among farmers with 1–5 years of farming experience is shown in Table 4.

The combined effect of TE and AE efficiencies showed that the average EE of soybean farming in a group of farmers with 1–5 years of experience was 0.654. It indicated that soybean farming was not yet economically efficient. The previous study by Setiawan [43] showed an AE of 1.73% and an EE of 1.66%. The cause of low EE was the low AE, even though the TE was relatively high. According to Henderson [44], TE or AE differences significantly affected all productivity indicators. The low AE, which caused low EE, indicated that soybean farming in a group of farmers with 1–5 years of experience has been unable to produce the maximum profit. It was likely the cause of farmers' decreased interest in cultivating soybean.

The distribution of AE and EE among a group of farmers with soybean farming experience of 6–10 years was less than 0.50. It showed that allocative and economically, soybean farming carried out by farmers with experience in soybean farming for 6–10 years was inefficient because it could not provide the maximum profit, even

Table 4: Distribution of TE, AE, and EE of soybean farming in the classification of 1–5 years of farming experience in Bali Province, Indonesia, in 2020

Level of efficiency	Classification of 1–5 years of soybean farming experience					
	TE	(%)	AE	(%)	EE	(%)
<0.50	0	—	0	—	0	—
0.50–0.69	0	—	1	100.00	1	100.00
0.70–0.90	0	—	0	—	0	—
>0.90	1	100.00	0	—	0	—
Total	1	100.00	1	100.00	1	100.00
Minimum		0.990747		0.659725		0.653620
Maximum		0.990747		0.659725		0.653620
Average efficiency		0.990747		0.659725		0.653620

TE – technical efficiency; AE – allocative efficiency; EE – economic efficiency.

Table 5: Distribution of TE, AE, and EE of soybean farming in the classification of 6–10 years of farming experience in Bali Province, Indonesia, in 2020

Level of efficiency	Classification of 6–10 years of soybean farming experience					
	TE	(%)	AE	(%)	EE	(%)
<0.50	0	—	20	100.00	20	100.00
0.50–0.69	4	20.00	0	—	0	—
0.70–0.90	13	65.00	0	—	0	—
>0.90	3	15.00	0	—	0	—
Total	20	100.00	20	100.00	20	100.00
Minimum		0.616546		0.035584		0.022911
Maximum		0.935635		0.499468		0.467320
Average efficiency		0.773864		0.234739		0.194373

TE – technical efficiency; AE – allocative efficiency; EE – economic efficiency.

though technically, most of the farmers were at a high level of efficiency (Table 5). The combined effect of TE and AE showed that the average EE of soybean farming in a group of farmers with 6–10 years of experience was 0.194, much lower than that of farmers with 1–5 years of experience. It meant that soybean farming with 6–10 years of farmers' experience was not economically efficient and could not provide the maximum profit.

The distribution of AE and EE among a group of farmers with 11–15 years of experience in soybean farming was less than 0.50 (Table 6). It meant that allocative and economically, soybean farming of all farmers with 11–15 years was inefficient because they were unable to produce the maximum profit.

The combined effect of TE and AE showed that the average EE of soybean farming in the group of farmers with 11–15 years of experience was 0.133, much lower than the groups of farmers with 1–5 years and 6–10 years of experience. It implied that soybean farming was not economically efficient. As in the case of other farming experience groups, the cause of low EE was the low AE, which indicated that soybean farming could not provide the maximum profit. It could be said that the longer the soybean farming experience of farmers in the Tabanan Regency of Bali Province, the lower the level of TE, AE, and EE. This finding contrasted with several previous studies in Nigeria and Ethiopia, which found that farming experience had a significant positive effect on EE [29] and AE [45], as well as being a social variable that had a significant effect in reducing economic inefficiency among soybean farmers [42].

The low EE in soybean farming in Tabanan Regency, Bali Province, Indonesia, based on the group of farmers' experiences, showed that soybean farming was not economically efficient. A solution to reduce production costs can be implemented to achieve better efficiency value. Another study conducted in Nganjuk Regency, East Java Province, Indonesia, showed that for soybean farmers who were still unable to achieve EE, the opportunity for saving production costs to achieve EE was high [46]. Effectively

Table 6: Distribution of TE, AE, and EE of soybean farming in the classification of 11–15 years of farming experience in Bali Province, Indonesia, in 2020

Level of efficiency	Classification of 11–15 years of soybean farming experience					
	TE	(%)	AE	(%)	EE	(%)
<0.50	0	—	6	100.00	6	100.00
0.50–0.69	3	50.00	0	—	0	—
0.70–0.90	3	50.00	0	—	0	—
>0.90	0	—	0	—	0	—
Total	6	100.00	6	100.00	6	100.00
Minimum		0.620777		0.026223		0.016278
Maximum		0.837784		0.474576		0.397592
Average efficiency		0.722483		0.170929		0.132853

TE – technical efficiency; AE – allocative efficiency; EE – economic efficiency.

using inputs was important in increasing farmers' income and reducing soybean production costs [47].

4 Conclusion

Factors that positively affected the efficiency of soybean production in Tabanan Regency, Bali Province, Indonesia, were land area, urea and NPK fertilizer use, and use of soybean seeds. The most responsive variable was the land area, with a coefficient of 0.83. The experience of farmers in soybean farming was a factor influencing the inefficiency of soybean production. Technically, the average efficiency of soybean farming among groups of farmers with farming experiences of 1–5 years, 6–10 years, and 11–15 years was above 0.70, which meant efficient. However, the average value of EE was lower than 0.70, implying that soybean farming was economically inefficient to cultivate.

Several efforts that can be made to increase soybean production at the farmer level are as follows: (1) increasing the effective use of planting area, fertilizers (urea and NPK), and soybean seeds; and (2) facilitating farmers by the agricultural service to improve knowledge through counseling, assistance, dissemination, and demonstration plots of soybean farming with various latest technologies to be observed directly and in a participatory way. This effort reduces farmers' tendency to think that the more experienced they are in soybean farming, they no longer need to obtain the latest information. These changes in mindset and habit are expected to increase soybean production, restoring farmers' interest in soybean farming.

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