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Technical Efficiency Potential of People's Coffee with a Lane System and Grafting System (Special Connection) in Bengkulu Province, Indonesia

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Abstract: This study aims to determine which is more efficient between coffee cultivated in columns and technically grafted coffee. Indonesia is the largest coffee-producing country in the world after Brazil and Vietnam, with a land potential of more than 1.2 million hectares and an average productivity of less than 0.7 tons per hectare. Cross-sectional data were collected from 326 farmers, consisting of 206 lane coffee farmers and 120 grafting coffee farmers. As a coffee-producing region, Bengkulu contributes to the low productivity of Indonesian coffee. Based on SFA analysis, the research results revealed that 87 % of coffee farmers with a grafting system in the study area have a technical efficiency level above 90%, when compared to the lane system, which is only 62 %, this shows that coffee with a grafting system has proven to be technically more efficient. The low technical production has affected the efficiency of coffee farmers in Bengku Province. The government made various efforts to increase production, one of which is plant genetic engineering technology through grafting, better known to the local community as shoot grafting, which has produced coffee varieties that are superior both in growth and production and are recognized based on Geographical Indications (GI) of the region of origin.
Keywords: coffee; strips; grafting; technical efficiency

印度尼西亚明古鲁省人民咖啡巷道系统和嫁接系统（特殊连接）的技术效率潜力

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摘要: 这项研究旨在确定柱式种植咖啡和技术嫁接咖啡哪种效率更高。印度尼西亚是继巴西和越南之后世界上最大的咖啡生产国，土地潜力超过 120 万公顷，平均生产力每公顷不到 0.7 吨。横断面数据收集自 326 个农民，其中包括 206 个巷道咖啡农民和 120 个嫁接咖啡农民。明古鲁作为咖啡产区，导致印尼咖啡生产力低下。根据国家安全局分析，研究结果显示，研究区内采用嫁接系统的咖啡农中，87%的咖啡农技术效率水平在 90%以上，而相比于巷道系统的技术效率仅为 62%，这表明咖啡种植者的技术效率水平在 90%以上。事实证明，嫁接系统在技术上更加高效。低技术生产影响了明古省咖啡农的效率。政府采取了各种措施来提高产量，其中之一是通过嫁接的植物基因工程技术，即芽接，该技术生产出生长和产量均优越的咖啡品种，并获得地理标志认可(胃肠道)原产地。

关键词：咖啡; 条带; 嫁接; 技术效率

1 Introduction

Indonesia is the world's largest coffee producer after Brazil, Vietnam, and Colombia. The agricultural sector plays a role in providing employment and income for the population as well as providing food and alleviating poverty[1]. Research results show that agriculture is an important driver of regional economic growth and contributes to an increase in regional gross output of around €300 million. only by the inflow of funds, while 14% of it is channeled to sectors other than agriculture[2]. Although various studies have shown that the added value of the agricultural sector is mostly absorbed by the industrial and other sectors. This shows the important role of the agricultural sector as a supporter and a main supplier of industrial raw materials.

The agricultural sector, especially coffee, has a fairly high economic value. In Bengkulu province, coffee is used as a leading commodity. It is no wonder that Bengkulu is the third largest coffee producing area in Indonesia, especially for robusta coffee. In line with coffee development in Bengkulu province in 2019 community groups activists protecting geographical indications of robusta coffee in Rejang Lebong district (MP2IG-KRRL) introduced local coffee varieties capable of producing as much as 2.17 tons/ha, namely sintaro 1, sintaro 2, and sintaro 3 with ID number G 000 000 087, which was developed in an area of 21,634ha, previously (2018) Kepahiang robusta coffee was introduced with ID number G 000 000 072 by the Geographical Indication Protection Society (MPIG) of Bukut Sari Village, Kabawetan District Kepahiang Regency[3].

Coffee plays an important role in various aspects of people's lives in Bengkulu province, both in the field of trade in agricultural products, the processing industry as a raw material, and tourism, which has brought Bengkulu Province the best Robusta coffee brand. These brands include Bencoolen Rejang Lebong, Bencoolen Kepahiang, and Bermani Coffee Rejang Lebong, which received three award categories at the AVPA (Agency for the Valorization of the Agricultural Products) International Coffee Championship, France, at the 34th Trand Expo Indonesia 2019 in Serang, Banten, Indonesia.

Modern agriculture is characterized by the rapid expansion of technology and information arising from the continuous monitoring, control, storage, organization, and activities of agriculture[4]. Therefore, technology is an important part of agricultural development as a driver for increasing production and farmer income[5]. Technology implementation is one of the main factors thought to influence fluctuations in coffee production and productivity[6]. In the productive sector, technology is crucial for increasing competitiveness and sustainable development[7]. The application of technological practices combined with environmental sustainability during the production and processing stages of coffee plants is thought to result in production at maximum levels[8]. This shows that the application of technology will impact increasing the production and sustainability of the coffee sector[9].

Generative propagation is more commonly used because it is easy to implement and produces seeds ready for planting in a shorter time; however, the nature of the plants produced is less uniform and the period from planting to fruiting is relatively longer compared to vegetative propagation[10]. Generative propagation is related to uncontrolled genetic variation (inherited traits) attached to heterozygous cultivars (genotype forms), slow seed multiplication rates, and short seed viability ranges[11]. As a result, the yields achieved are generally lower than those of the parent[12]. For this reason, the vegetative financing offered is a solution for the cultivation of coffee plants. Grafting on coffee plants is a form of vegetative propagation. Some of the advantages possessed by vegetative propagation include the following: (1) it has the same properties as the parent plant (mother); (2) the quality of the results obtained is more uniform; (3) it has two superior properties at once, namely the superior properties of the scion and superior properties of the rootstock; and (4) it starts to bear fruit (precocity) earlier[13].

The application of grafting technology is expected to increase people's coffee production. Grafting technology is recognized as having good advantages and benefits[14], but several supporting facilities are also needed to take advantage of these advantages, both directly in the use of inputs and indirectly through infrastructure and policies. Using existing inputs (factors of production) to achieve maximum production (output) shows the ability of producers to achieve efficiency[15-17]. Creating superior clone populations with desirable plant characteristics such as: precociousness, productive stability, architectural uniformity, higher productivity, fruit quality, and increased productionare fundamental factors in the application of grafting technology. In addition to having an earlier fruiting age, top-grafted coffee has superior properties of its main plants and uniform yield quality. In research[18,19], stated that plants propagated by grafting result in higher production and productivity. Therefore, the adoption of this technology is important to improve and apply to farmers, especially small-scale farmers, to increase their production and productivity[20].

However, increased production of coffee plants is not only determined by technology adoption, but technical factors also affect farmer efficiency (TE). According to[21], technical efficiency is the ability of producers to achieve maximum output by using existing production factors. For this reason, in developing countries, the application of technology in agriculture to increase technical efficiency is still a major issue that has been widely studied. Although empirical research related to grafting and lane coffee plantation systems is still lacking, there has not been much literature or research that discusses the technical efficiency of coffee production both in Bengkulu province, Indonesia, and in any country that compares grafting and lane coffee plantation systems. Researchers have attempted to provide information related to technical efficiency, which measures the comparative performance of farmers from different plantation systems. It is hoped that this research can contribute to the formulation of strategic policies to increase productivity and efficiency at the small farmer level, especially in the Bengkulu province of Indonesia and coffee-producing countries in general.

This study aims to determine which is more efficient between coffee cultivated in columns and technically grafted coffee

2 Materials and Methods

Existing studies on TE estimation mainly use two approaches: parametric approaches, such as stochastic frontier analysis (SFA), and non-parametric approaches, such as data envelopment analysis (DEA). The two approaches yield slightly different results depending on the type of data [21,22]. However, the SFA is probably the most appropriate model for measuring TE in studies related to the agricultural sector, especially in developing countries[23]. This opinion is based on the fact that the SFA can handle statistical errors. In addition, it allows hypothesis testing and a one-stage approach for the simultaneous estimation of frontier and production inefficiency models. Consequently, this study also uses the SFA model to estimate technical efficiency and evaluate the factors that affect coffee farmers in Bengkulu Province, Indonesia.

This study uses cross-sectional data collected through a household survey conducted in the Bengkulu Province of Indonesia. Our sample consisted of 326 coffee farmers from the areas covered in the survey during the 2021-2022 harvest season. Before the survey, the questionnaire was pre-tested, and after the pre-test, some questions were changed to obtain accurate results. The stratified sampling method was applied to obtain a homogeneous sample of farmers. Purposive location determination, which starts from the province to several smallest regions, aims to focus on only a few areas. This method can save time and money[24]. The sample in this study were coffee farmers as owners of productive coffee plantations, i.e., coffee plantations that were in productive condition. Samples were selected or obtained using the multi-stage sampling method with the following considerations: (1) there is a huge population and (2) the population is spread over a large area. The multi-stage sampling method is part of the probability sampling method. This means that each item in the population has the same chance of being included as a sample. Probability sampling or random sampling has freedom from bias but can represent a large number of samples and can also save time and money[24,25]. The multi-stage sampling method is the process of moving from a large sample to a narrow sample using a step by step process[26]. The main objective of the Multi-stage sampling method is to select samples that are concentrated in certain areas.

The number of samples in this study was 326 farmers who were divided into 2 groups of grafted coffee farmers, 120 farmers, and 206 strip coffee farmers using the following formula[27]

$$n_0 = \frac{WITH^2 pq}{It\ is^2} \quad (1)$$

where n_0 is the required sample size, Z is the t value at the 95% confidence level from the normal table (1.96), p is the probability that the respondent has a measurable characteristic, q is (1 p), namely, the probability of a respondent having no measurable characteristic, and e is the 5% significance level.

Assuming that 50% of respondents have measurable characteristics, the sample size can be calculated as follows:

$$n_0 = \frac{(1.96)^2(0.5)(0.5)}{(0.05)^2} \quad (2)$$

Based on the population in the selected area as a sample of farmers who had applied top grafting in productive conditions, there were 801 farmers and 1,375 farmers in the selected area as a sample of farmers who had not implemented top grafting. The appropriate sample size uses the recommended equation for small-size-restricted population correction as follows:

$$n = \frac{n_0}{1+(\frac{n_0-1}{N})} \quad (3)$$

The determination of the number of samples by group is obtained on the basis of the proportion of groups developed in[24], which aims to ensure that each stratum is adequately represented by the formula:

$$p_{ij} = \frac{N-n_{ij}}{N} \quad (4)$$

where:
P - proportion of the sample population;
n - number of members of the population (sample);
N - total population of the area;
i-j - total population of each group.

This study used primary and secondary data. Primary data were obtained from respondent farmers who were selected through interviews using a list of questions (questionnaires) that had been prepared as material in the interview to obtain information related to the research. Secondary data were collected as supporting data in this study. The data were obtained from various studies.

The measurement of technical efficiency depends on the estimation of frontier production, as a derivative of a given production function. Therefore, it is necessary to determine in advance the proposed functional form of the smallholder coffee production function to be estimated. The production function most commonly used in econometric estimation (because of its simplicity) is the Cobb-Douglas function. It is assumed that the elasticity of substitution between factors is always equal to one, implying that capital and labor are highly substituted in both the short and long run. Another commonly used function is the Transcendental Logarithm (Translog). The Translog (a more general function due to its flexible function form) allows a partial elasticity of substitution between various inputs; that is, the elasticity of scale can vary with output and factor proportions, allowing its long-run average cost curve to take the traditional U-shape. After preliminary testing for the most suitable model functional form under the available dataset, the Cobb-Douglas function was adopted to support the more commonly used Translog function.

The main focus of technical inefficiency measures is on the error term. This study adopts the one-stage estimation procedure proposed by[28] and later by [29] to estimate the stochastic frontier production. The one-stage procedure allows for simultaneous estimation of frontier production function parameters with model inefficiencies.

The equation is defined as follows:

$$lnAND_i = \beta_0 \sum_{j-1}^{J} \quad \beta_j lnX_{ij} + (in_i - in_i) \quad (5)$$

where ln is the natural logarithm, Yi denotes the output of coffee from farmer ith, and j is the factor of production input (i.e., Xi) considered in the model later. The SFA also allows model estimation in terms of the effects of technical inefficiency, based on the state of smallholder coffee plantations in the research area and relevant literature considered in the technical inefficiency model[30]. From the given stochastic production function (equation 3), the technical efficiency of farm j can be written as TEj=exp(-mj). Tej is measured on a scale of 0 to 1. A value of 1 indicates that farm j displays complete technical efficiency, while a value less than 1 indicates some degree of inefficiency. TEj is actually an expression of the farmer's capacity to achieve yields comparable to those indicated by production limits[31].

2.1 Variable Descriptions and Regression Expectations

This sub-chapter provides a description of the variables. Data about these variables are collected in absolute terms and then converted through logarithmic operations. Where data are provided per unit of measurement, a simple multiplication transformation is performed to obtain a total. The coffee production function is assumed to have the Cobb– Douglass form, which is transformed into a linear logarithmic form. The form of the coffee production function is as follows:

$$LnQ = Lna + \beta i\ LnXi + \beta_2\ LnX_2 + b_3\ LnX_3 \ldots + l_1D_1 + l_2D_2 + v_i - ch_i \quad (6)$$

where:
Y - production of coffee in the form of green beans (kg);
X_1 - land area (ha);
X_2 - number of coffee trees (btg);
X_3 - tree age (years);
X_4 - labor force (HKSP);
X_5 - urea fertilizer (kg);
X_6 - fertilizer SP-36 (kg);
X_7 - KCL fertilizer (kg);
X_8 - Phonska fertilizer (kg);
X_9 - NPK fertilizer (kg);
X_{10} - pesticide (ltr);
in_i-ch_i - error term (effect of inefficiency in the model);
vi - random variable related to external factors (modeling errors) distribution symmetrical and normally distributed (v_{ij}-N(0,ɓv^2));
h_i - non-negative random variable, which is assumed to affect the level of technical inefficiency and is related to internal factors, and the distribution is half normal (u_{ij} – | N(0, bv^2));
βi - Xi variable parameter.

2.2 Technical Inefficiency Analysis

The technical efficiency value is inversely related to the technical inefficiency effect and is only used for functions that have a certain number of outputs and inputs (cross section data). The inefficiency effect model used refers to the inefficiency model developed by[21]. The variable ui, which is used to measure the effect of technical inefficiency, is assumed to be independent, and its distribution is normally truncated with N(uit, σ^2). The determination of distribution parameter values (u_i) for the effect of technical inefficiency can be formulated as follows:

$$in_i = \delta_0 + \sum_{i=1}^{n=8} \quad \delta_i WITH_I \quad (7)$$

where:
ui - technical inefficiency effect;
$\delta 0$ – intercept;
Zi - coefficient of inefficiency variable, = 1…8;
i = 1 farmer age (years);
i = 2 education (years);
i = 3 experience (years);
i = 4 total children (Org);
i = 5 membership in farmer groups (2 - not members; 3 - new members without facilities; 4 - old members with facilities);
i = 6 distance between house and garden (km);
i = 7 land elevation (masl);
i = 8 rainfall (2 - little/less; 3 - moderate; 4 - high).

The technical efficiency and inefficiency equations in equation (3.0) were analyzed using Frontier 4.1. There are two stages in testing the stochastic frontier parameter and the effect of inefficiency: (1) parameter estimation using the Ordinary Least Squares (OLS) method; and (2) estimation of all parameters δi, intercept β0, βi and variance of ui and vi using the Maximum Likelihood Estimator (MLE) method. Variations in the output of the frontier due to technical inefficiencies can be indicated by the gamma parameter (γ) as follows,

$$\sigma^2 = \sigma_{in}^2 + \sigma_{in}^2 \quad (8)$$

$$y = (\sigma_{in}^2 \sigma)/\sigma^2 \quad (9)$$

where σ^2 is the total variance of the error term. The variance value can be used to determine the value of γ. Parameter value γ is the contribution of technical inefficiency to the total residual effect. For this reason, the parameter value γ is between 0 and 1 or 0 ≤ γ ≤ 1.

3 Results and Discussion

The main objective of this research was to estimate TE and analyze the influencing factors among coffee farmers in Bengkulu Province, Indonesia. Before discussing our econometric results, we conducted a test for our hypotheses (Table 1).

Tab. 1 Hypotheses testing (Developed by the authors, 2023)

Estimated Value N = 206	Estimated Value N = 120	Hypothesis	t-hit. N = 206	t-hit. N = 120	Decision
1.6662902	2.1808	*H0:* βi + βz = 0 *H1:* βi + βz ≠ 0	1.6524	1.6579	Reject H0 0.1

First, we tested the existence of inefficiency where the null hypothesis confirmed that the technical inefficiency result was 0. However, this null hypothesis was rejected at the 10 % significance level, which confirmed the existence of technical inefficiency weaknesses in coffee production. Recognizing the technical inefficiency fallacy, the second test attempted to verify whether at least one variable could explain the variation in technical efficiency. To this end, we established the second null hypothesis, which stated that among all the variables included in the technical inefficiency model, one significantly explained the variation in technical efficiency. The null hypothesis was accepted, which confirmed the existence of at least some variables that are significant in the technical inefficiency model among coffee farmers, both row and grafting.

The maximum-likelihood estimates of the parameters for the production cut-off line and the efficiency technical drawbacks in the model, determined by Equation (6), are presented in Table 2.

Tab. 2 Estimation results of the coffee production function (Developed by the authors, 2023)

Input Variable	Line Coffee				Grafting Coffee			
	Coefficient	Std error	t-ratio		Coefficient	Std error	t-ratio	
Constant	4.7835	0.7740	6.1799		5.5039	0.5166	10.6544	
Land area	0.3749	0.1248	3.0029	Say	0.4344	0.0730	5.9477	Say
Jlh Tanaman	0.2669	0.0801	3.3297	Say	0.1751	0.0589	2.9733	Say
Plant Age	-0.1594	0.0536	-2.9744	Say	-	-	-	
Umur Tan Primer	-	-	-		0.0453	0.0630	0.7180	
Age of Tan Secondary School	-	-	-		-0.1516	0.0956	-1.5855	
Modified Tan Age	-	-	-		-0.2018	0.0760	-2.6547	Say
Labor	0.1175	0.1267	0.9277		0.2942	0.0606	4.8543	Say.
Urea Fertilizer	0.0070	0.0033	2.1497	Say	0.0051	0.0035	1.4406	
SP-36 fertilizer	0.0104	0.0036	2.9146	Say	0.0102	0.0030	3.4544	Say
KCL fertilizer	0.0052	0.0035	1.5042		0.0116	0.0032	3.6044	Say
Phonska fertilizer	-0.0079	0.0042	-1.8614	Say	0.0055	0.0049	1.1215	
NPK fertilizer	0.0185	0.0033	5.6810	Say	0.0168	0.0025	6.6194	Say
Pesticides (Herbicides)	-0.0135	0.0077	-1.7440	Say	-0.0165	0.0111	-1.4899	

The results in Table 2 show that all inputs used in the production function are inelastic; a 1 % increase in each input will cause an increase in coffee output of less than 1 %. Of the ten input variables considered in our model, chemical fertilizer (NPK) is an important production factor that has or has the most influence on coffee production, with a production coefficient of 0.02 for each coffee farmer, both lane and grafting. This means that a 1 % increase in the quantity of chemical fertilizer (NPK) increases the coffee production rate by approximately 0.02%. The other highest elasticity follower is for chemical fertilizer SP-36 with the same production elasticity for both strip coffee and grafting, namely 0.01. This implies that SP-36 fertilizer has a significant positive impact on coffee production. This finding is consistent with our expectations and in line with other studies that state that fertilizer has a significant positive effect on production, such as[32] and[33]. In addition, the input of land area and the number of productive coffee plants in farmers' gardens are also sensitive to coffee production, where an addition of 1 % of land area and the number of coffee plants will increase production by 0.2 to 0.4. This finding agrees with previous expectations and with[34,35].

The results reported in Table 3 show a statistical summary of the level of technical efficiency of coffee farmers in the study area. We found that 62 % of lane coffee farmers and 87 % of grafted coffee farmers in our sample had TEs ranging from 90 % to 100%. The range of coffee farmers' TE values is similar to the findings[36]. These results show that grafting coffee farmers have a much better level of technical efficiency than lane coffee farmers.

Tab. 3 Distribution of ET of lane and grafting coffee farmers (Developed by the authors, 2023)

Efficiency level	Lane Coffee		Grafting Coffee	
	Frequency	Percentage	Frequency	Percentage
< 50	0	0	0	0
0.51-0.60	0	0	0	0
0.61-0.70	3	1.4563	3	2.5000
0.71-0.80	20	9.7087	2	1.6667
0.81-0.90	54	26.2136	10	8.3333
0.91-1.00	129	62.6214	105	87.5000
Mean	0.9018		0.9439	
Std. Deviation	0.0733		0.0609	
Maximum	0.9907		0.9863	
Median	0.8311		0.8595	
Minimum	0.6196		0.6435	
N	206	100	120	100

The average level of technical efficiency was found to be up to 87 %, although this is more than the proportion of coffee farmers who reach over 90%, implying that it is possible to increase coffee production by 13 percent, this represents the proportion of agricultural inputs and technology currently used. Alternatively, these results suggest that an average of 13% of the expected coffee production is lost due to technical inefficiencies of farmers.

Table 4 shows the effect of factor inefficiency. The results showed that the age level gave a negative value to the technical efficiency efforts carried out by the two groups of coffee farmers in the study area. The results also show that education has no effect on the technical efficiency of the two groups of farmers, but the experience of coffee farming has had a positive impact on the lane coffee farmers but has no impact on the grafting coffee farmer group, even though they both show a positive value. This phenomenon illustrates the differences between each group in the application of technology in an effort to increase production.

Tab. 4 Estimation results of effects of technical inefficiency in coffee production (Developed by the authors, 2023)

Input Variable	Line Coffee				Grafting Coffee			
	Coefficient	Std Error	t-ratio		Coefficient	Std error	t-ratio	
Constant	2.7579	1.3193	2.0905		4.3166	2.0465	2.1093	
Farmer Age	-0.7656	0.3863	-1.9820	Say	-0.9543	0.4200	-2.2721	Say
Education	0.0540	0.1362	0.3967		0.0748	0.2059	0.3632	
Experience	0.2996	0.1798	1.6663	Say	0.3205	0.2004	1.5995	
Jlh Anak	0.0939	0.0987	0.9508		0.2491	0.1142	2.1808	Say
KeAngDa Klp Now	-0.0609	0.1136	-0.5362		-0.5438	0.2067	-2.6308	Say
Distance from Garden to Rmh	-0.1372	0.0393	-3.4882	Say	-0.0730	0.0635	-1.1489	
Land Altitude (masl)	-0.0791	0.1307	-0.6048		-0.0396	0.2493	-0.1588	
Rainfall	-0.1302	0.2024	-0.6432		-0.9899	0.4842	-2.0445	Say

The results of the study also showed that the number of children and membership in farmer groups were able to have an effect on grafting coffee farmers and not on lane coffee farmers. The distance between the house and the bed turned out to have an effect on the farming of lane coffee farmers, but when it was related to the application of this technology, it did not have an effect. The results also show that the height of the land above sea level and rainfall have a negative value on coffee farming for both groups of coffee farmers in the study area, especially for grafting coffee farmers where rainfall has a real effect on coffee production, which generally occurs in coffee plants in the study area. has a closed canopy, but grafted coffee plants are usually planted in open land without a canopy, so when it rains, it will have a direct impact on the coffee plants.

This result can be used by farmers to apply the best scheme in an effort to increase technical efficiency and productivity. Finally, cropping systems that adopt technology (grafting) are variables that explain variations in the effectiveness of technical efficiency. This can be included in the technical efficiency model as a dummy variable to determine whether the application of grafting technology can increase the technical efficiency of coffee farmers. Statistically, it was found that grafting coffee plant systems tended to have a higher level of technical efficiency than strip coffee plants. This finding is in line with[37], which supports the benefits of single crop systems in increasing coffee farmer efficiency in the Ivory Coast.

4 Conclusion

Researchers around the world are interested in analyzing the level of technical efficiency of farmers and their determinants, which is a critical need for farmers and policy makers. Farmers find it useful because improving their managerial skills leads to an efficient allocation of inputs to produce the desired level of output. It also helps policy makers develop relevant policies directed at increasing crop productivity. This study applied the SFA model to a sample of 326 coffee farmers. In particular, coffee farmers in Bengkulu Province, Indonesia, were asked to obtain their technical efficiency scores, and then investigate the factors that affect the technical efficiency of coffee farmers in the study area. The average level of technical efficiency among coffee farmers in the study area was 87%. This number was found among coffee farmers who applied grafting technology to their coffee plants. From a technical point of view, this implies that there is potential to increase coffee production by approximately 13% with the current level of agricultural inputs and technology available. Analysis of partial production elasticities and returns to scale reveals that all inputs used in the production function are inelastic; that is, a 1 % increase in any input will lead to an increase in production of less than 1 % in coffee output. In addition, we found that coffee production was more responsive to chemical fertilizers, followed by land area and number of plants. While pesticides have been shown to have a negative effect on farmers' coffee production, for this reason, the use of pesticides, especially herbicides, to deal with growth or problems with weeds must be according to the recommended dosage.

Our results further reveal that farmer age has a direct effect on both groups of coffee farmers in the study area, both lane coffee farmers and grafting coffee farmers. Based on the research results, the following policy implications are proposed. The main focus should be placed on increasing technology adoption for farmers, especially for young farmers in rural areas, to encourage them to make coffee the best crop to develop. In addition, counseling must be strengthened especially to strengthen farmers in a farmer group, which is truly a solution to the problems faced by coffee farmers and must target all farmers in all locations. Organizing is a solution for increasing farmers' managerial knowledge and skills, resulting in higher technical efficiency. The government and the private sector must support small-scale farmers to obtain financing either through access to credit or soft loans so that the coffee cultivation business carried out by farmers can be maximized and get the expected production results to meet the needs in the coffee bean trade. Further findings indicate that further research and development is required for coffee development, including the release of superior coffee varieties. In this case, the responsibility of the government through extension workers is to encourage farmers to adopt coffee plant technology and use superior coffee seeds, which can provide higher production yields as currently being developed and are suitable for research areas such as Sintaro 1, Sintaro 2, and Robusta Kepahiang coffee, which has been recognized by the Ministry of Agriculture with its geographical indication. Finally, our results show that the practice of the coffee grafting system on coffee plantations in Bengkulu Province, Indonesia, currently coffee plants still need a tree canopy to cope with conditions when there is high intensity rain or can adopt other technologies to overcome rainfall conditions. However, time is limited.

4.1 Recommendations and Future Research

In this study, the information obtained was also limited to the previous season from coffee farmers throughout the Bengkulu Province of Indonesia; therefore, our findings may not be generalizable. Therefore, future research should consider a larger sample of farmers and a longer time span covering the entire Bengkulu province.

4.2 Suggestions

In general, for annual crops, technically, the level of efficiency achieved by farmers is quite high on average when compared with annual crops, which is due to various activities in the production process. A high level of efficiency will be meaningful if it is accompanied by a maximum level of production. For this reason, the use of production input factors is very important in the production process to maximize production achievements to increase farmers' income. Therefore, the application of cultivation technology must be supported by the readiness of production input facilities and production infrastructure such as transportation and agricultural machinery, considering that the agricultural sector is less popular with the public in anticipation of the need for human labor.

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