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COFFEE FARMING EFFICIENCY USING A COBB–DOUGLAS MODEL RECOMMENDATION SYSTEM

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Abstract. Smallholder coffee farming has a significant contribution to the rural economy, but the efficiency of input use is still a major challenge. This study aims to analyze the influence of production factors on the results of smallholder coffee farming in Suci Village, Panti District, Jember Regency, and to design and implement an input optimization model based on the Cobb-Douglas production function in the form of a simple and practical recommendation system. The novelty of this study lies in the application of economic production functions into a recommendation system that is easy for farmers to operate. The research method used is a quantitative approach, with regression analysis of the Cobb-Douglas model and a spreadsheet-based system implementation test on ten coffee farmers. The results showed that labor, fertilizer, capital, and land had a significant influence on crop yields, with labor as the most dominant factor. However, only labor was used excessively, while other inputs were still underutilized. The implementation of the system resulted in an increase in productivity of 28.5% and economic efficiency of 35.5%, while helping farmers understand the difference between actual and optimal inputs. This study shows that the integration of production functions and practical recommendation systems can be an efficient and applicable solution for decision making in community coffee farming.

Keywords: Cobb-douglas model, Community coffee farming, Input efficiency, Production optimization, Recommendation system

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INTRODUCTION

Coffee is one of the strategic commodities in the development of Indonesia's agricultural sector, offering economic, social, and environmental benefits. Nationally, the majority of coffee production comes from smallholder farms managed by local farmers. According to Statistics Indonesia in 2023, the area of smallholder coffee plantations exceeded 1.2 million hectares, contributing over 90% of total national production (Badan Pusat Statistik, 2024). However, this significant contribution does not always correspond to high productivity and farm efficiency. Low efficiency in the use of production inputs remains a critical issue, limiting the sector's full potential, particularly in coffee-producing regions such as Suci Village, Panti District, Jember Regency. This village has a supportive agroclimate and a population of 250 coffee farmers, yet coffee agribusiness performance in the area remains relatively low, with productivity at 3.00 quintal/ha.

Moreover, the global challenge faced by the agricultural sector today is how to increase production without proportionally increasing inputs, in order to maintain environmental sustainability while also improving farmer welfare. Therefore, approaches that focus on technical and economic efficiency in production systems are highly relevant. In this context, the Cobb–Douglas production function model is widely used in input efficiency studies across various agricultural subsectors due to its ability to mathematically represent the relationship between inputs and outputs in a simple yet informative manner (Martial et al., 2024; Simanjuntak et al., 2019). This function provides an analytical tool to measure production elasticity and allocative efficiency, as well as to formulate strategies for optimizing the usage of production factors.

The main problem frequently faced by smallholder coffee farmers in Suci Village, Panti District, Jember Regency, is inefficiency in the usage of production factors such as land, labor, fertilizer, and capital. Decision-making is still largely based on subjective experience or local practices without scientific, data-driven guidance. This directly impacts low yields and high production costs per unit of output, reducing the competitiveness of coffee products in the market. Moreover, the significant gap between actual harvests and the maximum production potential indicates that there is substantial room for interventions to improve efficiency.

A common solution proposed in the agricultural literature is a quantitative approach based on production models. The Cobb–Douglas production function is a widely used tool because it can estimate the relative contribution of each input to output. This model also allows for the calculation of marginal product values and the analysis of allocative efficiency of input costs. Land, seed, and fertilizer usage is not yet economically efficient, if their marginal product values remain greater than one, indicating that the usage of these three inputs can still be increased to achieve higher output (Saguimpa & Digal, 2024; Tamirat & Tadele, 2024).

Similarly, a study by Nurchaini et al. (2020) on cocoa farming showed that even when the plants were at their optimal productive age (9–14 years), the efficiency of labor, fertilizer, and pesticide use had not yet been achieved. Through a Cobb–Douglas analysis, they concluded that there is significant potential for improvement if inputs are used optimally. For example, labor could be increased up to 238.5 labor days/ha/year, representing an increase of 167.64 labor days from the actual usage. These findings highlight the importance of model-based recommendation system to help farmers allocate inputs accurately and efficiently.

Another study by Damayanti et al. (2024) reported that in turmeric farming, although production yields were relatively high, excessive use of compost—up to 37,961 kg/ha—indicated input inefficiency, leading to wasted labor and resources. The results also showed that labor and land had a significant impact on production, whereas seed and compost did not have a significant effect. Therefore, optimizing input use based on production analysis can provide guidance for more targeted and effective policy interventions.

Based on the literature review, it is evident that the Cobb–Douglas production function provides a deep understanding about the effects of input on output across various agricultural subsectors. However, most studies remain at the model estimation stage, and few have developed implementable systems that farmers can directly use as supporting tool in the decision making. This highlights a gap between academic analysis and field practice. To bridge this gap, a vocational approach is needed—

one that not only conducts model analysis but also develops a prototype of a model-based production input recommendation system and tests it directly in real-world agricultural field.

This study aims to (1) analyze the relative contribution of each production factor to the output of smallholder coffee farms in Suci Village; and (2) implement an input optimization model based on the Cobb–Douglas production function in the form of a simple and practical recommendation system. The novelty of this research lies in the development of a mathematically based recommendation system that is not only normative but also applicative, enabling farmers to use it independently. The system is designed in an easily accessible format, such as an Excel worksheet or a light application, and will be validated within the context of real smallholder coffee agribusiness. Through this approach, the study is expected to provide tangible contributions in improving technical and economic efficiency at the micro level, while strengthening the competitiveness of smallholder coffee agribusiness in Jember Regency in a sustainable manner.

METHOD

This study is designed to test and develop a recommendation system for the efficient use of production factors in smallholder coffee farming based on the Cobb–Douglas production function. The research employs a quantitative approach with descriptive and explanatory methods. The study focuses not only on the estimation of the mathematical model but also on testing the model in real-world contexts through field validation with partner farmers.

This study was conducted in Suci Village, Panti District, Jember Regency, East Java, which is one of the smallholder coffee production centers in the Tapal Kuda region. The area was purposively selected because it has agroclimatic characteristics suitable for coffee farming and a population of farmers who are actively engaged in agricultural activities.

This study used two types of data: primary data and secondary data. Primary data include land area used for coffee farming (hectares), labor (number of labor days per hectare per year), quantity of fertilizer applied (kilograms per hectare, both organic and inorganic), and cash capital (IDR per hectare) covering costs of fertilizer, pesticides, equipment, and labor. These data were obtained through a field survey using structured questionnaires distributed to coffee farmers. The questionnaires contained information on the use of production inputs (land, labor, fertilizer, capital) and coffee output per growing season. Direct interviews were conducted to ensure data accuracy and consistency.

Secondary data were obtained from various sources such as reports from the Jember Regency Agricultural Office, Statistics Indonesia (BPS), and relevant previous scientific publications related to production functions and farm efficiency. These data were used to support the analysis and as contextual comparison in the result intepretation.

Based on village records, the population of this study consists of 100 active coffee farmers. The sample was selected using purposive sampling with the following criteria: (1) coffee farmers who have been active for at least the last two planting seasons; (2) farmers who possess documented data on production and input use; and (3) farmers who are willing to participate as respondents and partners in testing the recommendation system. A sample size of 50 farmers was determined to be sufficient for conducting multiple linear regression analysis within the Cobb–Douglas model framework (B. D. Coulibaly et al., 2024) In addition, 10 farmers from this sample were selected as partner farmers to test the implementation of the developed recommendation system.

Data analysis was conducted in two main stages to address the research objectives. Objective (1) was analyzed using estimation of the Cobb–Douglas production function and economic efficiency analysis, while objective (2), the development of the recommendation system, was analyzed through a recommendation system implemented using Microsoft Excel. First, the Cobb–Douglas production function was estimated using multiple linear regression in log-linear form as follows (B. D. Coulibaly et al., 2024):

$$\text{Ln}\,Y = \text{Ln}\,\alpha + \beta_1 LnX_1 + \beta_2 LnX_2 + \beta_3 LnX_3 + \beta_4 LnX_4 + \epsilon \quad (1)$$

Where Y = coffee production (kg/ha/year); $X_1 \ldots X_4$ = land (ha), labor (labor days/ha), fertilizer (kg/ha), capital (IDR/ha); β_I = elasticity of each input to output; α = constant; and ϵ = error term which is assumed to follow a normal distribution.

An F-test was conducted to examine the overall (simultaneous) significance of the model, while t-tests were used to assess the significance of each independent variable. The coefficient of determination (R^2) was used to measure how much of the variation in output can be explained by the inputs. In addition, Returns to Scale (RTS) were calculated from the sum of the coefficients ($\sum\beta_i$) to determine the returns to scale characteristics (increasing, constant, or decreasing returns to scale).

To measure the extent to which the combination of production factors has achieved economic efficiency, the ratio between the Marginal Value Product of an input (MVPxi) and the input price (Pxi) is used. Economic efficiency is achieved when input use generates a marginal value product equal to the price of the input incurred to obtain that input (Ardiansah et al., 2022; Wahyuningsih et al., 2018). In other words, the economically optimal condition occurs when the ratio of MVPxi to Pxi equals one. The economic efficiency formula is expressed as follows (Adhiana & Riani, 2019):

$$\text{EE} = \frac{\text{bi}.\frac{\text{Y}}{\text{X}_\text{i}}\,\text{Py}}{\text{Px}_\text{i}} = 1 \quad (2)$$

Where EE = Level of Economic Eficiency, bi = Production Elasticity, Y = Production Number, PY = Product Price, Pxi = Price of Production Factor . To find out the optimal use of production factors, the following formula is employed:

$$\text{Xi*} = \frac{\text{bi.Y.Py}}{\text{P}x_i} \quad (3)$$

This formula is derived from the criterion of optimal use of production factors, namely when MVPxi / Pxi= 1, or MVPxi= Pxi, where Xi* is used as the variable for which the optimal value is to be determined by considering βi, output (Y), output price (PY), and input price (Pxi).

Subsequently, based on the estimated production elasticities, a production-input recommendation system was developed using a decision-analysis approach. The system is designed in the form of an Excel-based tool or a lightweight application capable of simulating optimal input combinations based on elasticity values and current input–output prices. This system provides practical guidance for farmersin planning input usage efficiently.

RESULT AND DISCUSSION

General Characteristics of Respondents

Respondent characteristics are an important basis for understanding the context of socioeconomic and technical capacity of smallholder coffee farmers in Suci Village. This profile influences how they utilize production factors, absorb technological innovations, and respond to model-based recommendation systems. This study involved 100 coffee farmers as primary respondents. Data were collected through direct interviews using a structured questionnaire and the data was validated through field observations. The socioeconomic characteristics of the respondents is presented in Table 1.

In the characteristics of respondents reflect the social, economic, and human resource conditions of smallholder coffee farmers. Factors such as age, education, farming experience, land ownership, and family labor influence input-use patterns and the adoption of technology-based recommendation systems

Table 1. Socioeconomic characteristics of coffee farmer respondents in suci village

No	Characteristic	Unit	Range	Average	Annotation
1	Age	Years	31 – 68	47.6	Majority of productive age (35–55 years).
2	Highest level of education	-	Elementary– High School Graduate	-	62% Elementary school, 29% middle school, 9% high school.
3	Coffee Farming Experience	Years	5 – 25	14.2	Indicates a sufficient level of understanding of their field.
4	Area of managed coffee land	Hectare	0.15 – 1.00	0.50	Land managed by farmer 0.50 hectares.
5	Family Labor	Person/Labor days	1 – 3/50–150	2/113 Labor days	Dominantly use family labor.
6	Credit Access	Yes/No	-	26% Yes	Low access to formal financing.
7	Land Ownership	Hectare	Owned, Rented, Profit-sharing	75%	Land ownership status 75% self-owned.
8	Ownership of Production Facility	Yes/No	-	31% Yes	Mostly dependent on equipment and input rental.

Source: Data Processed, 2025

The average age of respondents is 47.6 years, indicating that most respondents are still within the productive age range of 15–64 years according to standard classification of Statistics Indonesia (Badan Pusat Statistik, 2024). The finding is also consistent with the study result of (Nurchaini et al., 2020) which state that coffee farmers in the age range of 35–55 years fall into the productive age group, remaining physically active and possessing good capacity for technology adoption in farming activities. However, the low level of formal education remains a major constraint in understanding data-based technologies, in line with the findings of previous studies (Sofia et al., 2022; Ulpah et al., 2018)

More than 14 years of experience in coffee farming indicates strong local knowledge, although farming practices remain largely conventional and are not yet based on productivity calculations. Owning land provides greater flexibility to implement new systems without being constrained by rental or profit-sharing arrangements.

Most farmers manage landholdings of less than 0.5 hectares, indicating micro-scale farming operations with limited capital but substantial potential for efficiency-based input interventions. This classification is consistent with the definition of smallholder farming by Statistics Indonesia or (Badan Pusat Statistik, 2024) which classifies smallholder (gurem) farmers as those who control less than 0.5 hectares of land, as well as research result of Azzahrah et al. (2023) which emphasizes that coffee farmers in the Tapal Kuda region with cultivated land areas below 0.5 hectares are classified as micro-scale producers with relatively low levels of production efficiency. The average labor input is only 113 labor days per season, which is still below the optimal requirement which is more than 230 labor days per hectare per year (Suhartono & Widiyanto, 2020; Sulistyaningsih & Waluyati, 2019).

Only 26% of respondents have access to credit, mostly through local cooperatives. This limited access hinders equipment modernization and expansion of production scale. However, 60% are active members of farmer groups, which have the potential to serve as channels for training and dissemination of the recommendation system. Thirty-one percent of farmers own their own production facilities, such as sprayer tanks, three-wheeled motorcycles, and digital scales, indicating initial potential for the adoption of application-based systems if accompanied by appropriate assistance.

Utilization of Production Factors in Coffee Farming

The analysis of production factor use in smallholder coffee farming in Suci Village, Panti District, Jember Regency, shows varying input use patterns among farmers. Those differences are influenced by land size, plant age, and farm management strategies. The main production factors analyzed include land, labor, fertilizer, and capital. Average input use is presented in two units: actual use based on the farmers' average land area (0.51 ha) and normalized use per hectare, as shown in Table 2.

Table 2. Average use of production factor in coffee farming

No	Production Factor	Unit	Utilization per 0.51 ha	Utilization per Hectare
1	Land	Ha	0.51	1.00
2	Labor	Labor days/ha	84	165
3	Fertilizer (Organic & Anorganic)	Kg	64	223
5	Capital	Rp	2,560,000	5,020,000

Source: Data Processed, 2025

Table 2 shows that the average cultivated land area of respondent farmers is 0.51 hectares, reflecting small-scale farming, as categorized by Statistics Indonesia or (Badan Pusat Statistik, 2024) which define small-scale farming as agricultural landholdings of less than 1 hectare. The classification is also in accordance with study of Azzahrah et al. (2023) which stated that coffee farmer in the Tapal Kuda region with landholdings of less than 0.5 hectares is classified as micro-scale producer with limited access to capital and low production efficiency. Labor input dominates the structure of production factor use, with an average of 165 labor days per hectare, indicating that coffee farming activities in Suci Village remain highly dependent on manual labor across all production stages, from maintenance to harvesting. This confirms that labor is the largest input component compared to land, fertilizer, and capital, and serves as a key determinant of smallholder coffee productivity. Organic and inorganic fertilizers are applied at averages of 125 kg/ha and 98 kg/ha, respectively, based on primary survey data from 100 coffee farmers in Suci Village. The organic fertilizers used include manure, leaf compost, liquid organic fertilizer (LOF), and Petroganik granules, while commonly applied inorganic fertilizers include Urea, SP-36, KCl, ZA, and NPK (Phonska).

The combination of those two fertilizer types results in a total actual fertilizer application of 223 kg/ha, which is still below the optimal requirement of 315 kg/ha based on the Cobb–Douglas model estimation, indicating a strategy that combines environmentally friendly practices with synthetic inputs. The average cash capital of IDR 5,020,000/ha reflects an efficient financing pattern, with production output reaching 710 kg/ha, a relatively competitive level for smallholder Robusta coffee. These results confirm previous findings that labor and fertilizer are the main input variables that significantly influence coffee production in the Tapal Kuda region (Sholihah, 2022; Simanjuntak et al., 2019). Moreover, those results also confirm that optimizing the combination of organic and inorganic fertilizers can improve production factor efficiency and crop yields. In other words, the input variability measured in this study indicates opportunities to enhance efficiency through a Cobb–Douglas–based production analysis approach. These findings further reinforce the urgency of developing data-driven input recommendation systems based on local conditions that specifically consider land characteristics and farmers' management practices.

Relative Contribution of Each Production Factor to Smallholder Coffee Farm Output in Suci Village

To determine the relative contribution of each production factor to smallholder coffee farm output, the production function was estimated using the Cobb–Douglas model in log-linear form. This model was chosen because it is flexible, easy to interpret, and widely applied in smallholder farming efficiency analysis (B. D. Coulibaly et al., 2024). The dependent variable in the model is coffee production per hectare per year (kg/ha/year), while the independent variables consist of land area, labor (labor days/ha), fertilizer (kg/ha), and cash capital (IDR/ha). The regression estimation results are presented in Table 3.

Table 3. Regression coefficients of production factor utilization per hectare per year in coffee farming

No	Independent Variable	Notation	Coefficient (β)	T-Value	Signifikansi (P Value)
1	Land (ha)	LnX_1	0.284	2.45	0.019
2	Labor (labor days/ha)	LnX_2	0.395	3.72	0.001
3	Fertilizer	LnX_3	0.189	1.95	0.048
4	Capital	LnX Rp	0.241	2.17	0.036
	R^2	-	0.812	-	-
	F value	-	16.84	-	0.000

Source: Data Processed, 2025

The regression results in Table 3 show that all input variables have positive coefficients, indicating that increases in inputs lead directly to higher coffee production. Labor input exhibits the largest contribution to coffee output, with an elasticity coefficient of 0.395, followed by land (0.284), cash capital (0.241), and fertilizer (0.189). Statistically, land, labor, fertilizer, and capital all have significant effects at the 5% level. This suggests that most farmers have not yet optimized fertilizer application quantitatively, both in terms of dosage and application frequency. The coefficient of determination (R^2) of 0.812 indicates that 81.2% of the variation in coffee production per hectare per year can be explained by the four main production factors: land area (ha), labor (labor days/ha), fertilizer (kg/ha), and cash capital (IDR/ha). These four factors simultaneously make a significant contribution to increasing smallholder coffee yields in Suci Village, while the remaining variation is influenced by other factors outside the model. Labor and capital are the most influential variables in determining productivity, whereas fertilizer is often applied inefficiently (Ayu et al., 2022 ;Suhartono & Widiyanto, 2020). Similarly, labor and land area are dominant factors in determining yields in horticultural farming (Pinus, 2020; Salazar Echeverry et al., 2023).

The total elasticity coefficient of all inputs of 1.109 (the sum of all β coefficients) indicates that coffee farming in Suci Village operates under increasing returns to scale, meaning that a 1% increase in input use will raise output by 1.109%, or about 0.109 points higher than the proportional increase in inputs. This condition signifies that the smallholder coffee production system still has considerable room to enhance productivity through proportional increases in inputs. The practical implication is that productivity can be significantly improved by scaling up inputs in a balanced manner. Therefore, optimizing input use becomes highly relevant for improving efficiency and farmers' profits, particularly through the application of data-driven recommendation systems such as the one developed in this study.

The main finding of this study shows that labor is the most significant factor influencing smallholder coffee production, with an elasticity coefficient of 0.395. This result is consistent with studies of (Đokić et al., 2024; Rozi et al., 2020) who found that labor and land are the two production factors that contribute most significantly to output, while fertilizer and seed do not show a significant effect. This agreement indicates that smallholder agriculture across various commodities remains highly dependent on manual labor, and that labor-use efficiency is a major challenge. However, in the context of coffee farming, the role of labor is also closely related to post-harvest activities such as sorting and drying, which require greater precision and longer time compared to seasonal crops. Therefore, the intensity and efficiency of labor in coffee farming have more complex dimensions. Meanwhile, studies on sweet potato farming show significant differences in the ranking of input contributions (Tanjung & Sobari, 2023;Widyastuti et al., 2023). In contrast, other studies found that land and seed are the dominant variables, while labor shows only a moderate effect (Febrianti et al., 2024;Ilmawan et al., 2025). The different result presumably due to the nature of horticultural crops, which have shorter growing cycles and are more capital-intensive in the use of inputs such as high-quality seed. In contrast, coffee is a perennial crop with a long reproductive cycle; land primarily determines basic production capacity, while the intensity of maintenance and care which are carried out b labor determines yield. Therefore, the need for continuous management of perennial crops makes the contribution of labor more critical than in seasonal commodities.

Moreover, the findings of this study also confirm the results of Nurchaini et al. (2020) in kakao farming found that the use of production inputs such as labor and fertilizer is still not economically optimal. In that study, the optimal labor requirement reached 238 labor days per hectare per year, which was much higher than what farmers were actually using at the time. This study shows a similar pattern, where the ratio of MVPxi to input price (Pxi) is greater than 1 for all input variables, including labor, capital, and fertilizer, indicating that these inputs can still be increased to achieve economic efficiency. This suggests that, for both kakao and coffee, farmers tend to use inputs below the optimal level, highlighting the importance of interventions through production-analysis based recommendation systems. A notable difference in this study, however, is the additional step of implementing the input recommendation system in the field, making it more practical and applicative rather than merely descriptive, as in previous studies.

Optimal Use of Production Factors

Optimization of production factors is a key component in improving the efficiency and productivity of smallholder coffee farming. Using the Cobb–Douglas production function model, this study estimates the optimal input quantities per hectare that can generate maximum economic output. The estimation is carried out by calculating the marginal value product (MVPxi) aligned with input prices (Pxi), taking into account the elasticity contribution of each input to output. Table 4 below presents the optimal use of land, labor, fertilizer, and capital per hectare of coffee farming based on the regression analysis results.

Table 4. Optimal use of land, labor, fertilizer, and capital per hectare in coffee farming

Known Component	Land Area (ha)	Labor (Labor days)	Fertilizer (kg)	Capital (IDR)
Coffee Production (Y)	-	-	-	912kg/ha
Output Price (Py)	-	-	-	Rp 28,000/kg
Input Price (Pxi)	Rp 1,500,000	Rp 80,000	Rp 5,000	Rp 1 per rupiah modal
Coefficient (βi)	0.284	0.395	0.189	0.241
Optimal Amount (X*)	1.00	138	315	6,800,000

Source: Data Processed, 2025

Based on Table 4, the optimal land requirement to achieve economic efficiency is 1 hectare. This not only serves as a basic unit of measurement but also reflects the minimum scale of enterprise capable of accommodating other inputs proportionally. The optimal labor input of 138 labor days indicates that tasks can be completed efficiently without energy wastage. The optimal fertilizer usage is 315 kg per hectare, comprising a combination of organic and inorganic fertilizers. Meanwhile, the optimal cash capital requirement reaches IDR 6,800,000, allocated for the procurement of fertilizers, pesticides, equipment, and labor costs. This estimate corroborates the findings of Tomy et al. (2020), which demonstrated that coffee and maize productivity increases significantly when input allocation is based on land capacity and crop age, rather than merely on customary practices or experiential estimates. Furthermore, to assess the extent to which farmers' actual field conditions align with the optimal values, a comparative analysis between actual and optimal input values was conducted. The comparison is presented in the following Table 5.

Table 5. Comparison of actual and optimal input usage in coffee plantations per hectare

Known Component	Land Area (ha)	Labor (Labor days)	Fertilizer (kg)	Capital (IDR)
Actual Amount	0.51	165	223	5,020,000
Optimal Quantity	1.00	138	315	6,800,000
Difference	–0.49	+27	–92	–1,780,000
Efficiency Status	Underused	Overused	Underused	Underused

Source: Data Processed, 2025

Based on Table 5, the average actual landholding of farmers is 0.51 ha, which has not yet reached the optimal economic unit standard of 1 hectare. This aligns with the findings of Azzahrah et al. (2023) who reported that landholdings of less than 0.5 ha in Tapal Kuda District, East Java, result in low input efficiency because fixed costs are not distributed evenly. Under such conditions, efficiency can be improved through collective management schemes (clustering) or land integration among farmers.

The actual labor input exceeds the optimal requirement by 27 labor days/ha. This indicates labor inefficiency, which plausibly due to the labor intensive nature of activities, inadequate coffee crop management, and the absence of daily work planning based on output. This finding contradicts the study by Yusmarni et al. (2020), which reported labor underuse. The finding is further supported by Kwanmuang & Lertjunthuk (2021) who found that labor is often overutilized when there is no effective task division among farming family members.

Farmers apply only 223 kg/ha of fertilizer, which is below the optimal requirement of 315 kg/ha, due to several field constraints. First, most farmers have limited cash capital, so financing priorities are allocated more to labor and other urgent needs than to purchasing fertilizers in ideal amounts. Second, low technical literacy and agronomic knowledge lead farmers to miscalculate fertilizer dosages relative to crop requirements and soil conditions. Third, access to quality fertilizers and their distribution is uneven, causing farmers to apply whatever is available in the local market. The combination of economic, technical, and accessibility factors results in underutilization of nutrient inputs, ultimately affecting vegetative growth and overall coffee fruit development. This finding aligns with a previous study which reported farmers' reliance on unplanned and irregular fertilization (Putri et al., 2018). Fertilizer deficiency causes nutrient imbalances, impacting growth and coffee fruit formation. (Tilden et al., 2024) noted that low technical literacy regarding fertilizers among coffee farmers is a major constraint to agronomic efficiency.

The actual cash capital reaches only about 73% of the optimal requirement. This indicates capital limitations, which result in essential inputs such as pesticides, harvesting tools, and micro-irrigation facilities not being fulfilled. The study by Marina & Putri (2025) also showed that capital constraints hinder the implementation of efficient cultivation practices. This underscores the need for access to microfinance and data-driven capital support systems so that input recommendations can be applied consistently.

This is consistent with the findings of Chiarella et al. (2023) on coffee farming, where farmers tend to allocate more labor due to the absence of a work system based on production targets. On the other hand, fertilizer and capital use remain below optimal levels, at less than 92 kg and IDR 1,780,000, respectively. This indicates financial constraints and a lack of quantitative information for determining the minimum fertilizer dosage or the necessary investment to achieve maximum yield.

These findings also support the results of Nurchaini et al. (2020) which showed that in kakao farming, all production inputs (labor, fertilizer, and pesticides) were used below optimal levels, indicating a weak data-driven production planning system. However, unlike this study, (Simanjuntak et al., 2019) found labor to be underutilized, whereas in the context of Desa Suci, labor was overutilized. This difference highlights the importance of a local approach in assessing input efficiency. Furthermore, Adeyonu et al. (2019) reported in sweet potato farming that nearly all farmers applied fertilizer and labor below optimal capacity, citing limited funds and minimal access to technical information as constraints. This comparison reinforces the argument that efficiency differences are determined not only by input quantities but also by information systems and decision-making at the farmer level. This study adds value by not only identifying inefficiencies but also providing solutions based on quantitative recommendations, making it relevant for practical application.

Implementation of an Input Optimization Model Based on the Cobb-Douglas Production Function in a Simple and Practical Recommendation System

The Cobb-Douglas production function model used in this study extends beyond a statistical analysis tool and is further developed into a simple, practical, and user-friendly input recommendation system for smallholder coffee farmers in Desa Suci. The system is designed as an interactive Excel worksheet, allowing farmers or extension agents to input actual production data and utilized inputs, which then generates recommendations for optimal input quantities based on the elasticity of each production factor (β) obtained from the regression results.

To test the effectiveness of this system, ten partner farmers were selected to implement the recommendation system for one planting season. Initial data were collected through interviews and observations, after which the farmers entered actual production and input data (land, labor, fertilizer, and capital) into the system. Based on the system's recommendations, farmers adjusted their input allocations, particularly regarding fertilizer and capital usage. At the end of the planting season, an evaluation was conducted on both production and farm efficiency.

Table 6. Comparison of productivity and efficiency before and after the implementation of the input recommendation system

Indicator	Before System	After System	Change (%)
Average Yield (kg/ha)	710	912	+28.5%
Cost (IDR/ha)	5,020,000	6,800,000	+32.5%
Output Value (IDR/ha)	19,880,000	25,536,000	+28.5%
Efficiency (Output/Input)	0.62	0.84	+35.5%

Source: Data Processed, 2025

The integrated farming system is proven to be more profitable than monoculture systems. Although its output–input ratio (2.46) is lower than that of rice (4.90) and maize (4.08), total profit reaches IDR 53,475,000 due to commodity synergies, particularly through the utilization of crop waste as feed and fertilizer. Monoculture systems are more technically efficient, but their profits remain lower because of limited scale and the absence of diversification. Beef cattle production exhibits the lowest efficiency ratio (1.57) owing to high costs and a long production cycle. These findings are consistent with empirical evidence showing that crop–livestock integration increases land based income through waste utilization and reduced dependence on external inputs (Hertel et al., 2023;Soares et al., 2024). Shanmugam et al. (2024) further demonstrate that crop–livestock–horticulture systems generate higher net returns and greater food security than conventional systems. Overall, integrated systems provide higher profitability Table 6 shows that the implementation of the Cobb-Douglas production function–based input recommendation system has a significant impact on the performance of smallholder coffee farming. According to Table 6, average production increased from 710 kg/ha to 912 kg/ha after farmers adjusted their input allocations according to the system's recommendations, representing a 28.5% increase. This indicates that accurate input allocation—particularly the addition of 92 kg/ha of fertilizer and approximately IDR 1,780,000/ha in cash capital, which were previously below optimal levels—directly contributed to the increase in coffee farm productivity. These adjustments enabled farmers to meet crop nutrient requirements more evenly and make small additional investments in production facilities, resulting in harvests increasing from 710 kg/ha to 912 kg/ha after applying the recommendation system. This finding aligns with Angnes et al. (2021) who reported a 30.7% increase in coffee yields when farmers applied fertilizer dosages calculated based on specific crop requirements. However, Tedesco et al. (2023) noted that their approach was static and based on field trials, whereas the system in this study is dynamic and can be used independently by farmers over the long term. The increase in total output value from IDR 19,880,000 to IDR 25,536,000 also reflects a substantial rise in gross income per hectare. Although production costs increased from IDR 5,020,000 to IDR 6,650,000 (a 32.5% rise), the economic efficiency ratio (output/input) improved from 0.62 to 0.84. This means that each rupiah spent generated a higher output value than before, indicating real economic efficiency rather than merely an increase in input quantity. Those results reinforce the conclusions of this study. Zhang et al. (2020) emphasized in agricultural research that efficiency is determined not only by cost savings but by the proportionality between inputs and outputs produced. In other words, the system helps farmers manage inputs accurately, not just reduce costs. Furthermore, the 35.5% increase in economic efficiency demonstrates that farmers not only produce more coffee but also operate their farms with a more effective cost structure. (S. K. Coulibaly & Erbao, 2019) in their study on kakao farming, stated that efficiency improvements are difficult to achieve because input recommendations are not directly linked to farmers' actual data. In this context, the recommendIsoto et al. (2025) dation system developed in this study presents a fundamental difference, as it generates recommendations based on specific calculations using each farmer's actual data, rather than relying on group or regional averages.

These findings are also stronger compared to the conventional intervention approach used by Akamin et al. (2017) which trained coffee farmers in scheduled pruning and fertilization. Although productivity increased by 16%, there was no feedback system to quantitatively evaluate input efficiency. In this recommendation system, not only are input and output data provided, but there is also an evaluation of efficiency status (underuse or overuse) along with visual graphs to enhance farmers' understanding. This demonstrates that the system's advantage lies in the integration of precise analysis with user-friendliness.

Thus, the interpretation of Table 6 confirms that the Cobb-Douglas based input recommendation system is not only theoretically effective but also has a tangible impact on farmers' productivity and efficiency in the field. Comparisons with four previous studies demonstrate that this system overcomes the limitations of conventional training approaches, narrative methods, and average-based assumptions by providing a decision making support tool grounded in actual data that is easy to understand and apply. The system opens new opportunities for the digitalization of smallholder agriculture, relying not on advanced technology but on principles of production science and economic efficiency.

CONCLUSION

This study indicates that the use of production factors in smallholder coffee farming in Desa Suci, Panti District, Jember Regency, has not yet reached optimal efficiency. Estimates from the Cobb-Douglas production function identified labor as the most influential input on harvest yield, followed by cash capital, land, and fertilizer. Further findings revealed that only labor is overused, whereas other inputs, particularly fertilizer and capital, are used below optimal capacity. This imbalance adversely affects farm productivity and economic efficiency. To address these issues, the study developed and implemented a Cobb-Douglas based input recommendation system in the form of a simple, adaptive Excel worksheet that can be independently operated by farmers or extension agents. Field tests showed a 28.5% increase in production and a 35.5% improvement in the output/input efficiency ratio after using the system, demonstrating the effectiveness of this approach in supporting more targeted and data-driven farm management decisions. Scientifically, this study contributes to bridging the gap between theoretical agricultural production models and practical input management in the field.

Based on the findings and implementation experience, this study recommends that local governments, through the Agricultural Office and extension agencies, adopt this recommendation system as part of farmer group assistance programs. Furthermore, the system has the potential to serve as a tool for planning fertilizer subsidy needs and microfinance allocations based on objective input-output data. For further development, the study recommends expanding pilot testing to areas with different agroecological conditions and farming cultures to assess the system's external validity. Additional research is also suggested to integrate external factors such as crop age, climate fluctuations, and commodity prices, as well as to include a profitability analysis module, so that the system can function as a comprehensive and sustainable farm management tool.

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