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Coconut (*Cocos nucifera L. Var. Viridis.*) farming efficiency in Central Sulawesi: technical, allocative, and economic

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Abstract: Coconut farmers in some regions frequently neglect proper agricultural practices, making coconut farming inefficient. The purpose of the study was to analyze economic efficiency, technical efficiency and allocative efficiency of coconut farming. The research method uses descriptive quantitative. The research location was purposively selected in Parigi Moutong Regency. Technical efficiency was examined using production function analysis, particularly using the stochastic frontier. Meanwhile, allocative and economic efficiency was determined by deriving the dual cost function from production costs. coconut farming was not technically efficient, generating an average value of 79.83%. Two technical factors, education and experience, could potentially reduce technical inefficiency. However, the economic efficiency was nearly efficient, reaching 97.9%, while the allocative efficiency was inefficient, acquiring 78.2%. The calculation of efficiency has been extensively applied in agricultural commodities, including food crops as well as in plantation crops like cocoa. However, currently, these three types of efficiency have not been implemented in the coconut commodity, particularly in Central Sulawesi.

Keywords: Coconut farming; Efficiency; Stochastic frontier

Introduction

Agricultural development in Indonesia plays a very important role in the country's economy. At the beginning of the New Order government, agricultural development policies influenced agricultural policies in Indonesia (Sutanto, 2002; Mukhlis et al., 2024). Agribusiness plays a role in providing and distributing production media / facilities, managing cultivation businesses, developing cultivation, processing results, marketing products, and organizing product procurement and distribution. The performance of the agribusiness system will be optimal if all its subsystems run well according to their functions (Saragih et al., 2007). If there is a disruption in one of the subsystems in the future, it is likely that the overall system will be affected. The coconut agribusiness system is a combination of the performance of upstream subsystems, farming, processing, marketing, and supporting services (Hill & Jones, 2013; Kaunang et al., 2024). Coconut plants possess high economic value, accounting for the abundance of coconut plantations in Indonesia. Native to tropical regions, coconut plants are prevalent throughout Indonesia, from coastal areas to higher-altitude mountainous regions. These coconut plants play a strategic role for the Indonesian population and are considered a social commodity, as their products rank among the nine essential items for the community (Alamsyah, 2005).

Central Sulawesi Province is among the regions that significantly contribute to the Gross Regional Domestic Product (GRDP) from the agricultural sector. In 2021, the plantation sub-sector contributed 8.20% to the GRDP (BPS of Central Sulawesi Province., 2020). Coconut is a predominant plantation crop in Central Sulawesi (Sisca Vaulina, Khairizal, 2018; Rauf et al., 2023). The processed coconut meat product, copra, is a flagship product of this province (Rauf et al., 2023).

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In 2021, the three regions of regency in Central Sulawesi Province with the highest coconut production consist of Banggai 49,116.34 tons, Parigi Moutong 36,571.19 tons and Tojo Una-Una 31,245.74 tons. Green coconut (*Cocos nucifera L. Var. Viridis*) emerged as the predominant variety of coconut farmed by the community. However, the productivity of coconut plants varies across regions in Central Sulawesi, with only a few areas having productivity above the provincial average (BPS of Central Sulawesi Province., 2022).

Initial observations conducted at a sample research location revealed several issues, including the old age of coconut trees, maintenance occurring solely during the harvest season, limited replanting compared to the number of old trees, and marketing challenges that compel farmers to rely on middlemen, thereby affecting the selling price for coconut farmers. Technically, coconut farmers do not practice the recommended farming techniques, as the coconut plants receive minimal maintenance except during the harvest period. Additionally, farmers refrain from utilizing fertilizers and pesticides, as highli (Aumora et al., 2016).

This background evinces the inefficient farming practices for this leading commodity in Central Sulawesi. Therefore, it is essential to implement technical efficiency in farming to promote the optimal utilization of production factors, boost production, and ultimately elevate the income of coconut farmers in Central Sulawesi. Numerous studies applying efficiency calculations in agricultural commodity farming have been extensively documented, including technical, allocative, and economic efficiency in rice crop (Junaedi et al., 2023), soybean crop (Rinaldi et al., 2023), corn crop (Edison, 2021), cassava crop (Anggraini et al., 2017); (Abedullah et al., 2006), shallot crop (Laksmayani, 2015) and plantation crops such as cocoa (Nursalam et al., 2021). Some research about production effectiveness also applied on swine breeding herds (Parisutthikul et al., 2010). Unfortunately, no study has calculated these three types of efficiency for the coconut commodity. Hence, this research is highly crucial as it can serve as a reference for future coconut farming.

Method

The research location was purposively selected in Parigi Moutong Regency due to its productivity exceeding the average output of Central Sulawesi (Table 1). This research was conducted from April to December 2022. The population consisted of a group of similar individuals with predetermined qualities and characteristics, while the sample represented a subset of the population being studied. The total population was 854 households.

According to Arikunto (2002), if the population exceeds 100 individuals, a sample can be taken with an error rate of 10%, 15%, 20%, or more. Therefore, the sample size of respondents in this study totaled 128 farmers. This study utilized both primary and secondary data. Primary data were directly obtained from coconut farmers (respondents) through direct observation. In contrast, secondary data were gathered from literature and relevant offices or institutions at the district, regency, and provincial levels in Central Sulawesi.

Efficiency analysis was adopted to determine the effectiveness of the production inputs utilized in coconut farming. Efficiency analysis encompasses technical efficiency, price efficiency, and economic efficiency.

Technical Efficiency

Technical efficiency refers to the effort to utilize the smallest possible input to achieve the maximum possible output (Soekartawi, 2006). The stochastic frontier production function was employed to determine the level of efficiency and the factors affecting technical efficiency, with the following equation.

$$Y_i = f\left(X_{L_i}\beta\right)\varepsilon_i \quad (1)$$

Y_i is the output; X_{L_i} denotes the input vector, β signifies the coefficient parameter vector; ε_i indicates a specific error where $\varepsilon_i = v_i - u_i$; v_i is an error term from external factors and u_i is an error term from internal factors.

The level of technical efficiency was calculated using the following equation.

$$ET_i = \frac{Y_i}{\hat{Y}_i} \quad (2)$$

ET_i refers to the level of technical efficiency; Y_i depicts actual production; and $\hat{Y}_i$ implies potential production.

The frontier production function in this study was run using the following equation.

$$L_nY = \alpha_0 + \beta_1 lnx_1 + \beta_2 lnx_2 + \ldots + \beta_n lnx_n + (v_i - u_i) \quad (3)$$

Y demonstrates production; α_0 is constant (intercept); $\beta_1$refers to a coefficient parameter; $X_{1\ldots n}$ are inputs; and $v_i - u_i$ denotes the error term.

The technical inefficiency effect model was established using the following formula.

$$u_i = \delta_0 + \delta_1 lnz_1 + \delta_2 lnz_2 + \ldots + \delta_n lnz_n \quad (4)$$

u_i signifies technical inefficiency effect; δ_0 represents intercept; δ_1 indicates the coefficient of the estimator parameter; and z_{1-n} depicts an inefficiency model.

Allocative Efficiency

Allocative efficiency was measured by deriving the dual cost function from the production function. The production cost equation is as follows:

$$ln_c = \beta_0 + \beta_1 lnP_1 + \beta_2 lnP_2 + \cdots + \beta_n lnP_n + \beta_n lnY + (v_i - u_i) \quad (5)$$

ln_c is cost; P_1 denotes input; Y indicates output; β_1 refers to a coefficient parameter (β_i = 1, 2, 3, ….); v_i signifies external variables excluded in the model; and u_i implies an inefficiency effect in the model.

Economic Efficiency

Economic efficiency is the inverse of cost efficiency (CE). The level of economic efficiency in farming was obtained using the following formula.

$$EE = \frac{1}{CE} \quad (6)$$

CE was derived from the results of the frontier software program. The value of economic efficiency ranges between 0 and 1. Economic efficiency is a combination of technical efficiency and allocative efficiency; hence, allocative efficiency was drawn using the following equation.

$$AE = \frac{EE}{TE} \quad (7)$$

AE ranging between 0 ≤ EA ≤ 1 (Coelli, 1996)

Result and Discussion

Characteristics of Farmers

The characteristics of farmers denote specific traits or distinctive features associated with their socioeconomic status. Isdijoso et al (1990) asserted that several aspects influence a farmer's skills in managing their farming business, including age, education, status, and the number of dependents in the family. The characteristics of coconut farmers in Parigi Moutong Regency encompassed age, education level, and farming experience.

Age of Respondents

A person's age determines their work performance (Suratiyah, 2015). Younger respondents who were physically and mentally healthy depicted greater physical abilities, were more agile, and were quicker to adopt innovations or new ideas in their farming activities. In the research location, almost 100% or 128 respondents fell within the productive age range of 15-64 years, thus having the potential to work as coconut farmers, which requires strong physical capability due to unpredictable environmental conditions and risks.

Education Level

Education is a learning tool that instills attitudes favorable to more modern agricultural development (Maramba, 2018). Furthermore, Kurniati (2012) stated that the higher the level of education a farmer has, the easier it is for them to access information, whether through newspapers, books, or extension workers. Table 2 displays the characteristics of the education level of coconut farmers in Parigi Moutong Regency.

Table 2. Classification of the Education Level of Coconut Farmers in Parigi Moutong Regency, 2022

Education Level	Respondent (N)	Percentage (%)
Elementary	45	35.16
Junior High	36	28.13
Senior High	42	32.81
Bachelor's Degree	5	3.91
Total	128	100.00

Table 2 illustrates that coconut farmers in Parigi Moutong Regency have the following education levels: 45 farmers (35.16%) attained elementary school education, 36 (28.13%) completed junior high school, 42 (32.81%) graduated from high school, and five (3.91%) had a bachelor's degree. The low education level of most coconut farmers was primarily due to poor economic conditions, hindering their ability to afford adequate education for their children.

Farming Experience

Farming experience is one of the determining factors for the success of farming activities. It is closely related to the farmer's age; the older the farmer, the longer they have been farming. Table 3 demonstrates the farming experience of coconut farmers in Parigi Moutong Regency.

Table 3. Classification of Farming Experience of Coconut Farmers in Parigi Moutong Regency, 2022

Farming Experience (year)	Respondent (N)	Percentage (%)
0-13	35	27.34
14-27	55	42.97
28-41	32	25.00
42-55	6	4.69
Total	128	100.00

Table 3 indicates that the highest level of farming experience among coconut farmers in Parigi Moutong Regency falls within the range of 14-27 years, reaching 42.97%, or 55 respondents. It suggested that these farmers possessed considerable experience in coconut farming. Such experience is anticipated to enable them to make more effective decisions in farm management and become more skilled, thus boosting productivity. Having a long farming experience tends to make farmers more cautious in their decision-making (Soekartawi., 2007).

Technical Efficiency of Coconut Farming

Table 4 exhibits the results of the production function estimation for coconut farming in Parigi Moutong Regency. The employed stochastic frontier production function model was the Cobb-Douglas production function, estimated using the Maximum Likelihood Estimation (MLE) method.

The results of the stochastic frontier production function and technical inefficiency estimation for coconut farming in the research location acquired a positive sigma square (σ^2), with a coefficient of 0.1553, and was significant at 1%. It indicated conformity with the distribution assumption, which was normal or half-normal distribution. The gamma (γ) parameter value relates to the variance of the technical inefficiency effects estimated from the stochastic frontier production function. The gamma variance acquired a value of 0.7265 (72.65%) and was significant at 1%. The model exhibited an impact of technical inefficiency, as demonstrated by the gamma variance, revealing that the variation in the error term was influenced by technical inefficiency factors, with the remaining 27.35% due to noise. Table 5 portrays the results of the Cobb-Douglas stochastic frontier production function estimation for coconut farming.

Table 4. Results of Cobb-Douglas Stochastic Frontier Production Function Estimation for Coconut Farming Using the MLE Method

Variable	Expected Sign	Coefficient	Standard Error	t-ratio
Constant	+/-	7.8174***	0.1044	74.9055
Land Area	+	-0.0759	0.0801	-9.4770
Number of trees	+	1.2469***	0.1031	12.0984
Fertilizer (Salt)	+	0.9235***	0.1832	5.0406
Labor	+	-0.3516	0.2271	-1.5480
Sigma Square (σ^2)		0.1553***	0.0389	3.9962
Gamma		0.7265***	0.0837	8.6772
Mean Efficiency				0.7983

*** Significant at α = 1% (t-table = 2.6174)
** Significant at α = 5% (t-table = 1.9799)

The analysis results in Table 4 unveil that two variables, "number of trees" and "fertilizer (salt)", have a positive and significant impact, significant at 1%. In contrast, "land area" and "labor" variables have a negative effect on coconut farming.

"Number of trees" positively and significantly affected coconut farming at a significance level of 1%. This variable acquired a coefficient value of 1.2469, indicating that a 1% growth in the number of trees will boost coconut production by 1.2469%. The coefficient value for the "fertilizer (salt)" was 0.9235, meaning that a 1% increase in fertilizer (salt) will result in a 0.9235% rise in coconut production. This finding is consistent with a previous study by (Lanamana et al., 2016), which discovered that fertilizer positively and significantly affected production at a significance level of 1%. Hence, the better the management of inputs, including land area, number of trees, fertilizer (salt), and labor, the greater the results.

The estimation generated an average technical efficiency of coconut farming of 0.7983, suggesting that coconut farming in the study area was inefficient. In this case, enhancing input management is essential to achieve efficiency in input use. Manihuruk et al (2018) mentioned that farmers are considered efficient in using production inputs if they have a technical efficiency value of 1 and inefficient if it is less than 1.

Table 5 illustrates the distribution of the technical efficiency levels in coconut farming. Coconut farming in Parigi Moutong Regency attained an average technical efficiency of 0.7983, with the lowest value being 0.2040 and the highest value being 0.9727. In other words, respondent farmers had the potential to achieve 20.17% (1-0.7983) higher yields to reach maximum and technically efficient results.

Table 5. Distribution of Technical Efficiency Levels in Coconut Farming in Parigi Moutong Regency, 2022

Efficiency Level	Respondent (N)	Percentage (%)
≤ 0.20	0	0.00
0.21 – 0.40	5	3.91
0.41 – 0.60	25	19.53
0.61 – 0.80	12	9.37
0.81 – 1.00	86	67.19
Total	128	100.00
Minimum	0.2040	
Maximum	0.9727	
Average Technical Efficiency	0.7983	

As exhibited in Table 5, of 128 farmers, 86 (67.19%) fall into the high-efficiency category (0.81-1.00), while 25 (19.53%) belong to the medium-efficiency category (0.41-0.60), and 12 (9.37%) are included in the medium-efficiency level (0.61-0.80). Additionally, five farmers (3.91%) fall into the low-efficiency category (0.20-0.40).

The low level of technical efficiency in coconut production in Parigi Moutong Regency was due to suboptimal utilization of production inputs, non-optimal yield per plant, and excessive labor for land clearing relative to production volume. On average, the technical efficiency value was close to 1, meaning that farmers should optimally allocate 20.17% more production inputs to achieve 100% technical efficiency.

Furthermore, Murniati et al (2017) claimed that differences in technical efficiency among farmers indicate varying levels of mastery and application of technology. Both internal factors, encompassing education, age, farming experience, and frequency of attending extension services, and external factors, such as land conditions, contribute to the variation in farmers' technological proficiency.

Factors Affecting Technical Inefficiency in Coconut Farming

Understanding the factors causing technical inefficiency is crucial for reducing inefficiency and elevating technical efficiency, impacting production and productivity. Technical inefficiency sources are associated with a farmer's managerial ability, which can be observed through characteristics such as age, education, experience, and family size. Table 6 displays the results of the analysis of factors affecting inefficiency in coconut farming in Parigi Moutong Regency.

Table 6. Factors Affecting Technical Inefficiency in Coconut Farming in Parigi Moutong Regency, 2022

Variable	Expected Sign	Coefficient	Standard Error	t-ratio
Constant	-	0.6277	0.1385	4.5317
Farmer's Age	-	0.6890	0.2497	2.7590
Education	-	-0.4596	0.3153	-1.4579
Experience	-	-0.3895***	0.5473	-7.1169
Family size	-	0.0265	0.6692	0.3979

*** Significant at α = 1% (t-table = 2.6025)
** Significant at α = 5% (t-table = 1.9799)
* Significant at α = 10% (t-table = 1.6577)

Table 6 reveals the factors affecting technical inefficiency in coconut farming in Parigi Moutong Regency, encompassing the farmer's age, education, experience, and family size. Higher levels of formal education either reduce inefficiency or enhance technical efficiency, as indicated by the results, demonstrating that education had a negative coefficient significant at 1%. Accordingly, farmers become less inefficient as they pursue higher levels. This finding confirms what (Laksmayani, 2015) discovered in the study of shallot farming in Donggala Regency.

The "farming experience" variable also negatively impacted inefficiency, suggesting that more experienced farmers became more efficient in allocating production inputs. This finding aligns with the research by Suharyanto et al (2018) and (Suprapti et al., 2014).

The coefficient for "farmer's age" was positive, implying that as farmers aged, their technical inefficiency escalated. Hence, older farmers could be less efficient in their farming practices, while younger farmers could be more adaptable and active in adopting new technologies.

The analysis of the "family size" variable established a coefficient of 0.0265 and a positive sign, signifying that family size did not significantly impact technical inefficiency. It may be attributed to the small number of family members among farmers.

Allocative and Economic Efficiency in Coconut Farming

Allocative efficiency reflects the relationship between costs and output. Both allocative and economic efficiencies were derived from input costs using prevailing prices in the study area. The analysis employed the stochastic frontier Cobb-Douglas production function, from which the dual frontier cost function (*isocost* frontier = C*) was derived. This function estimated the parameters of input cost coefficients for coconut farming.

Coconut farming is considered allocatively efficient if it can produce output using minimal costs and inputs. This analysis included cost components based on the price of each production factor allocated by coconut farmers. Allocative efficiency was obtained by dividing economic efficiency by technical efficiency. Economic efficiency was estimated from the stochastic frontier cost function using the Maximum Likelihood Estimation (MLE) method. Table 7 lists the results of the estimation of the stochastic frontier cost function.

Table 7. Stochastic Frontier Cost Function for Coconut Farming in Parigi Moutong Regency, 2022

Variable	Expected Sign	Coefficient	Standard Error	t-ratio
Constant	+/-	2.5039**	1.2650	1.9794
Coconut Seed Price	+	1.4472***	0.2044	7.0810
Salt Price	+	-0.0965	0.2247	-0.4294
Labor Wage	+	-0.4283	0.1455	-2.9438
Production	+	0.9487***	0.0183	5.1709
Sigma-squared (σ^2)		0.0130***	0.0016	8.0779
Gamma (ɣ)		0.2996***	3.1698	9.4525
Average Cost Efficiency		1.0221		

*** Significant at α = 1% (t-table = 2.6174)
** Significant at α = 5% (t-table = 1.9799)

Table 7 displays an average economic efficiency of 1.0221, signifying the economically inefficient utilization of input. Economic efficiency is achieved when both technical efficiency (ET) and allocative efficiency (EA) are reached (Puspitasari, 2017). Economically inefficient inputs are those that are not optimally utilized, hence not providing maximum economic benefit. The price of coconut seeds and production emerged as significant coefficients affecting the cost of coconut production.

Economic efficiency is the inverse of cost efficiency (CE). CE was calculated using Frontier 4.1 software and subsequently utilized to calculate allocative efficiency. Table 8 depicts the distribution of economic efficiency levels among coconut farmers in Parigi Moutong Regency.

Table 8. Distribution of Economic Efficiency Levels in Coconut Farming in Parigi Moutong Regency, 2022

Efficiency Level	Respondent (N)	Percentage (%)
0.80 – 0.90	0	0
0.91 – 1.00	126	98.44
1.00	2	1.56
Total	128	100.00
Minimum	0.928	
Maximum	1.000	
Average	0.979	

According to Table 8, the economic efficiency of coconut farmers in Parigi Moutong Regency is high or close to efficient, with 126 respondents (98.44%) falling into the efficiency range of 0.91 – 1.00. The efficiency values ranged from 0.928 to 1.000, with an average of 0.979. As Abedullah et al (2006) noted, an efficiency value greater than 0.70 can be categorized as relatively efficient.

Allocative efficiency confirms the relationship between costs and output. Allocative efficiency refers to the ability of farmers to employ inputs in optimal proportions at given prices and production technologies. It is achieved when the marginal product value equals the input price, indicating the optimal allocation of production resources. Table 9 portrays the distribution of allocative efficiency levels among coconut farmers in the study area.

Table 9. Distribution of Allocative Efficiency Levels in Coconut Farming in Parigi Moutong Regency, 2022

Efficiency Level	Respondent (N)	Percentage (%)
< 0.30	2	1.56
0.30 – 0.50	10	7.82
0.51 – 0.70	27	21.09
0.71 – 0.90	30	23.44
0.91 – 1.00	59	46.09
Total	128	100.00
Minimum	0.189	
Maximum	0.971	
Average	0,782	

Following Table 9, coconut farming in Parigi Moutong Regency attained an average allocative efficiency of 0.782, with the lowest value of 0.189 and the highest of 0.971. Therefore, if farmers can achieve the highest allocative efficiency, they can save 19.46% of costs (1 – 0.782/0.971), while the least efficient farmers can save up to 75.83% (1 – 0.189/0.782).

Conclusion

The analysis and discussion led to the following conclusions: 1). Technical Efficiency: (a) Coconut farming in Parigi Moutong Regency was technically inefficient, with an average technical efficiency of 0.7983 (79.83%). It indicated that farmers had the potential to achieve a 20.17% higher output to reach technical efficiency; (b) Factors such as education and experience played a significant role in reducing technical inefficiency. Farmers with better education and more experience were likely to manage their farms more efficiently. 2). Economic Efficiency: Coconut farmers in Parigi Moutong Regency acquired an average economic efficiency of 0.979 (97.9%), considered high and close to efficient. It signified that, economically, farmers almost achieved optimal efficiency in their input utilization. 3). Allocative Efficiency: Allocative efficiency remained non-optimal, with an average allocative efficiency of 0.782 (78.2%). It suggested that input allocation in coconut production was not fully efficient, leaving room for improvement in resource allocation to achieve better allocative efficiency.

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Author Contributions

R.A.R., L.D and S.R.M: Conceptualization, developing ideas, analyzing, writing, reviewing, responding to reviewers' comments; E.R., H.S., M.K.: analyzing data, overseeing data collection, reviewing scripts, and writing.

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Conflicts of Interest

The authors declare no conflict of interest.

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