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Determinants and allocative efficiency of milkfish (*Chanos chanos*) production in polyculture systems in Pangkep District, Indonesia

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Abstract. *Asruddin, Nadja RA, Salam M, Arief AA. 2026. Determinants and allocative efficiency of milkfish (*Chanos chanos*) production in polyculture systems in Pangkep District, Indonesia. Asian J Agric 10 (1): g100159. https://doi.org/10.13057/asianjagric/g100159.* The use of polyculture systems in milkfish (*Chanos chanos*) farming is implemented to increase productivity and improve farmers' income. This study aims to analyze the technical factors affecting milkfish production and to determine the allocative efficiency of the combination of production inputs used by farmers. The research was conducted in Pangkep District, South Sulawesi Province, Indonesia, during the 2023 production cycle. Primary data were collected through structured interviews using questionnaires with 117 milkfish farmers applying polyculture farming systems. A Cobb-Douglas production function was employed to examine the factors influencing milkfish production per production cycle, while an allocative efficiency analysis evaluated the ratio of marginal value product to input price (MVP/Px). The variables observed included land area, seed stocking, additional feed, fertilizer, medicines, labor, and capital. The results show that land area, seed stocking, additional feed, fertilizer, and labor have a positive and statistically significant effect on milkfish production ($p < 0.05$), whereas medicines and capital do not show a significant effect. The allocative efficiency analysis indicates that several production inputs have not yet been utilized at economically optimal levels. The estimated optimal input levels per farm per production cycle include a land area of 2.117 ha, seed stocking of 15,874 fish, additional feed of 978.528 kg, fertilizer of 318.991 kg, and labor of 45.447 man-days. These findings suggest that improving the allocation of key production inputs could enhance production performance and economic efficiency in milkfish polyculture farming systems

Keywords: Allocative efficiency, aquaculture economics, Cobb-Douglas production function, input use, resource allocation

Abbreviations: AE: Allocative Efficiency, CDPF: Cobb-Douglas Production Function, FM: Farm Managerial, IM: Inefficiency Model, IV: Independent Variable, MVP: Marginal Value Product, PI: Policy Implications, RTS: Return to Scale, VIF: Variance Inflation Factor

INTRODUCTION

Milkfish (*Chanos chanos*) is an important fishery resource in many regions, providing nutrition and income and playing a key role in the aquaculture sector. This is particularly true in polyculture systems, where milkfish is typically integrated with shrimp and seaweed (Guanzon et al. 2004; Pai et al. 2022; Patangngari et al. 2025). Milkfish can be farmed under various levels of intensity, ranging from extensive to semi-intensive systems (Sumagaysay-Chavoso and Diego-McGlone 2003; Guanzon et al. 2004; Yusuf et al. 2023). Consequently, this activity serves as one of the efforts to enhance productivity and income for fish farmers. On a broader economic scale, the global aquaculture sector has a production value of approximately USD 313 billion at first-sale value (Food and Agriculture Organization (FAO 2024)), while in Indonesia, milkfish production is valued at approximately USD 1.09 billion (Badan Pusat Statistik (BPS 2022)). At the regional level, South Sulawesi Province, Indonesia, is one of the main production centers, with milkfish production valued at approximately Rp 4.54 trillion (equivalent to about USD 303 million) (BPS 2022). One region that reflects these conditions is Pangkajene and Islands District (Pangkep District) in South Sulawesi Province, a milkfish-producing area with 11,015 hectares of brackish water ponds (Dinas Kelautan dan Perikanan (DKP 2020)). Production supports both the domestic market and exports (Malik et al. 2022), and farming is conducted under monoculture and polyculture systems across 12,199 hectares (Utojo and Ratnawati 2013). In this production system, productivity and profitability are highly dependent on how inputs are allocated and utilized. Variations in input use can lead to differences in production performance and economic outcomes, influenced by input-output relationships, access to capital (Ali et al. 2018), knowledge (Asamoah et al. 2012), risk preferences, and environmental conditions (Sidhoum 2023). Polyculture is increasingly being adopted to boost production and income (Azhari et al. 2025; Nauta et al. 2025) and allows for the shared use of land, labor, feed, fertilizer, and capital, which has the potential to improve the efficiency of resource allocation. Geographical characteristics, particularly in archipelagic regions, further contribute to spatial variations in input use.

Previous studies have identified key production factors affecting milkfish output, including land, seed, fertilizer, and feed. However, most studies focus on production determinants without assessing whether inputs are allocated efficiently from an economic perspective. This may lead to inefficiencies, increasing costs and reducing profitability. While production function analysis explains technical relationships between inputs and outputs, allocative efficiency analysis evaluates whether inputs are used at economically optimal levels, achieved when marginal value product equals input price (Coelli et al. 2005).

Despite its importance, studies on allocative efficiency in milkfish polyculture systems, particularly in Pangkep District, remain limited. More importantly, previous studies have not examined whether input use in polyculture systems is simultaneously technically productive and economically optimal, especially under multi-species interactions.

Therefore, this study contributes by integrating production function analysis and allocative efficiency evaluation at the farm and production-cycle levels in milkfish polyculture systems. This approach enables identification of input misallocation and its economic consequences, which cannot be captured by conventional production or income analyses alone. This is particularly important in polyculture systems, where shared resource use may mask inefficiencies, resulting in production outcomes that appear optimal but are economically suboptimal.

The aim of this study is to analyze the factors affecting milkfish production and to evaluate the allocative efficiency of each input in polyculture milkfish farming in Pangkep District. The findings are expected to provide an empirical basis for improving farm management practices and formulating more efficient input management policies at the farm level. However, this study has limitations. First, it is limited to Pangkep District, so the findings cannot be widely generalized. Second, the observed variables are limited and may not fully capture all influencing factors. Future research should expand coverage to other regions and include more comprehensive variables.

MATERIALS AND METHODS

The conceptual framework

The conceptual framework of this study describes the relationship between production inputs and milkfish output in a polyculture system. It is assumed, based on previous studies on production functions and aquaculture systems, that milkfish production is influenced by several key factors, including land area, number of seeds, supplementary feed, fertilizers, medicines, labor, and capital. These inputs are utilized in the production process, where milkfish are cultivated together with other commodities under a polyculture system. The interaction among these inputs determines the level of production achieved. Furthermore, the resulting production serves as the basis for evaluating the allocative efficiency of input use. This framework also underlies the specification of the empirical model used in the analysis. The conceptual framework of this study is presented in Figure 1.

Study area and data collection

This study was conducted in Pangkep District, South Sulawesi, Indonesia (Figure 2). Data were collected from March 1 to June 1, 2024, using a structured questionnaire in seven sub-districts: Mandalle, Segeri, Ma'rang, Labakkang, Bungoro, Pangkajene, and Minasa Tene, which represent all areas where milkfish polyculture pond farming is practiced in the district.

The questionnaire was developed based on previous empirical studies on aquaculture production and was pilot-tested prior to the main survey to ensure clarity and consistency. Enumerators received training on interview procedures and accurate recording of quantitative production data. Participation was voluntary, and informed consent was obtained from all respondents.

An initial target of 20 respondents per sub-district was established to ensure regional representation. However, due to the absence of an official farmer registry, probability-based random sampling was not feasible. Of the 140 targeted respondents, 117 provided complete and valid data and were included in the analysis. Respondents were identified with the assistance of local fisheries extension officers based on their active engagement in milkfish polyculture farming.

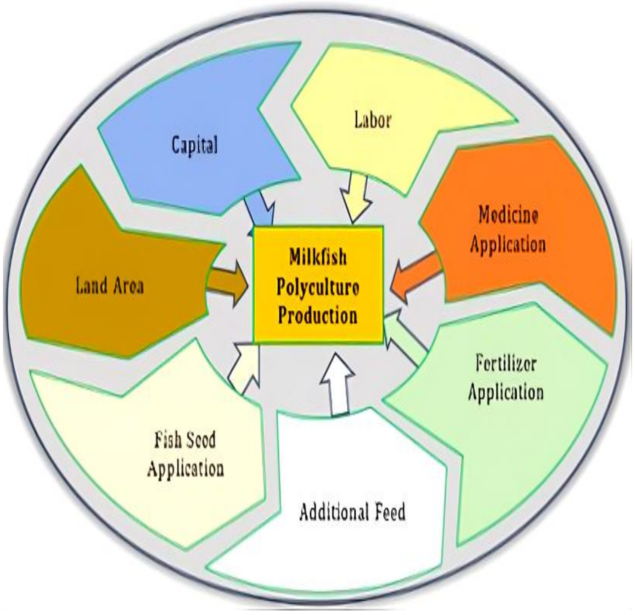

Figure 1. The conceptual framework

Operational definition of variables

Production and input data referred to the most recent production cycle completed in 2023 (stocking to harvest), with an average duration of 4-6 months, thereby minimizing recall bias. The unit of analysis was per farm per production cycle. Output was measured in kilograms per cycle. All input variables were recorded based on their total use per farm within the same production cycle. Land area was measured in hectares per farm, while inputs such as seed, feed, fertilizer, labor, medicines, and capital were calculated on a per-cycle basis. Production data were primarily based on farmers' records and were cross-checked, where available, with sales receipts or harvest records to improve data reliability. Output and input prices were measured based on the prevailing market prices during the corresponding production cycle in 2023. Output price (P_y) refers to the average selling price at harvest, while input prices (P_xi) represent the actual purchase prices paid by farmers during the production cycle. All economic efficiency estimations, including allocative efficiency analysis, were therefore conducted on a per-farm basis to maintain consistency with the unit of analysis. Therefore, all allocative efficiency estimates were performed using per-farm data to ensure consistency across production quantities, input use, and price variables. The production system applied by respondents can be classified as traditional to semi-intensive, with relatively homogeneous cultivation practices across the study area, allowing consistent comparison of farm performance.

Data analysis

Analysis stage

In the data analysis stage, it is crucial to test classical assumptions before proceeding with further tests. The classical assumption tests applied include the normality test (to assess whether the data are normally distributed), the multicollinearity test (to ensure that independent variables are uncorrelated and do not interact), and the heteroscedasticity test (to assess whether the regression model has constant variance). A classical assumption test is necessary in statistical analysis, so that it can provide an accurate, non-biased, and consistent estimate (Mardiatmoko 2020). A classical assumption test can help the researcher confirm whether the regression model is statistically sound. As a consequence, analysis becomes more accurate and reliable, enabling an informed interpretation and decision.

Research variables

This study uses two types of variables: independent and dependent. The independent variables include land area (LL), seed stocking (BB), additional feed (PT), fertilizer (PP), medicine application (OB), labor (TK), and capital (MD), while the dependent variable is milkfish production in the polyculture system (Y). The description of these variables is presented in Table 1. To analyze the effect of production inputs on milkfish production, the Cobb-Douglas production function (CDPF) is applied and expressed mathematically in Equation (1).

$$Y = A\, LL^{\beta 1}\; BB^{\beta 2}\; PT^{\beta 3}\; PP^{\beta 4}\; OB^{\beta 5}\; TK^{\beta 6}\; MD^{\beta 7} e^{\varepsilon} \qquad [1]$$

In analyzing the Cobb-Douglas function, the equation is transformed into its natural logarithmic (ln) form to facilitate parameter estimation. The equation is presented in Equation (2).

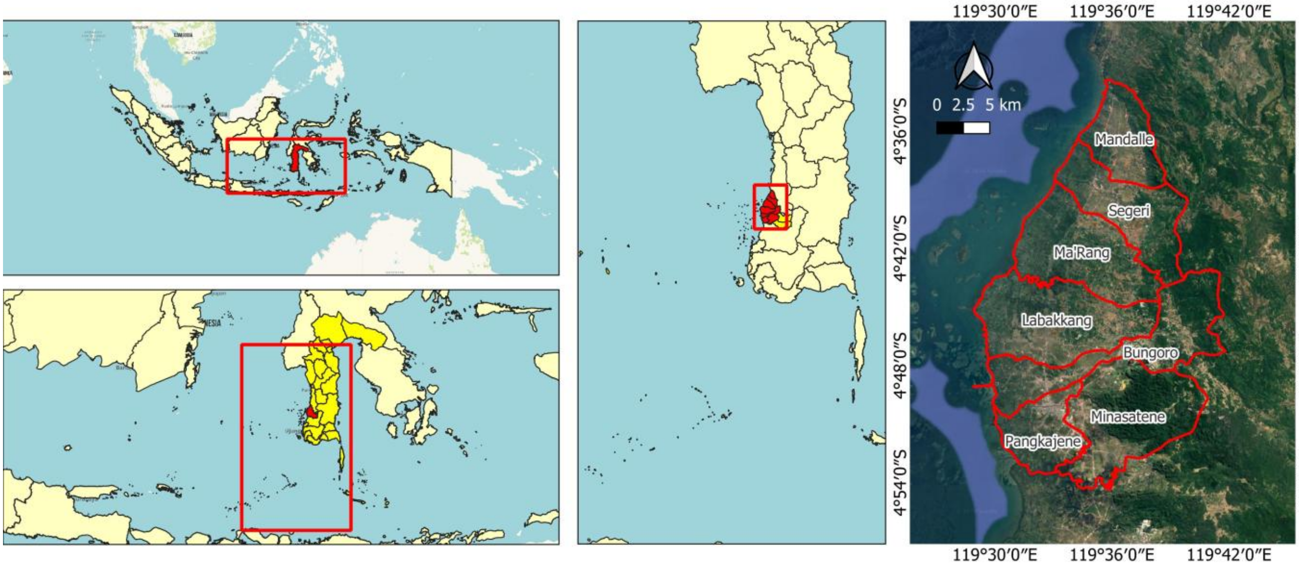

Figure 2. Research location

Table 1. Variables of dependent and independent

A.	**Dependent Variable: Y = Milkfish Production (kg)**

B	**Independent variables**		**Measurement unit**	**Expected results***	**References**
	Name of variables	**Symbols**			
	Land area	LL	ha	+/Sig.	Bosma and Verdegem (2011), Muti'ah et al. (2021), Sharma et al. (2021)
	Seed stocking	BB	fish	+/Sig.	Debbarma et al. (2021), Al-Zahrani et al. (2023), Diao et al. (2023), Mawundu et al. (2023), Showhdy et al. (2025)
	Additional feed	PT	kg	+/Sig.	Aragão et al. (2020), Busti et al. (2020), Bera et al. (2021)
	Fertilizer	PP	kg	+/Sig.	Waidbacher et al. (2006), George and Essien-Ibok (2024), Isnaini et al. (2024)
	Medicine application	OB	kg	+/Sig.	Islam et al. (2016), Engle (2021), Muti'ah et al. (2021), Tudor et al. (2022), Ray et al. (2023), Tong et al. (2024)
	Labor	TK	man-days	+/Sig.	Islam et al. (2016), Engle (2021), Muti'ah et al. (2021), Tudor et al. (2022), Ray et al. (2023), Tong et al. (2024)
	Capital	MD	IDR	+/Sig.	Gbigbi (2021), Muti'ah et al. (2021), Haryanto et al. (2023), Bala and Shuaibu (2024)

$$lnY = lnA + B_1 lnLL + B_2 lnBB + B_3 lnPT + B_4 lnPP + B_5 lnOB + B6 lnTK + B_7 lnMD + \varepsilon \qquad [2]$$

Where, Y is milkfish production (kg), LL is land area (ha), BB is milkfish seed (fish), PT is feed (kg), PP is fertilizer (kg), OB is medicine (kg), TK is labor (man-days), MD is capital (IDR), β_1-β_7 are output elasticities of each input, A is a constant, and ε is the error term.

Analysis of return to scale

Return to scale (RTS) analysis determines the magnitude of return to scale and the scale conditions of the polyculture milkfish pond business by summing the regression coefficients from the Cobb-Douglas function. Mathematically, it can be written in Equation 3.

$$RTS = \beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5 + \beta_6 + \beta_7 + \varepsilon \qquad [3]$$

With the criteria: (a) If $\sum\beta_i > 1$, the production process exhibits increasing returns to scale. (b) If $\sum\beta_i = 1$, the production process exhibits constant returns to scale. (c) If $\sum\beta_i < 1$, the production process exhibits decreasing returns to scale, if every addition of one unit of production input produces less output compared to the previous input unit (Yu and Zhao 2013).

Analysis of allocative efficiency

Production efficiency can be analyzed using the Allocative Efficiency approach. Allocative efficiency, also known as price efficiency, measures the relationship between the Marginal Value Product (MVP) of an agricultural input and the price of that input (Px), which is explained mathematically through Equations 4, 5, 6:

$$NVPxi/Pxi = 1 \qquad [4]$$

$$MVP_{xi} = PM_{xi}.P_Y \qquad [5]$$

$$MVP_{xi} = b_i \frac{y}{xi} + P_Y \qquad [6]$$

In this case, MPV_{xi} denotes the marginal product value of the input to-i, PM_{xi} denotes the marginal product of these production factors, and b_i is the regression coefficient. Meanwhile, the variable X_i represents the average use of input i in its respective units, and Y reflects the average output in kilograms. P_{xi} shows the unit price of inputs to -i (in IDR per unit), while P_Y states the average cost per unit of production. Once the MPV for each input is known, the next step is to calculate the average allocative efficiency using the formula in Equation 7.

$$EA = \frac{MVP1 + MVP2 + MVP3 + MVP4 + MVP5 + MVP6 + MVP7}{7} \qquad [7]$$

With the criteria: (a) If the value of MVP/Px = 1, the use of production input is optimum or efficient. (b) If MVP/Px > 1, then the use of production input is not optimum or efficient, so it is necessary to increase the amount of production input used. (c) If MVP/Px < 1, the use of production input is not optimum or inefficient, so it is necessary to reduce the amount of production input used.

The allocative efficiency analysis in this study adopts a short-run production framework, in which not all inputs can be adjusted within a single production cycle. Capital was excluded from the allocative efficiency calculation because it is relatively close to a fixed input. In short-run production theory, optimal adjustment applies only to variable inputs, whereas fixed inputs are relatively inflexible (Debertin 1986).

RESULTS AND DISCUSSIONS

Respondent characteristics

The respondents in this study were milkfish farmers who applied a polyculture system with other commodities. The average age of respondents was 48 years, ranging from 23 to 73 years. The level of education ranged from primary school to bachelor's degree, although most respondents had completed junior secondary school. The number of household dependents ranged from 4 to 5 persons. The majority of respondents considered pond farming as their primary occupation, although a small proportion had additional secondary jobs. Farming experience varied from 8 years to more than 45 years, with an average of 23 years. Approximately 44% of respondents were members of farmer groups, while 56% were not affiliated with any group. Land tenure status varied, including owned land (64%), rented land (10%), and sharecropping arrangements (25%). In total, about 72% of respondents had participated in agricultural extension activities.

Data normality test

The normality of the data in this study was tested using the Kolmogorov-Smirnov Test. The data is declared to follow a normal distribution if the Asymp. Sig value obtained exceeds 0.05. The test results are presented in Table 2, with the Asymp. Sig value obtained being 0.755, exceeds the threshold of 0.05 (Asymp. Sig 0.755 > 0.05). Therefore, the data are normally distributed and can be used for further analysis.

Multicollinearity test

The purpose of the multicollinearity test is to assess whether there is a correlation among the collected variables. If the Variance Inflation Factor (VIF) is less than 10 and the tolerance is greater than 0.100, this indicates no multicollinearity problem. The VIF values of all the variables shown in Table 3 are below 10, while the tolerance values are above 0.100. Thus, it can be concluded that there is no multicollinearity among the independent variables.

Heteroscedasticity test

Heteroscedasticity was tested using the Glejser test by regressing the absolute residuals (|e|) on the independent variables. A model is considered free from heteroscedasticity if the significance value (Sig.) of each independent variable exceeds 0.05. The results presented in Table 3 show that all variables have significance values greater than 0.05, indicating that heteroscedasticity is not present in the model.

F-test results

Based on the F test calculation results presented in Table 4, the significance value (Sig.) is 0.000. The value of Sig. 0.000 is smaller than 0.05 that has been set; thus, simultaneously, the observed production factors: land area (LL), seed stocking (BB), additional feed (PT), fertilizer use (PP), medicine application (OB), labor (TK), and capital (MD) affect the production of milkfish (Y) using polyculture systems in Pangkep District.

The t-test results

In Table 5, the degrees of freedom were calculated as df = N - k - 1 (117 - 7 - 1 = 109). The critical t-values for the two-tailed test were 1.982 at α = 0.05 and 2.622 at α = 0.01 with df = 109. Based on the results shown in the table, the variables land area, seed stocking, additional feed, fertilizer, and labor have t-count values greater than the t-table value (1.982) or significance values smaller than α (0.05). Meanwhile, the independent variables medicine application and capital have t-count values lower than the t-table value (1.982) or significance values greater than α (0.05). This indicates that the variables land area, seed stocking, additional feed, fertilizer, and labor contribute significantly to milkfish production in polyculture systems. In contrast, the variables "medicine application" and "capital" do not contribute significantly to milkfish production.

The Cobb-Douglas function analysis results

Table 6 presents the regression results showing the influence of production inputs on milkfish yield. The estimated coefficients are derived from the log-linear specification of the Cobb-Douglas production function, allowing direct interpretation as output elasticities. As shown in Equation 2, the log transformation simplifies the interpretation of parameter estimates. Equation 8 shows the CDPF mathematical equation based on the results of the CDPF analysis calculations in Table 5.

$$ln\mathrm{Y} = -0.130 + 0.060 ln\mathrm{LL} + 0.203 ln\mathrm{BB} + 0.445 ln\mathrm{PT} + 0.254 ln\mathrm{PP} + 0.006 ln\mathrm{OB} + 0.388 ln\mathrm{TK} + 0.142 ln\mathrm{MD} + \varepsilon \quad [8]$$

Table 2. Data normality test (Kolmogorov-Smirnov test)

One-sample Kolmogorov-Smirnov test		**Unstandardized residual**
N		117.000
Normal parameters^{a,b}	Mean	0.000
	Std. deviation	0.243
	Absolute	0.062
Most extreme differences	Positive	0.052
	Negative	-0.062
Kolmogorov-smirnov Z		0.673
Asymp. Sig. (2-tailed)		0.755

Test distribution is normal.
Calculated from data.

Table 3. Multicollinearity test and heteroscedasticity test

Dependent variable: Milkfish production	**Multicollinearity test results coefficients**[a]		**Heteroscedasticity test results coefficients**[b]	
	Collinearity statistics			
Independent variables	**Tolerance**	**VIF**	**T**	**Sig**
(Constant)			-1.422	0.158
Land area (ln_LL)	0.967	1.034	-1.980	0.051
Seed stocking (ln_BB)	0.937	1.068	-2.005	0.057
Additional feed (ln_PT)	0.865	1.156	1.767	0.080
Fertilizer (ln_PP)	0.926	1.080	-1.416	0.160
Medicine application (ln_OB)	0.970	1.030	1.069	0.288
Labor (ln_TK)	0.863	1.159	-0.708	0.481
Capital (ln_MD)	0.927	1.079	1.897	0.061

Coefficient of determination analysis results (R^2)

Based on the test data in Table 7, the coefficient of determination (R^2) of 0.693 indicates that the Cobb-Douglas output function model can explain 69.3% of the variation in production. Meanwhile, the remaining 30.7% is caused by other factors not included in the model.

Analysis of return to scale

Based on the estimated Cobb-Douglas production function presented in Table 6, the return to scale (RTS) is obtained by summing the estimated output elasticities. The resulting total elasticity of 1.498 indicates the presence of increasing returns to scale, as shown in Equation 9.

Return to scale (bi) = 0.060+ 0.203 + 0.445 + 0.254 + 0.006 + 0.388 + 0.142 = 1.498 [9]

Analysis of allocative efficiency

The results of the AE analysis of milkfish farming in the polyculture system in this study are presented in Table 8 and Figure 3. The average AE value for polyculture milkfish farming was 1.686, as shown in Table 8. The MVPxi/Pxi values for each variable are as follows: land area 2.161, seed stocking 1.134, feed 3.631, fertilizer 1.917, medicine 0.975, and labor 1.274.

Table 4. F-test results

	Source	**SS**	**d*f***	**MS**	**F**	**p-value**
1	Regression	15.455	7	2.208	35.218	0.000b
	Residual	6.833	109	0.063		
	Total	22.288	116			

Predictors: (Constant), Capital, Fertilizer, Medicine applications, Labor, Supplementary Additional Feed, Land area, Seed

Table 5. Partial test (t-test) results

Independent variables	**Coefficients**[a]	
	t	**Sig.***
(Constant)	-.054	0.957
Land area (ln_LL)	2.036	0.044
Seed stocking (ln_BB)	8.938	0.000
Additional feed (ln_PT)	3.578	0.001
Fertilizer (ln_PP)	6.811	0.000
Medicine application (ln_OB)	0.245	0.807
Labor (ln_TK)	4.962	0.000
Capital (ln_MD)	0.964	0.337

a. Dependent variabel: ln_Y
t-table (α=0.01) 2.622 and (α=0.05) 1.982

Note: *: Significant level of 95%, ns: Not significant

Table 6. Regression analysis results

Independent variables	**Unstandardized coefficients (B)**	**Std. error**	**Standardized coefficients (Beta)**
(Constant)	-0.130	2.378	
Land area (ln_LL)	0.060	0.030	0.110*
Seed stocking (ln_BB)	0.203	0.023	0.490*
Additional feed (ln_PT)	0.445	0.124	0.204*
Fertilizer (ln_PP)	0.254	0.037	0.375*
Medicine application (ln_OB)	0.006	0.023	0.013[ns]
Labor (ln_TK)	0.388	0.078	0.283*
Capital (ln_MD)	0.142	0.148	0.053[ns]

a. Dependent variabel: ln_Y

Note: *: Significant level of 95%, ns: not significant

Table 7. The results of the determination coefficient test (R^2)

Model summary				
Model	**R**	**R square**	**Adjusted R- square**	**Std. error of the estimate**
1	0.833[a]	0.693	0.674	0.250

Table 8. Results of AE analysis of polyculture milkfish farms

Variable	b_i^a	Average Y_i	Py	X_i	Pxi	PMxi	MVPxi	MVPxi/Pxi	Optimum^c
Land area (ha)	0.060	1465	12,000	0.980 ha	500,000 IDR/ha	90.028	108.033	2.161	2.117 ha
Seed stocking (fish)	0.203	1465	12,000	14,000 fish	225 IDR/fish	0.021	255.000	1.134	15,874 fish
Additional feed (kg)	0.445	1465	12,000	270 kg	8,000 IDR/kg	2.421	29.047	3.631	978.528 kg
Fertilizer (kg)	0.254	1465	12,000	166 kg	14,000 IDR/kg	2.237	26.839	1.917	318.991 kg
Medicine application (kg)	0.006	1465	12,000	5 kg	20,000 IDR/kg	1.625	19.504	0.975	4.904 kg
Labor (man-days)	0.388	1465	12,000	36 man-days	150,000 IDR/man-day	15.929	19.114	1.274	45.447 man-days
Average								1.686	

Note: βi: Output elasticity of input i, PMxi: Marginal physical product, MVPxi: Marginal value product, Py: Output price (IDR per kg), Pxi: Input price (IDR per unit)

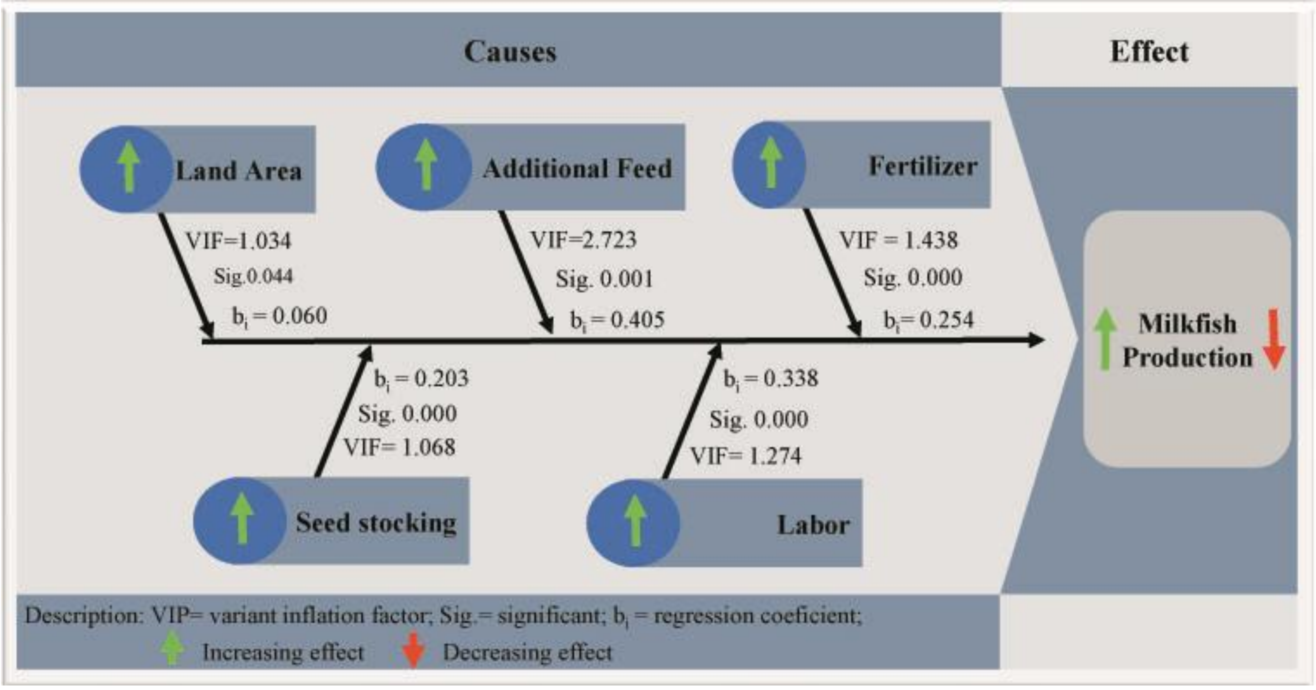

Figure 3. Graphical summary of the causes and effects of milkfish production, as well as the model of technical effects and allocative efficiency in the polyculture system of milkfish farming

Discussion

Cobb-Douglas Production Function (CDPF) analysis

Based on the results of the F test in Table 4, a value of 0.000 was obtained, which is smaller than α 1% (0.01), which means that simultaneously the observed factors, namely land area (LL), seeds stocking (BB), additional feed (PT), fertilizer (PP), medicine application (OB), labor (TK), and capital (MD), have a significant effect on milkfish production. This indicates that the combination of these variables can explain the variation in milkfish production within the polyculture system in Pangkep District. Previous studies have also found that the variables of land area, number of seeds, and fertilizer have a significant effect on increasing milkfish production (Suparjo and Gozali 2020; Maulidiyah et al. 2024). In addition to using the F test, this data was also analyzed using the return-to-scale method to determine the scale of milkfish farming in polyculture systems in Pangkep District. This analysis is done by summing the regression coefficients of the Cobb-Douglas production function in Equation 9. Based on the calculation, a value of $\sum b = 1.498$ was obtained, indicating $\sum b > 1$. This value indicates that the business is in a condition of Increasing Returns to Scale (IRS). This condition illustrates that a 1% increase in the use of production factors increases output by more than 1%, specifically by 1.498%. In this study, milkfish cultivation was carried out using a polyculture system, namely, cultivating milkfish alongside other organisms. Differences in the composition of organisms in the pond can have a positive or negative influence on the efficiency of input use. In addition, variations in the composition of cultivated organisms can affect the conditions of scale, resulting in increasing, constant, or decreasing returns to scale. The results of this study are in line with the findings of Pai et al. (2022), which showed that differences in the number of milkfish and shrimp in a polyculture system had a significant effect on business scale. In addition to the explanation of the F-test and the return-to-scale (RTS) test presented above, the effect of each variable can be further examined based on the t-test results in Tables 5 and 6.

The t-test results indicate that land area (LL) significantly affects milkfish production ($p = 0.04 < 0.05$). The land area (LL) variable has a significant effect on production, with a low beta coefficient, indicating that its contribution to production is relatively low compared to other inputs. This is because most agricultural enterprises operate on a small- to medium-scale basis, so production is influenced not only by land area but also requires adjustments to other inputs. The significant effect of land area (LL) on production is likely because it provides sufficient space for fish to maintain their survival. Larger ponds provide more space for fish movement, which supports optimal growth performance (El-Hack et al. 2022). This significant positive effect of land area on production supports previous studies indicating that land area influences milkfish production (Suparjo and Gozali 2020; Adhiana et al. 2023).

The number of fish seeds stocked (BB) significantly affects milkfish production ($p = 0.000 < 0.01$), with a beta coefficient of 0.490, indicating that a 1% increase in stocking leads to a 0.490% increase in output, ceteris paribus. Increasing the quantity of fingerlings is feasible because the actual number of fingerlings used by farmers is still relatively adequate given the capacity of the ponds they utilize. These findings are consistent with those of Chiang et al. (2004), who stated that seed density can affect the efficiency and productivity of fish in ponds. Therefore, increasing the number of fingerlings is still feasible, but caution is needed to consider pond capacity and rearing carrying capacity. This has been emphasized by previous researchers, who noted that excessive stocking density can reduce growth rates and survival (Pai et al. 2022).

The additional feed factor (PT) significantly influences milkfish production ($p = 0.001 < 0.01$; $\beta = 0.204$), indicating that a 1% increase in feed use increases output by 0.204%, *ceteris paribus*. Regarding the supplementary feed (PT) variable, it has a significant effect, indicating that supplementary feed plays a key role in fish farming. In addition to increasing quantity, improving the quality of feed containing essential nutrients for farmed fish is also necessary. Properly formulated feed can improve growth performance (Chikwati et al. 2012). Fish farmers in Pangkep have been using various types of alternative feeds combined with local ingredients as part of efforts to improve feed nutrition. Therefore, farmers can improve feed quality by utilizing alternative feeds to increase milkfish production in polyculture systems. The fertilizer use variable (PP) has a positive and significant effect on milkfish production ($p = 0.000 < 0.01$; $\beta = 0.375$), indicating that a 1% increase in fertilizer application increases output by 0.375%, *ceteris paribus*.

More fertile water conditions allow for better availability of natural nutrients, thereby meeting the nutritional needs of small fish. Thus, appropriate fertilizer use has the potential to support growth and improve fish survival. Farmers in Pangkep typically use urea as their primary fertilizer, though in traditional-scale operations, they generally supplement it with some organic fertilizers (Agusanty et al. 2022). Proper fertilizer application can still be implemented by farmers to support improvements in the quality and growth of farmed fish. Green (2015) emphasizes that the proper use of fertilizers can improve pond fertility and that fertilizer application can enhance the growth of natural feed in fish ponds.

The labor variable (TK) has a significant effect on milkfish production, as indicated by the t-test results ($p = 0.000 < 0.01$) with a beta coefficient of 0.283. This implies that a 1% increase in labor input increases milkfish production by 0.283%, *ceteris paribus*.

Increasing labor (TK) input is still feasible by utilizing family members. Additional labor (for land preparation, fertilization, feeding, and fish harvesting) is essential to support the polyculture milkfish farming process, given the limited technology available. These findings are consistent with previous research, which indicates that labor plays a crucial role in supporting increased production and can facilitate the harvesting process (Cassey et al. 2018; Maulidiyah et al. 2024).

The use of chemicals (OB) does not have a significant effect on milkfish production ($p = 0.807 > 0.01$). This is likely because the use of medications-particularly saponins-by fish farmers in Pangkep District is generally limited and primarily focused on controlling pests and predators. Research in other regions has also utilized the natural compound saponin to prevent competitive organisms (Dong et al. 2017; Fu et al. 2021). The use of saponin in aquaculture activities is generally incidental and only carried out when significant disturbances occur. Additionally, the implementation of preventive measures such as draining ponds before the cultivation cycle also plays a role in pest control. Therefore, the role of pharmaceuticals in directly increasing production tends to be limited. Bondad-Reantaso et al. (2023) also emphasize that proper management of drug application is necessary to avoid negative impacts on farmed fish. Furthermore, the capital variable (MD) also had no significant effect due to the relatively low use of technology in both traditional and semi-intensive ponds in Pangkep District. This phenomenon can be explained by the characteristics of the capital variables used in the study, which do not fall into the category of primary production inputs such as land, seeds, feed, fertilizer, labor, or pesticides. In this context, capital variables more accurately represent supporting components beyond primary inputs, including fuel (petroleum products), rental costs for machinery, nets, operational equipment, and various other supporting needs.

Analysis of allocative efficiency

The land area (LL) has an MVPxi/Pxi value of 2.161 (Table 8), indicating that land use is nearly allocatively efficient but still underutilized, as the value exceeds one. This implies that an increase in land area (LL) can maximize profits provided that optimal conditions are met. However, in practice, the land area (LL) in the study area is relatively dense, as reflected by the widespread distribution of ponds throughout the coastal region. Based on observations, some land borders rice fields or is used for other aquaculture purposes, such as salt ponds. The failure to achieve optimal conditions is likely due to the land area conditions at the study site. Increasing inputs to achieve maximum profit can be done by utilizing the land optimally through the cultivation of milkfish alongside other commodities in a polyculture system, as currently practiced by farmers in Pangkep District. Nauta et al. (2025) state that integrated fish farming can increase productivity and profits.

The seed stock variable (BB) in Table 8 shows an MVPxi/Pxi ratio of 1.134, indicating that seed inputs have not yet achieved perfect allocation efficiency, so seed inputs need to be increased. Increasing the input quantity of seed (BB) remains feasible, as the optimal value is 15,874 fish per farmer per cycle at a relatively affordable price ranging from 120 to 225 IDR per fish. However, caution is needed, given that the ponds used in Pangkep District are still on a traditional to semi-intensive scale with limited supporting equipment. In contrast, high stocking densities combined with strict water quality control can significantly increase revenue (Oké and Goosen 2019). Increasing the seed quantity without adjusting to pond capacity can lead to a decline in water quality (Ott et al. 2024). Stocking up to this optimal limit must account for interactions with other commodities co-cultivated with milkfish in polyculture systems to maintain system balance, both in terms of space and nutrient utilization. Therefore, increasing stocking density to the optimal limit of 15,874 fish is feasible, but the pond's carrying capacity must still be considered-particularly regarding equipment supporting water fertility-and the types of other species co-cultivated with milkfish in the polyculture pond must be taken into account.

Fertilizer use (PP) in Table 8 shows an MVPxi/Pxi ratio of 1.917, indicating that it is not yet allocatively efficient, as the ratio exceeds 1. This suggests that increasing fertilizer application can still raise production value. The failure to achieve optimal fertilizer input allocation may also be due to pond conditions that do not support optimal fertilizer use. Pond conditions in Pangkep range from traditional to semi-intensive. Fertilization practices aimed at reducing fertilizer costs generally involve the use of alternative fertilizers to support pond fertility (Boyd 2018; Colt and Schuur 2021; Musyoka and Nairuti 2021; Barbosa et al. 2024). The relatively high discrepancy between actual and optimal values in this study indicates that the model results represent ideal conditions that do not fully account for the limitations of traditional pond systems and the use of organic inputs in the field. Thus, while the application of supplemental fertilizer (PP) remains economically viable, its implementation must balance increased production, pond water fertility, and pond management capacity. The feed variable (PT) at an MVPxi/Pxi ratio of 3.631 indicates that the utilization of feeding inputs at these balance coincidences has not reached allocative efficiency under current conditions. The supplementary feed variable (PT) requires a high input allocation because it is not yet allocatively efficient. This is likely due to the fact that feed is a fundamental component in improving fish survival. Failure to meet this supplementary feed (PT) allocation may also be attributed to the fact that feed constitutes a relatively high proportion of feed costs. Additionally, some fish farmers in Pangkep have innovated by producing their own feed to address the high costs of commercial feed as well as the relatively traditional to semi-intensive conditions of their ponds. Increasing supplemental feed (PT) in line with estimated allocative efficiency remains feasible despite the significant gap between actual and optimal levels. Increasing supplementary feed (PT) inputs can be achieved up to their optimal limit if supported by equipment that maintains pond water quality. According to Sriyasak et al. (2015), the accumulation of organic waste from excess feed can increase stress on fish due to deteriorating water quality. Therefore, model results should be understood more as an indication of economic potential rather than as a target to be achieved directly. The labor variable (TK) measured in man-days in Table 8 shows an MVPxi/Pxi ratio of 1.274. This ratio indicates that labor input has not yet reached allocative efficiency but is close to it. A ratio value greater than 1 indicates that the value of the marginal product of labor (MVPxi) is still higher than the cost of labor input (Pxi). Thus, each additional laborer still contributes to the increase in output, which exceeds the laborer's cost. Furthermore, the labor variable (TK) is also relatively efficient in this study. The role of labor is strategic in increasing profits, as noted by Ali et al. (2018), who state that it is a key factor in increasing production output in polyculture systems. However, it should be emphasized that labor with high levels of experience and education also contributes to production efficiency and profitability (Islam et al. 2023; Sumaryanto et al. 2026). The educational level of the workforce-in this case, the pond owners at the study site-remains low, with most having completed only elementary, junior high, or senior high school; however, their experience in fish farming is relatively high. Labor input, which is already relatively close to efficiency, can still be maximized through the skills and experience possessed by the fish farmers. Meanwhile, the limited number of workers can be optimized by utilizing family members, who represent a more cost-effective labor source. The use of medicines (OB) in this study shows an MVPxi/Pxi ratio of 0.975, as presented in Table 8. This value indicates that the allocation of medicine inputs is slightly below the allocatively efficient level because the ratio is smaller than 1, meaning that the additional value of output generated by medicine use is marginally lower than its cost. Therefore, from an economic perspective, the amount of medicine use may need to be slightly reduced to achieve allocative efficiency. Although medicines are applied to control diseases and pests in ponds, their use should remain proportional to production needs, since excessive application beyond the efficient level may reduce overall production performance.

Table 9. Farm managerial and policy implications

Independent variables	Expected results*		Farm Managerial (FM) and Policy Implications (PI)	
			FM implications	**PI implications**
Land Area	+/Sig.	Conf	Farmers need to improve land management practices, particularly water control and pond management, as land expansion is limited and optimizing existing ponds is more feasible.	Government should support land management policies, infrastructure development (irrigation and drainage), and technical training to improve pond efficiency.
Seed Stocking	+/Sig.	Conf	Farmers should adjust stocking density carefully to maintain water quality and balance in polyculture systems, while prioritizing the use of quality seed.	Government and private sector should improve access to affordable, high-quality seed and provide guidance on appropriate stocking density.
Additional Feed	+/Sig.	Conf	Feed use can be increased to support fish growth, but it should be done gradually considering financial constraints and water quality management..	Government should support access to affordable feed and provide training on efficient feed management.
Fertilizer	+/Sig.	Conf	Fertilizer use should be applied properly to maintain pond fertility and can still be increased within reasonable limits to support natural productivity.	Government should support fertilizer availability and provide training on balanced and efficient fertilization practices..
Labor	+/Sig.	Conf	Labor use should be adjusted to improve efficiency, as current labor input is relatively close to optimal levels.	Government should promote training and simple technology adoption to improve labor efficiency in aquaculture practices.

Note: Relevance: Conf: Confirmed; Unconf: Unconfirmed. Sig.: Significant

Overall, the results of the allocation efficiency analysis during the study in Pangkep District indicate that the use of production inputs remains relatively inefficient. Generally, there are still inefficiencies in the combination of inputs used, necessitating simultaneous adjustments that take into account the characteristics and limitations of each input at the individual farmer level.

Farm managerial and policy recommendations

From a managerial perspective, increasing milkfish production is more effectively achieved by optimizing key inputs such as seed quantity, feed, fertilizer, and labor, rather than simply increasing inputs across the board. Increases in fertilizer, seed quantity, and feed can still be implemented gradually while taking into account the carrying capacity of the ponds and environmental quality, particularly in traditional to semi-intensive systems. Land expansion is not a primary strategy due to its relatively small contribution and spatial constraints, making an intensification approach more relevant. Labor utilization can be increased to a limited extent by optimizing family labor, while the use of medicine must be tailored to needs to avoid incurring inefficient costs. Based on this, five main strategies are formulated in Table 9 through the Farm Managerial (FM) and Policy Implications (PI) approaches to support efficient production increases.

In conclusion, the research results indicate that milkfish farming operations in Pangkep District operate under conditions of increasing returns to scale. Estimates of the Cobb-Douglas production function show that land area, seed stocking, additional feed, fertilizer, and labor have positive and statistically significant effects on milkfish production, whereas the variables of medicine and capital do not show significant effects. The allocation efficiency of milkfish farmers in polyculture systems in Pangkep District remains below optimal conditions. Input allocation adjustments are needed for variables that have not yet reached allocative efficiency. The quantities of seed stocking and labor inputs are close to allocative efficiency, requiring only a slight increase in inputs to reach optimal conditions, whereas land area, additional feed, and fertilizer inputs are still far from optimal, thus requiring adjustments to the composition and proportion of input use, while medicines are in an inefficient state and require a reduction in inputs. The failure to achieve allocative efficiency is influenced by the limitations of traditional pond conditions and access to resources. These findings underscore the importance of integrating production function analysis with allocative efficiency when evaluating the performance of agricultural enterprises in polyculture systems. The analysis was conducted in only one district, Pangkep, so the results may not be generalizable to other areas. Furthermore, the use of data from only a single production cycle of polyculture milkfish farming does not yet capture seasonal variations or changes in efficiency over time. Therefore, future research is recommended to expand the geographic scope and use panel data to produce more robust efficiency estimates and strengthen policy implications.

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