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ALLOCATIVE EFFICIENCY AS A MANAGERIAL INNOVATION FOR SUSTAINABLE RICE PRODUCTIVITY IN KUPANG REGENCY

Ayu Fitriani*, Santhy Chamdra, Putri Manno Raga
Department of Agribusiness, Faculty of Agriculture, Universitas Nusa Cendana, Kupang, Indonesia
*Corresponding author: ayu_fitriani@staf.undana.ac.id

Abstract. Productivity in lowland rice farming within dryland archipelagic regions is often constrained by imprecise input management rather than a lack of technology. Farmers in Kupang Regency typically employ conventional intensification by increasing fertilizer inputs without considering marginal efficiency, leading to cost escalation. This study aims to deconstruct the structure of input usage, analyze allocative inefficiency, and formulate strategies for managerial redesign. A survey was conducted on 80 rice farmers in Noelbaki Village, Central Kupang District, selected using Proportional Random Sampling. Data were analyzed using the Cobb-Douglas production function and the ratio of Marginal Value Product (MVP) to input price. The findings reveal a significant efficiency gap: seeds have an elasticity of 0.418 but are underutilized, while fertilizers have an elasticity of 0.499 but are overutilized. The scale of operation is at decreasing return to scale (0.967). This study recommends reallocating budgets from fertilizer expenditure to high-quality seeds and strengthening farmers' financial literacy as managerial innovations to achieve economic sustainability and food security in East Nusa Tenggara.

Keywords: Competitiveness, ECI, Factors, TSI, RCA

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INTRODUCTION

Indonesia, as an agrarian country, places the agricultural sector as the primary foundation of the national economic system and a pillar of food security. The food crop subsector, particularly rice, plays a strategic role as the staple food source for the majority of the population. Despite various intensification and modernization efforts, national rice productivity shows a stagnant trend with uneven distribution across regions, where Java tends to be more productive than regions outside Java (Rachman et al., 2022; Sumaryanto et al., 2023). This disparity is particularly evident in East Nusa Tenggara (NTT) Province, an area agro-ecologically known as a dryland archipelagic region. While NTT possesses significant potential for lowland rice farming in areas with irrigation sources, it faces unique constraints distinct from the wet climates of Western Indonesia (Fitriani & Bani, 2025).

Kupang Regency serves as one of the strategic lowland rice production centers in NTT. However, rice productivity in this region tends to fluctuate and has not yet reached its optimal potential compared to the national average. A primary cause is the weak efficiency in the use of production inputs such as seeds, fertilizers, pesticides, and labor. Historically, production increases in developing regions have been pursued through "input-led growth"—simply adding more input quantities. However, recent studies suggest that this approach is no longer effective; it often escalates farming costs, diminishes profit margins, and creates environmental externalities (Kumar et al., 2021; Zhang & Wang, 2024). Furthermore, the excessive use of chemical fertilizers and pesticides leads to soil acidification and land quality degradation, ultimately threatening production sustainability (Bisht & Chauhan, 2020; Pahalvi et al., 2021).

The fundamental problem identified in Noelbaki Village is the "efficiency gap." Farmers often operate under the assumption that maximizing inputs equals maximizing outputs. This phenomenon aligns with findings by Nafisah and Fauziyah (2020)**,** which highlighted that farmers' risk behavior significantly influences input allocation, often leading to technical and allocative inefficiencies. In reality, economic theory suggests that rationality is defined by allocative efficiency, the ability to equate the Marginal Value Product (MVP) of an input with its market price. In this context, innovation in agriculture is not solely synonymous with adopting expensive machinery or digital technology (Smart Farming), but can be realized through improving farmers' "managerial capacity" to reallocate resources efficiently (Nawaz et al., 2022).

Existing literature has extensively examined rice farming efficiency. At the national level, recent studies have highlighted the persistent issue of technical inefficiency in various agro-ecological zones, such as in dryland areas of Lampung (Fauzan, 2020) and rainfed lowlands in North Sumatra (Fadilla et al., 2025). Specifically in the study location, Ritan et al. (2021) analyzed rice farming in Noelbaki Village and found that while farmers are technically capable, they struggle with allocative efficiency. However, these previous studies, including Salam et al. (2022) who compared inorganic and semi-organic systems, tend to stop at the measurement of efficiency scores without offering concrete managerial solutions. A significant research gap remains regarding the "managerial" aspect of these inefficiencies. Few studies specifically integrate allocative efficiency analysis as a basis for "financial literacy-based innovation" in dryland archipelagic contexts. While the importance of financial literacy has been acknowledged in recent works (Parawansa et al., 2024; Raza et al., 2023), its direct application as a strategy to correct input misallocation in NTT is missing. This study aims to fill that gap. Unlike Ritan et al. (2021) who focused on efficiency measurement, this study proposes a proactive "Managerial Innovation" framework. The specific objectives are: (1) to evaluate the structure of production input usage and their elasticity; (2) to analyze the allocative efficiency of key inputs (seed and fertilizer); and (3) to formulate managerial redesign strategies to transition farmers from habit-based farming to efficiency-based farming.

This study makes significant contributions to both theory and policy. From a theoretical perspective, it enriches the literature on production economics by showing that, in subsistence farming, allocative inefficiency is not solely a response to price signals but also reflects behavioral constraints associated with limited financial literacy. From a policy perspective, the findings provide empirical support for reorienting government subsidies away from input quantity assistance, such as bulk fertilizer distribution, toward input quality support, including the provision of certified seeds and managerial training, in order to promote sustainable food security in dryland regions.

METHOD

Research Design and Location

This research employed a quantitative explanatory approach to analyze the causal relationships between production factors and rice output. The research was conducted in Noelbaki Village, Central

Kupang District, Kupang Regency. This location was selected purposively as it represents a strategic lowland rice production center in the dryland archipelagic region of East Nusa Tenggara, where productivity remains suboptimal despite the existence of technical irrigation infrastructure. The research was carried out during the 2024 planting season.

Population and Sampling Technique

The population in this study comprised all lowland rice farmers belonging to two active farmer groups in Noelbaki Village, totaling 407 individuals. The sample size determination relied on the multivariate analysis guidelines by which recommend a minimum sample size of 15 times the number of independent variables to ensure sufficient statistical power. With five independent variables included in the Cobb-Douglas model (Land, Seed, Fertilizer, Pesticide, Labor), the minimum required sample size was 75 respondents (5×15). To ensure data robustness and anticipate potential outliers, 80 respondents were selected using the Proportional Random Sampling technique to guarantee adequate representation from each farmer group.

Data Collection and Analysis

Primary data were collected using structured questionnaires combined with direct field observations. The instrument focused on input usage (quantity and cost) and production output. The collected data were analyzed using three quantitative approaches. First, the Cobb-Douglas Production Function was employed to estimate the elasticity of production factors. Following the standard econometric approach for production analysis (Gujarati & Porter, 2009; Soekartawi, 2010) , the model was transformed into a natural logarithm (Ln) form to linearize the relationship between inputs and output:

$$\ln Y = \beta_0 + \beta_1 lnX_1 + \beta_2 lnX_2 + \beta_3 lnX_3 + \beta_4 lnX_4 + \beta_5 lnX_5 + \varepsilon \ldots (1)$$

The variables included in the model are measured as follows: Rice Production (Y) represents the total harvested dry grain in kilograms (kg). Land Area (X_1) is measured in hectares (ha). Seed (X_2) is the quantity of seeds used in kilograms (kg). Fertilizer (X_3) is the total physical weight (kg) of all inorganic fertilizers applied, consisting of Urea, NPK, TSP, and Petroganik. Pesticide (X_4) is the total volume (Liter) of liquid pesticides used, including Monosultap, Alika (*Lambda-cyhalothrin and Thiamethoxam*), and *Cypermethrin*. Labor (X_5) is measured in Man-Days (HOK), standardized to an 8-hour workday equivalent per person. Second, the Return to Scale (RTS) was calculated by summing the regression coefficients ($\sum_{i=1}^{5} \beta_i$) to determine whether the farming system operates under constant, increasing, or decreasing returns to scale. The third stage was the allocative efficiency analysis. Efficiency values were calculated only for inputs proven to have a significant effect based on regression results. The allocative efficiency value (k) was calculated using the ratio between the Marginal Value Product (MVP) and the input price (P_x):

$$K = \frac{MVP_{xi}}{P_{xi}} = \frac{\beta_i \cdot (\bar{Y}/\bar{X}_i) \cdot P_y}{P_{xi}} \ldots (2)$$

Where Y is the average production, X_i is the average input, P_y is the output price, and P_{x_i} is the input price. A value of k = 1 indicates allocative efficiency. If k > 1, the input is underutilized and should be increased. Conversely, if k < 1, the input is overutilized and should be reduced (Pellokila, 2020; Sari et al., 2024).

RESULT AND DISCUSSION

Respondent Characteristics

The socio-economic profile of farmers is a determinant of managerial decision-making. As shown in Table 1, the average age of farmers is 51.51 years, categorizing them as an aging workforce, a common phenomenon in Indonesian agriculture.

Table 1. Characteristics of Lowland Rice Farmers in Noelbaki Village

No	Characteristic	Unit	Average
1	Farmer age	Years	51.51
2	Household size	Persons	5.06
3	Farming experience	Years	24.80
4	Formal education	School years	5.75
5	Cultivated land area	Hectares	1.02

Source: Data Processed, 2025

The low level of formal education (5.75 years, not completing primary school) poses a challenge for adopting complex technologies. However, the extensive experience (24.8 years) suggests that farmers possess strong tacit knowledge, although this often leads to "path dependence", a reluctance to change traditional habits, such as excessive fertilization.

Input Use in Lowland Rice Farming

Analysis of production input use provides important insights into the intensity of farming practices and farmers' resource management strategies. To ensure comparability across farms with different land sizes, all production inputs were normalized on a per-hectare basis. Table 2 presents the average use of key production inputs per hectare during one cropping season in lowland rice farming in Noelbaki Village.

Table 2. Average Use of Production Inputs in Lowland Rice Farming

Production Input	Unit per ha	Average Value
Seed	kg	34.81
Total fertilizer	kg	616.43
Pesticides	liters	4.24
Labor	workdays (HOK)	41.08
Output	kg	7,249.06

Source: Data Processed, 2025

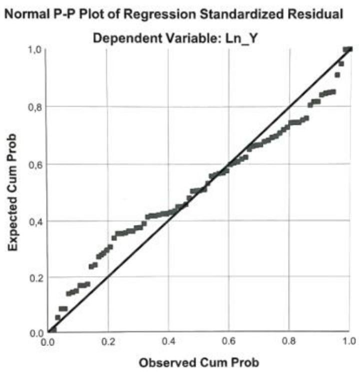
The relatively high level of fertilizer use, averaging 616.43 kg/ha, indicates a semi-intensive lowland rice production system. Fertilizer input in this study consists mainly of inorganic fertilizers, including urea, NPK Phonska, and TSP, complemented by subsidized organic fertilizer (Petroganik). Field observations reveal that farmers rely heavily on urea to stimulate vegetative growth, often exceeding recommended application rates. In contrast, the application of potassium (from NPK) and phosphorus (from TSP) tends to be imbalanced, while the use of Petroganik remains insufficient to effectively improve soil organic matter and soil health. The average pesticide use of 4.24 L/ha reflects relatively intensive chemical control practices, with multiple spray applications during one cropping season and the use of mixed insecticide formulations. Such application intensity suggests that pest management is largely preventive and input-oriented, rather than based on economic threshold considerations. Although the average rice yield of 7.25 tons per hectare reflects considerable production potential, the strong dependence on nitrogen-based fertilizers and chemical pest control raises concerns regarding long-term soil sustainability and the efficiency of input use.

Classical Assumption Tests and Model Goodness of Fit

Before interpreting the Cobb–Douglas production function, classical assumption tests and a goodness-of-fit test were conducted to ensure the model yields Best Linear Unbiased Estimator (BLUE) results, in line with empirical applications of Cobb–Douglas production functions that emphasize proper model specification, stability, and reliability of estimated coefficients prior to economic interpretation (Ikeo, 2023; Stiefenhofer & Chen, 2024; Wang & Henderson, 2022).

Classical Assumption Tests

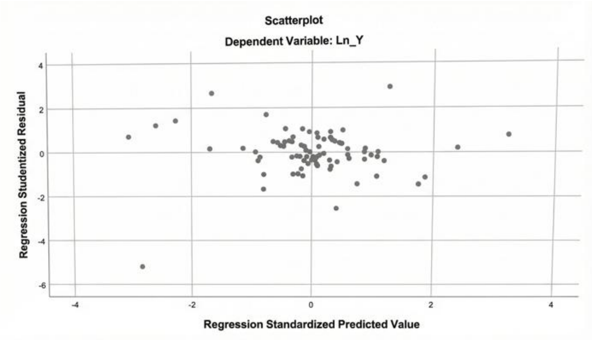
The validity of the regression model was confirmed through a series of classical assumption tests, including normality, heteroskedasticity, and multicollinearity, conducted using SPSS software in accordance with standard Ordinary Least Squares (OLS) diagnostics to ensure the Best Linear Unbiased Estimator (BLUE) criteria. The normality assumption was evaluated using the Normal P–P Plot of Regression Standardized Residuals (Figure 1). The plot shows that the residual points are distributed closely along the diagonal reference line, indicating that the residuals are approximately normally distributed. This visual pattern is consistent with standard regression diagnostics, in which residuals that follow the diagonal line imply conformity with the normality assumption (Mardiatmoko, 2024; Nurlatifah & Siburian, 2021; Subiyanto et al., 2021).



Source: Data Processed, 2025

Figure 1. Normal P–P Plot

Heteroskedasticity was assessed using a scatterplot of standardized residuals against standardized predicted values (Figure 2). The residuals are randomly scattered and symmetrically distributed around the zero line without any discernible pattern, indicating homoscedastic error variance and the absence of heteroskedasticity in the model (Saleh N. & Rosli M., 2024).



Source: Data Processed, 2025

Figure 2. Scatterplot Standardized Residual vs Predicted Value

Furthermore, the multicollinearity test results presented in Table 3 indicate that the Variance Inflation Factor (VIF) values for all independent variables, such as Land Area (1.277), Seed (1.402), Fertilizer (1.590), Pesticide (1.580), and Labor (1.042) are well below the commonly accepted threshold of 10, while all tolerance values exceed 0.10. These results confirm the absence of multicollinearity among the explanatory variables, in line with widely applied empirical criteria in recent econometric studies (Mardiatmoko, 2024; Muliana & Saputra, 2023; Ohaegbulem & Iheaka, 2024).

Coefficient of Determination (R^2)

The goodness of fit of the model is summarized in Table 3.

Table 3. Summary of Multicollinearity and Model Fit Statistics

Variable	Tolerance	VIF	R Square	Adj. R Square
(Constant)	**-**	**-**	**0.506**	**0.472**
Ln Land Area (X_1)	0.783	1.277		
Ln Seed (X_2)	0.713	1.402		
Ln Fertilizer (X_3)	0.629	1.590		
Ln Pesticide (X_4)	0.633	1.580		
Ln Labor (X_5)	0.960	1.042		

Source: Data Processed, 2025

The adjusted R-square value of 0.472 (R-square = 0.506) indicates that approximately 50.6% of the variation in rice production is explained by the five production inputs included in the model, namely land area, seed, fertilizer, pesticide, and labor. This level of explanatory power is considered adequate for farm-level, cross-sectional production data and is comparable to findings from other rice production studies, where physical input combinations typically explain around 43–51% of output variation (Anthony et al., 2021; Chau & Ahamed, 2022; Purnomo et al., 2025).

Similar magnitudes of R^2 have been reported in rice production analyses in Nigeria and Southeast Asia, reflecting the fact that input-based production functions capture only part of the inherently heterogeneous production process (Anthony et al., 2021; Chau & Ahamed, 2022). The remaining unexplained variation is commonly attributed to non-input factors such as farmers' managerial ability, farming experience, climatic variability, and institutional support, which have been shown to significantly influence rice productivity and yield risk (Chandio et al., 2021; Gul et al., 2022).

Consistent with this interpretation, field interviews conducted during the study indicate that limited access to agricultural extension services constitutes a critical unobserved factor affecting production performance. Previous studies similarly document that inadequate extension support constrains farmers' ability to adopt improved practices and optimize input use, thereby contributing to unexplained variation in output (Purnomo et al., 2025). In the study area, farmers reported infrequent visits from extension officers, leading to production decisions being made largely without professional guidance.

Cobb–Douglas Production Function

The Cobb–Douglas production function was employed to analyze the effects of production inputs on rice output. All variables were transformed into natural logarithms and estimated using multiple linear regression. The estimation results are presented in Table 4.

Table 4. Estimated Cobb–Douglas Production Function for Lowland Rice Farming

Variable	Coefficient ($\hat{\beta}$)	t-value	Sig.
Constant	3.749	3.931	0.000
Ln Land area (X_1)	0.002	0.944	0.994
Ln Seed (X_2)	0.418	2.920	0.005*
Ln Fertilizer (X_3)	0.499	5.054	0.000*
Ln Pesticide (X_4)	0.052	0.454	0.651
Ln Labor (X_5)	-0.004	-0.072	0.943

R^2 = 0.506; F-statistic = 15.141; α = 5%

Source: Data Processed, 2025

Table 4 presents the estimation results of the Cobb–Douglas production function for lowland rice farming. All variables were transformed into natural logarithms, allowing the estimated coefficients to be interpreted directly as output elasticities. The F-statistic value of 15.141 is statistically significant at the 5% level, confirming that the production inputs jointly have a significant effect on rice output and that the model is appropriate for further interpretation.

Among the input variables, seed input (X_2) and fertilizer input (X_3) have a positive and statistically significant effect on rice production. The elasticity of seed input is 0.418, implying that a 1% increase in seed usage increases rice output by approximately 0.42%, *ceteris paribus*. Theoretically, this finding can be explained by the concept of "genetic potential" in agronomy. Seed serves as the primary carrier of production technology; high-quality certified seeds possess superior physiological purity and vigor, which directly determine the percentage of germination and plant population density per hectare. This result highlights the critical role of seed quality in determining rice productivity, consistent with previous findings by Salam et al. (2022) and Fauzan (2020), who confirmed that seed quality is a significant driver of output in rice farming systems. Takeshima et al. (2025) further emphasized that adopting certified seeds is a fundamental determinant in closing yield gaps in developing regions.

Similarly, fertilizer input shows the highest elasticity value (0.499) and is highly significant, indicating that nutrient availability remains a key limiting factor. From a plant physiology perspective, this responsiveness aligns with the fundamental roles of Nitrogen, Phosphorus, and Potassium as essential macronutrients required for vegetative growth, root development, and grain filling phases. A 1% increase in fertilizer use is associated with an increase in rice output of nearly 0.50%, suggesting that improved nutrient management could substantially enhance productivity. This empirical evidence is verified by Fadilla et al. (2025), who observed that fertilizer intensification remains highly responsive in boosting rice yields, provided that the application is balanced.

In contrast, land area (X_1), pesticide use (X_4), and labor input (X_5) do not significantly affect rice output. The coefficient of land area is positive but statistically insignificant, suggesting that expansion of cultivated land alone does not necessarily translate into higher production. This may reflect relatively homogeneous farm sizes, diminishing returns to scale, or suboptimal land management practices. The insignificance of pesticide input indicates that current pesticide application levels may not be yield-enhancing, potentially due to inappropriate timing, dosage, or pest pressure that does not reach economic thresholds. Meanwhile, the negative but insignificant coefficient of labor input suggests that additional labor use does not contribute to higher output. This phenomenon reflects the theory of "disguised unemployment" or surplus labor, which is common in peasant agriculture where the marginal productivity of family labor approaches zero due to excessive workforce relative to land size (Ritan et al., 2021). Consequently, labor allocation in the study area has reached a saturation point where efficiency can only be improved by reducing labor intensity.

Overall, these results imply that rice production in the study area is more responsive to input intensification, particularly seeds and fertilizers, than to extensification or the increased use of labor and pesticides. This tendency contrasts with the traditional "input-led growth" model and resonates with recent findings by Salam et al. (2022) and Sarifuddin et al. (2024), who reported that excessive input accumulation often leads to diminishing economic returns due to high production costs. Furthermore, the findings confirm the existence of allocative inefficiencies, where certain inputs are utilized beyond their economically optimal levels. This corroborates the specific observation by Ritan et al. (2021) in Noelbaki Village, who identified that local farmers struggle to achieve allocative efficiency due to irrational input combinations. Therefore, productivity improvements should prioritize the efficient use of yield-enhancing inputs, specifically certified seeds as advocated by Takeshima et al. (2025), while rationalizing the allocation of land, labor, and pesticides. Achieving this requires a shift in farm management supported by extension services focused on financial literacy, a strategy emphasized by Parawansa et al. (2024) to correct input misallocation and enhance economic sustainability.

Production Elasticity and Returns to Scale

Regression coefficients from the Cobb–Douglas model represent production elasticities of each input. Seed elasticity was estimated at 0.418, while fertilizer elasticity was 0.499, implying that a 10% increase in seed and fertilizer use would raise rice output by approximately 4.18% and 4.99%, respectively. These results indicate that both inputs contribute substantially to production.
The degree of returns to scale (RTS) was calculated by summing all estimated elasticities:

$$RTS = \sum_{i=1}^{5} \beta_i = 0.002 + 0.418 + 0.499 + 0.052 - 0.004 = \mathbf{0.967}$$

Since RTS < 1, lowland rice farming in Noelbaki Village operates under decreasing returns to scale, meaning that proportional increases in all inputs lead to a less-than-proportional increase in output. This condition suggests systemic inefficiencies and limited responsiveness of land or farm management to uniform input expansion.

Allocative Efficiency and Production Risk

Allocative efficiency analysis focused on seed and fertilizer inputs, as they were statistically significant determinants of output. Allocative efficiency was measured by the ratio of marginal value product (MVP) to input price (Px), expressed as $K = MVP/P_x$. A value of K = 1 indicates allocative efficiency; K > 1 suggests underutilization, while K < 1 indicates overuse. Table 5 presents the allocative efficiency results.

Table 5. Allocative Efficiency of Seed and Fertilizer Inputs

Input	Allocative Efficiency ($K = MVP/Px$)	Interpretation
Seed	56.58	Underutilized
Fertilizer	0.39	Overutilized

Source: Data Processed, 2025

Note: K represents allocative efficiency calculated as MVP/Px, where MVP = PMx × Py. The output price (Py) reflects the average farm-gate price of unhusked rice in Kupang Regency, set at IDR 6,500/kg. A value of K = 1 indicates allocative efficiency; K > 1 indicates underutilization; and K < 1 indicates overutilization.

The Paradox of Fertilizer Overuse ($k = 0.39$)

The allocative efficiency ratio of 0.39 indicates a substantial level of fertilizer overuse relative to its marginal contribution to output. Economically, this implies that the marginal value product of fertilizer is considerably lower than its market price, resulting in diminishing economic returns at the margin. Several factors help explain this condition. First, the availability of subsidized fertilizer may distort farmers' price perception, encouraging excessive application beyond agronomic requirements (Raza et al., 2023). Second, fertilizer is often perceived as a risk-mitigation input, leading farmers to apply it as a form of yield insurance under uncertain soil and climatic conditions. Third, excessive nitrogen application may generate negative environmental externalities, including soil acidification and declining soil quality, which further reduce long-term productivity and efficiency (Wang et al., 2024).

The Opportunity of Seed Investment ($k = 56.58$)

Conversely, seed input exhibits a substantial level of allocative inefficiency, as reflected by the allocative efficiency ratio of 56.58. This value indicates that current seed use is far below its economically optimal level and that improvements in seed quality or appropriate seeding rates would generate relatively high marginal returns. Field observations suggest that many farmers rely on recycled seeds from previous harvests (F2/F3 generations) instead of certified first-generation seeds (F1). Such practices are associated with lower germination rates, reduced plant vigor, and greater heterogeneity in crop establishment, which collectively constrain yield performance. Consistent with this finding, previous empirical studies demonstrate that yield gaps in developing-country rice systems are strongly linked to inadequate seed quality and limited adoption of certified seeds (Takeshima et al., 2025).

Managerial Innovation: Redesigning the Farming Business Model

Based on these empirical results, this study proposes a managerial redesign framework that emphasizes efficiency-oriented decision-making rather than input intensification. The proposed approach seeks to reorient farm management practices toward more rational allocation of production inputs, particularly through strategic investment in high-quality seed, as a means of improving productivity and economic sustainability in lowland rice farming systems in Kupang Regency.

From Input-Intensive to Knowledge-Intensive

Innovation does not always mean digital sensors. For these farmers, innovation means "Financial Literacy." Extension services must pivot from teaching "how to plant" to "how to calculate." Farmers need to be trained to calculate simple Benefit-Cost Ratios. if farmers understood that the marginal economic return to additional fertilizer application is below its cost (k < 1), rational input adjustment would likely follow (Zhang & Wang, 2024).

Budget Reallocation Strategy (The "Switch" Innovation)

The proposed managerial innovation is a zero-sum cost strategy. Farmers do not need extra capital; they need to switch capital. The recommended action is to reduce Urea/NPK dosage by 20-30% (bringing k closer to 1). This will free up cash flow, which can then be reinvested to purchase Certified Seeds (Label Blue/Purple) and organic soil amendments. This strategy mitigates the risk of capital shortage while optimizing the high elasticity of seeds (Baglan et al., 2020).

Production Risks Associated with Input Inefficiency

Input inefficiency affects not only economic performance but also increases production risks that threaten long-term sustainability.

a. **Risks from excessive fertilizer use.** Over-application of chemical/inorganic fertilizers results in unnecessary costs and poses risks of land degradation, declining soil fertility, groundwater contamination, and disruption of soil microbial ecosystems. These cumulative effects may reduce long-term productivity and agroecosystem resilience, particularly in water- and nutrient-constrained environments such as East Nusa Tenggara (Fitriani & Bani, 2025).
b. **Risks from suboptimal seed use.** Inadequate quantity or poor-quality seed increases crop vulnerability to pests, diseases, and climatic variability. Crops established from inferior seed generally have weaker physiological resilience, raising the probability of yield losses or crop failure in marginal agroclimatic conditions.

The extreme imbalance in allocative efficiency values therefore signals the need for targeted managerial interventions to reduce production risks and promote more resilient and sustainable rice farming systems.

Managerial Innovation Recommendations Based on Input Efficiency

The findings indicate that the main challenge in lowland rice farming in Noelbaki Village lies not in technological limitations, but in suboptimal resource (input) management. This pattern is consistent with broader evidence showing that inefficiencies in smallholder agriculture are often driven by managerial and incentive-related constraints rather than by a lack of technology (Gautam et al., 2022). Based on regression results, production elasticities, allocative efficiency measures, and identified risks, several practical managerial innovations are recommended:

a. **Reallocation of farm budgets.** Farmers should be encouraged to reduce expenditure on fertilizers that are currently overused and redirect resources toward certified high-quality seed in more optimal quantities. This strategy can improve allocative efficiency while reducing the risk of yield loss, and is consistent with global recommendations to shift agricultural support away from input quantity subsidies toward productivity and efficiency-enhancing investments (Baglan et al., 2020; Gautam et al., 2022; Takeshima et al., 2025).
b. **Strengthening managerial and financial knowledge.** Extension programs should go beyond technical cultivation practices to include basic financial literacy and farm management skills. Enhancing farmers' capacity to evaluate costs, marginal returns, and input allocation decisions can significantly improve economic efficiency and farm performance (Raza et al., 2023; Zhang & Wang, 2024).
c. **Balanced and environmentally friendly fertilization.** Farmers need guidance on site-specific and balanced fertilizer application according to crop and soil requirements. Promoting partial substitution of chemical fertilizers with organic or bio-based inputs can improve soil health, enhance nutrient-use efficiency, and support long-term sustainability (Wang et al., 2024; Wu et al., 2024).

These recommendations are low-cost and highly applicable, yet they offer substantial potential to improve both economic and environmental efficiency. Managerial innovation grounded in input-use efficiency represents a critical pathway toward sustainable agricultural transformation in dryland-prone regions such as East Nusa Tenggara.

CONCLUSIONS

Motivated by the persistent stagnation of rice productivity in the dryland archipelagic region of East Nusa Tenggara, this study aimed to analyze the allocative efficiency of farming inputs and formulate a managerial redesign strategy. The empirical results confirm that the lowland rice farming system in Noelbaki Village operates under a Decreasing Return to Scale (0.967) regime, indicating that the era of growth through simple input expansion is over. The study uncovers a stark efficiency paradox: farmers are incurring marginal losses through excessive fertilization ($k = 0.39$) while missing out on significant potential gains from seed investment ($k = 56.58$).

Therefore, the path to sustainable food security in Kupang Regency lies in "Managerial Innovation." This involves a paradigm shift from maximizing physical inputs to optimizing allocative efficiency. The core recommendation is a "Budget Reallocation Strategy": reducing chemical fertilizer dependency and redirecting funds toward certified seeds and soil health. In terms of policy implications, the findings suggest that the local government must pivot from volume-based subsidies (specifically inorganic fertilizers) to quality-based support. This recommendation aligns with the global call to "repurpose" agricultural support, as argued by Gautam et al. (2022), who emphasize that shifting budget allocation from distortive input subsidies to high-return public goods like seed systems is crucial for climate-smart agriculture. Furthermore, Jamil (2022) highlighted that improving the inclusivity and governance of fertilizer subsidy schemes is urgent to prevent inefficiency in Indonesia. Thus, policy interventions should focus on ensuring the availability of certified seeds and providing extension services centered on financial literacy.

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