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Resource Allocation Optimization for Pond-Based Farming in Rembang Regency, Indonesia

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Abstract. Salt production in Rembang Regency plays a strategic role in supporting coastal economic resilience; however, it still faces fluctuations in production and prices due to climate variability and limited resource efficiency. This study aims to determine the most optimal pond farming strategy to enhance the economic sustainability of salt farmers. A quantitative approach was applied using the linear programming method to analyze the combination of salt, vannamei shrimp, and milkfish under two seasonal conditions, dry and rainy seasons, considering constraints in land, capital, and labor. The results show that during the dry season, optimal resource allocation is achieved through salt production with a maximum profit of IDR 47,864,060, while during the rainy season, the optimal combination is obtained through milkfish, vannamei shrimp polyculture, generating a profit of IDR 4,707,023. Labor emerged as the most critical factor, with the highest shadow prices (IDR 64,420 and IDR 1,886.36), indicating that labor efficiency significantly affects profitability. The policy implication of this study emphasizes the importance of implementing season-based commodity rotation and enhancing labor efficiency through capacity-building programs as adaptive strategies to strengthen the economic resilience of coastal salt farmers.

1 Introduction

Salt is a strategic commodity that plays a vital role not only in national food security but also in supporting the socio-economic livelihoods of coastal communities in Indonesia. Rembang Regency, located in Central Java, is one of the largest salt-producing centers in Java. Geographically, Rembang lies along the northern coast of Central Java with a coastline

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stretching 63.5 kilometers, positioning it as one of the major traditional salt production hubs in Java. The total area of salt ponds in the region reaches 1,184 hectares, involving approximately 2,785 salt farmers, with an annual production volume of around 115,000 tons in year [1]. According to data from Statistics Indonesia (BPS) 2024, the agricultural sector—particularly the fisheries and marine sub-sector, including salt—contributes significantly to Rembang's Gross Regional Domestic Product (GRDP). However, this potential has not been fully realized due to various structural and operational challenges.

The challenges faced by salt production have intensified in response to increasingly erratic climate change. Shifts in the onset of the rainy season significantly affect the success rate of salt production. Extended dry seasons may allow for longer harvest periods but often coincide with sharp declines in selling prices. Conversely, wet dry-season cycles frequently lead to crop failure and reduced salt productivity [2]. In Rembang Regency, approximately 75% of salt farmers still rely on traditional production methods that are highly vulnerable to seasonal disruptions, thereby increasing the risk of harvest failure. As a result, the average productivity remains below the national standard, reaching only 60 tons per hectare per season compared to the standard of 80 tons. Preliminary field observations further reveal that salt produced by Rembang farmers often contains NaCl concentrations ranging from 90% to 92%, which falls short of the Indonesian National Standard (SNI) requirement of a minimum 94% NaCl content for edible salt. This discrepancy contributes to lower market value. Compounding the issue, salt prices during peak harvest periods have plummeted by up to 80%—from IDR 5,000/kg to as low as IDR 600–800/kg—while production costs remain relatively high [3]. Consequently, salt farmers in Rembang Regency have experienced significant economic hardship because of these issues.

Farmers have attempted to implement polyculture or crop substitution techniques in salt ponds during the rainy season or during unseasonably wet dry seasons. Polyculture refers to a pond management technique that combines more than one type of aquaculture activity within the same plot of land, thereby promoting more efficient use of resources and increasing income diversification. The development of salt pond aquaculture can be carried out through polyculture by integrating salt production with the cultivation of other commodities such as shrimp, milkfish, saline tilapia, and seaweed. Several studies have indicated that polyculture techniques in salt ponds can lead to significantly higher profits for aquaculture farmers [4]. In the case of Rembang Regency, salt farmers have begun applying polyculture practices involving salt production alongside the cultivation of vannamei shrimp and milkfish. However, in practice, the cultivation of shrimp and milkfish has not yet been carried out intensively, as farmers only scatter fry into shared ponds without structured management. Therefore, a study is needed to determine the optimal composition and resource allocation within polyculture systems, in order to maximize economic returns for pond owners.

One viable approach is to conduct a study on the optimization of profits derived from polyculture farming practices. This is necessary to identify which combinations of commodities can generate the highest economic returns for salt farmers in Rembang. Profit optimization can be achieved using linear programming analysis, which offers a methodological advantage in determining the maximum attainable profit within defined resource constraints [5-6]. Prvious studies have demonstrated that this analytical tool is well-suited for assessing maximum profitability in polyculture systems, thereby enabling researchers and practitioners to identify which farming scenarios yield the highest economic returns given the limitations faced by producers [7–8].

Furthermore, in response to the challenges faced by salt farmers in Rembang Regency, this study analyzes the optimization of seasonal resource allocation in pond-based farming systems using a linear programming approach. The research focuses on identifying profit-maximizing aquaculture strategies through the integration of salt production, vannamei shrimp cultivation, and milkfish farming under different seasonal conditions. Although previous studies have examined optimization in salt pond systems, there remains a research gap concerning the practical implementation of polyculture management among members of the Sari Makmur Farmers Cooperative Group in Kaliori, Rembang Regency. Therefore, the findings of this study are expected to provide a scientific foundation for developing adaptive, season-based polyculture models that enhance the economic sustainability and resilience of coastal salt farmers.

2 Research method

2.1 Studi area dan data

This study was conducted among salt farmers who are members of the Sari Makmur Farmers' Cooperative Group in Kaliori Subdistrict, Rembang Regency. A quantitative approach was employed, with the research location determined purposively. The site was selected based on the consideration that the area is one of the highest salt-producing centers in Central Java Province and that a number of farmers have adopted polyculture techniques in their pond-based farming systems. Data was collected through surveys, observations, and structured interviews using questionnaires. Respondents were selected using purposive sampling, specifically targeting farmers who applied polyculture techniques involving more than two types of commodities in their salt pond farming. This study was carried out within a three-month period, spanning from February to April 2025, out of 160 cooperative members, 20 farmers met the specified criteria and were selected as research respondents.

2.2 Analytical methods

2.2.1 Linier programming methods

Linear programming is an optimization method used to maximize or minimize an objective function by considering the constraints imposed by the limited availability of resources within a given business activity. The objective function represents the primary goal to be achieved—such as maximizing profit or minimizing cost—while the constraint functions describe limitations arising from available resources, such as land, labor, or capital. In this study, the linear programming method is applied to calculate the optimum profit in pond-based farming activities in Kaliori Subdistrict, Rembang Regency. Three farming scenarios are compared: salt production, vannamei shrimp cultivation, and milkfish farming, each analyzed under the constraints faced by local farmers. The linear programming model is formulated mathematically to derive an optimal solution to the problem at hand.

Furthermore, in formulating the linear programming model for the three types of pond-based farming, it is assumed that the production activities occur across two distinct seasons: the dry season and the rainy season. This assumption is necessary to comprehensively analyze farming scenarios that yield optimal profits throughout the year under seasonal conditions. During the dry season, all three commodities—salt, vannamei shrimp, and milkfish—are assumed to be cultivable under optimal conditions. However, in the rainy season, only vannamei shrimp and milkfish cultivation are considered feasible due to environmental constraints that are unfavorable for salt production. The overall research process flow is illustrated in Figure 1.

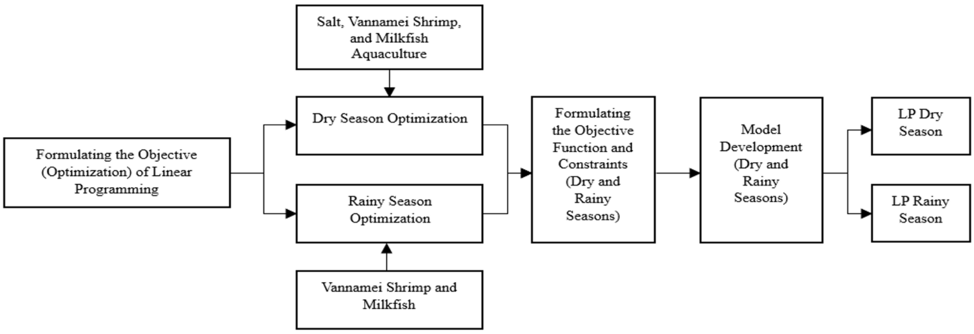

Fig. 1. Flowchart of linear programming optimization analysis for pond utilization in Kaliori, Rembang

3 Results and discussion

3.1 Linear programming model

3.1.1 Linear programming constraints

Total of 20 farmers from the Sari Makmur Farmers' Cooperative Group were identified as practicing polyculture techniques in their pond-based farming systems. Field findings revealed that during the dry season, farmers primarily engaged in salt farming as the main activity, while incorporating intercropping of milkfish and vannamei shrimp. In contrast, during the rainy season, farming activities focused solely on milkfish and vannamei shrimp cultivation due to unfavorable conditions for salt production. The characteristics of the salt ponds managed by the observed farmers are presented in Table 1.

Table 1. Average land area, capital, and labor in polyculture-based farming systems

Commodity	Land Area (m²)	Capital (IDR)	Labor	Profit (IDR)
Salt	15,000	59,464,440	743	48,308,060
Shrimp	5,000	4,169,600	31	1,630,400
Milkfish	5,000	2,371,148	283	1,212,914

Table 1 presents empirical data collected directly from farmers. The total land area utilized by farmers during one production season averages 15,000 square meters (1.5 hectares), with the duration of the production season ranging from approximately four to five months. The application of polyculture techniques implies that this land is used simultaneously for cultivating both vannamei shrimp and milkfish. Field observations revealed that salt farmers allocate approximately 5,000 square meters—specifically the seawater reservoir pond used for salt irrigation—for polyculture aquaculture of vannamei shrimp and milkfish. The total capital and labor constraints applied in this study are equivalent to those used in salt farming, amounting to IDR 59,464,440 in capital and 743 labor days. To ensure clarity and avoid misinterpretation in the data analysis, polyculture practices in this study are assessed based on standardized measurements per square meter of pond area. Table 2 presents the normalized data for each aquaculture activity per square meter of land utilized.

Furthermore, since pond-based farming activities are managed according to seasonal cycles, the linear programming model is differentiated by dry and rainy seasons. During the dry season, farmers cultivate three mains commodities: salt, vannamei shrimp, and milkfish. Typically, shrimp and milkfish are raised in reservoir ponds that supply water to the salt pans.

In contrast, the rainy season allows for only two commodities—vannamei shrimp and milkfish due to environmental limitations. During this period, the salt pans are inundated by rainwater, making salt production unfeasible; instead, farmers utilize the water-filled plots for stocking shrimp and milkfish fried. Based on Table 2, constraint functions for each season can be formulated accordingly.

Table 2. Average land area, capital, and labor input per 1 m² of farming activity

Commodity	Land Area (m²)	Capital (IDR)	Labor
Salt	1	3,964.30	0.0495
Shrimp	1	833.92	0.0562
Milkfish	1	474.23	0.0126

In this study, the linear programming model for pond-based farming was formulated separately for the dry and rainy seasons to account for seasonal variations in resource availability and production feasibility. During the dry season, three commodities—salt *(X_1),* vannamei shrimp *(X_2),* and milkfish *(X_3)*—were included in the optimization model. The system was constrained by the total available land area, production costs, and labor input, represented respectively as follows:

$$\textit{Total land area constraint} = x1+x2+x3 \leq 15{,}000 \quad (1)$$
$$\textit{Maximum cost constraint} = 3{,}964.30(x1)+833.92(x2)+474.23(x3) \leq 59{,}464{,}440 \quad (2)$$
$$\textit{Labor constraint} = 0.0495(x1)+0.0562(x2)+0.0126(x3) \leq 743 \quad (3)$$

The decision variables could not take negative values = $x1, x2, x3 \geq 0$

For the rainy season, only vannamei shrimp (x_2) and milkfish (x_3) were included in the model due to environmental constraints that render salt production infeasible.

$$\textit{The constraint system consisted of a total land area limit } x2+x3 \leq 15{,}000 \quad (4)$$
$$\textit{a cost limitation} = 833.92x2+474.23x3 \leq 59{,}464{,}440 \quad (5)$$
$$\textit{labor constraint} = 0.0562x2+0.0126x3 \leq 743 \quad (6)$$

The non-negativity condition for both variables was also applied= $x2, x3 \geq 0$

This dual-seasonal formulation enables a comprehensive evaluation of how resource constraints affect optimal land-use strategies across differing climatic conditions.

3.1.2 Objective of linear programming optimization

The objective function of the linear programming optimization in this study is to identify the most profitable farming scenario. Profit is calculated as the product of total production and selling price. Table 3 presents the average total profit obtained from each type of aquaculture practiced by pond farmers in Kaliori, Rembang.

Table 3. Average farming profit under polyculture techniques

Commodity	Selling Price (IDR/Kg)	Production Cost (IDR/Kg)	Profit (IDR/Kg)	Total Production (Kg)	Total Profit (IDR)
Salt	740	400	327	147,550	48,308,060
Shrimp	56,888	37,638	319,249	63	1,630,400
Milkfish	20,638	14,835	5,803	281	1,212,914

Based on Table 3, the objective functions for profit optimization can be formulated for each season as follows.

Objective function for profit optimization in the dry season:

$$\text{Maximize } Z=3220,54x1+326,08x2+242,58x3 \quad (7)$$

Objective function for profit optimization in the rainy season:

$$\text{Maximize } Z=326,08x2+242,58x3 \quad (8)$$

3.2 Linear programming optimization results

The results of the linear programming optimization analysis are classified into two categories: first, profit optimization during the dry season; and second, profit optimization of farming activities during the rainy season, based on a case study of salt ponds managed by the Sari Makmur Farmers' Cooperative Group in Kaliori.

3.2.1 Optimization results of pond-based farming during the dry season

The research findings indicate that during the dry season, all available land, capital, and labor resources are fully allocated to salt farming activities. This result, as presented in Table 4, demonstrates that under full utilization of resources, salt farming yields a profit of IDR 47,864,060 (Z), suggesting that salt remains the most profitable commodity for pond utilization—even in the context of declining salt prices as noted by Mohandis [9]. In contrast, the suboptimal performance of vannamei shrimp and milkfish farming is primarily attributed to farmers' limited cultivation efforts during the dry season. Field observations revealed that most farmers merely stock shrimp and milkfish fingerlings without adhering to proper good aquaculture practices (GAP), such as regular pellet feeding or size-based fish sorting. As a result, these commodities do not contribute significantly to overall profitability.

Table 4. Statistical results of linear programming optimization during the dry season

Commodity	Salt (X1)	Milkfish (X2)	Shrimp (X3)
Land Allocation Decision (m²)	14,860	0	0
Profit per m² (IDR)	3,221	326	243
Total Profit (IDR)	47,864,060		

The dual value analysis in Table 5 reveals that each additional unit of labor has a shadow price of IDR 64,420, indicating that an increase of one unit of labor would raise total profit by IDR 64,420. This suggests that labor is a highly sensitive and crucial production factor within the optimization model. This result is supported by field observations showing that the majority of labor input originates from within the household, making it an implicit cost rather than a direct financial expenditure. Consequently, farmers with larger household labor availability can achieve higher profits due to increased internal labor contributions [10–11]. This insight provides a valuable basis for policymakers and farmers to design strategic interventions, such as enhancing labor efficiency or implementing training programs such as scheduling production activities more efficiently through the division of household labor, shift arrangements, or work rotation aimed at reducing labor requirements per square meter of land. Conversely, the shadow prices for capital and land are zero, indicating that additional units of these resources do not contribute directly to profit improvement under current conditions.

Table 5. Statistical results of salt pond farming resources during the dry season

Constraint	RHS (Limit)	Used	Slack (Remaining)	Dual Value (IDR)
Capital (IDR)	59,464,440	59,464,440	0	0
Land (m²)	15,000	14,860	140	0
Labor	743	743	0	64,420

The sensitivity (ranging) analysis reveals the tolerance limits for the profit coefficients of each decision variable, as presented in Table 6. Salt (X_1) remains the optimal choice if its profit per square meter does not fall below IDR 934.62. Conversely, milkfish (X_2) and vannamei shrimp (X_3) would only become optimal choices if their respective profit margins per m² increase beyond IDR 3,607.52 and IDR 837.46. The reduced costs for X_2 and X_3, amounting to IDR 3,281.52 and IDR 594.46 respectively, further indicate that substantial improvements in unit profitability are required for these commodities to become economically competitive. Therefore, enhancing production efficiency in milkfish and shrimp farming becomes essential if they are to be considered viable alternatives under resource-constrained conditions [12–13].

Table 6. Sensitivity analysis results of salt pond farming during the dry season

Variable	Reduced Cost (IDR)	Allowable Range for Profit Coefficient (IDR/m²)
X1 (Salt)	0	934.62 – ∞
X2 (Milkfish)	3,281.52	–∞ – 3,607.52
X3 (Shrimp)	594.46	–∞ – 837.46

Based on the results of the linear programming analysis, it can be concluded that salt production is the most optimal enterprise for maximizing profit under limited production resource conditions, particularly capital and labor. Salt demonstrates the highest efficiency in terms of profit per square meter, as well as relatively lower costs and labor requirements compared to milkfish and vannamei shrimp. Therefore, it is recommended that pond-based aquaculture prioritize salt production in resource allocation. To enhance the potential of polyculture systems, improvements in production efficiency for milkfish and shrimp are essential. This can be achieved through technological innovation in cultivation practices and input management, thereby enabling these commodities to become economically competitive under resource-constrained scenarios.

3.2.2 Optimization results of pond-based farming during the rainy season

The optimization results presented in Table 7 indicate that, under rainy season conditions, the optimal commodities for cultivation are milkfish and vannamei shrimp, with land allocations of 12,795.45 m² and 2,204.55 m², respectively, yielding a maximum profit of IDR 4,707,023. In this scenario, salt is excluded from the model due to its agronomic unsuitability during the rainy season, as salt production requires low precipitation. These findings highlight the inconsistency in farmers' cultivation practices of vannamei shrimp and milkfish, even during the rainy season. In-depth field observations reveal that farmers tend to stock fingerlings but do not consistently apply pellet feed. Instead, they typically apply urea fertilizer prior to cultivation to stimulate the growth of natural algae, which serves as the primary feed source for both shrimp and milkfish.

Table 7. Statistical results of linear programming optimization during the rainy season

Variable	Value
Shrimp (units)	12,795.45
Milkfish (units)	2,204.55
Profit (IDR)	4,707,023.00

The main constraint that most limits profit optimization is labor, which has the highest shadow value (dual value) of IDR 1,886.364, as shown in Table 8. This means that each additional unit of labor can increase profit by that amount. Land is also an active constraint, with a shadow value of IDR 220.364, indicating that land is a limited resource that directly contributes to increased profit when expanded. Conversely, capital (cost) is not an active constraint, with a slack of IDR 47,740,880, meaning it does not limit the model under rainy season conditions. In other words, capital is currently available in more than sufficient quantities compared to the actual optimal requirement. This condition suggests that if farmers consistently carry out the polyculture of *Litopenaeus vannamei* and *Chanos chanos* by increasing labor input for feed administration, it will certainly enhance the profitability of the polyculture system during the rainy season, rather than simply waiting for the dry season.

Table 8. Statistical results of salt pond farming resources during the rainy season

Constraint	Shadow Price (Dual Value)	Slack	RHS Range (Resource Bound)
Capital	0	47,740,880	11,716,360 – ∞
Land	220.364	0	13,267.86 – 61,916.67
Labor	1,886.364	0	180 – 840

Ranging analysis in Table 9 shows that the upper and lower bounds of the objective function coefficients for milkfish and shrimp are relatively wide (milkfish: 243–1134; shrimp: 69.857–326), indicating that the optimal solution is relatively stable with respect to changes in the estimated profit per unit area for both commodities. As long as the profit per square meter for milkfish remains within the range of 243 to 1134, and the profit for shrimp stays between 69.857 and 326, both commodities will continue to be selected in the optimal solution. Minor variations in profit per square meter, such as those resulting from market price fluctuations, will not affect farmers' decision-making. Therefore, diversifying pond cultivation with milkfish and shrimp during the rainy season is a rational strategy, with a focus on labor efficiency and optimal land utilization, as well as the potential for further profit improvement through the adoption of advanced aquaculture technologies [14–15].

Table 9. Statistical sensitivity results of salt pond farming during the dry season

Variable	Value	Reduced Cost	Objective Coefficient Range (Z)
Milkfish	12,795.45	0	243 – 1134
Shrimp	2,204.55	0	69.857 – 326

4 Conclusion and recommendation

The results of the linear programming analysis for aquaculture scenarios indicate that seasonal land allocation strategies represent an optimal approach under resource constraints such as cost, labor, and land area. During the dry season, salt emerges as the most profitable commodity per unit area and exhibits the highest labor efficiency compared to milkfish and shrimp, thus receiving full allocation in the optimal solution. In contrast, during the rainy season, when salt production is not feasible, a combination of milkfish and shrimp constitutes a rational cultivation strategy. Sensitivity (ranging) analysis demonstrates that the solution is relatively stable in response to variations in profit per unit of land and also highlights labor as the most critical limiting factor to further profit enhancement.

It is recommended that salt pond farmers adopt a seasonal commodity rotation system, focusing on salt production in the dry season and a milkfish–shrimp polyculture during the rainy season. To maximize overall profitability, improvements in labor utilization efficiency are necessary, for example, through the adoption of labor-saving aquaculture technologies or targeted skill development programs. Moreover, increasing the overall capacity of labor will directly contribute to profit growth, making investment in productive and efficient labor supply a strategically important step.

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Abstract

Salt production in Rembang Regency plays a strategic role in supporting coastal economic resilience; however, it still faces fluctuations in production and prices due to climate variability and limited resource efficiency. This study aims to determine the most optimal pond farming strategy to enhance the economic sustainability of salt farmers. A quantitative approach was applied using the linear programming method to analyze the combination of salt, vannamei shrimp, and milkfish under two seasonal conditions, dry and rainy seasons, considering constraints in land, capital, and labor. The results show that during the dry season, optimal resource allocation is achieved through salt production with a maximum profit of IDR 47,864,060, while during the rainy season, the optimal combination is obtained through milkfish, vannamei shrimp polyculture, generating a profit of IDR 4,707,023. Labor emerged as the most critical factor, with the highest shadow prices (IDR 64,420 and IDR 1,886.36), indicating that labor efficiency significantly affects profitability. The policy implication of this study emphasizes the importance of implementing season-based commodity rotation and enhancing labor efficiency through capacity-building programs as adaptive strategies to strengthen the economic resilience of coastal salt farmers.

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Salt production in Rembang Regency plays a strategic role in supporting coastal economic resilience; however, it still faces fluctuations in production and prices due to climate variability and limited resource efficiency. This study aims to determine the most optimal pond farming strategy to enhance the economic sustainability of salt farmers. A quantitative approach was applied using the linear programming method to analyze the combination of salt, vannamei shrimp, and milkfish under two seasonal conditions, dry and rainy seasons, considering constraints in land, capital, and labor. The results show that during the dry season, optimal resource allocation is achieved through salt production with a maximum profit of IDR 47,864,060, while during the rainy season, the optimal combination is obtained through milkfish, vannamei shrimp polyculture, generating a profit of IDR 4,707,023. Labor emerged as the most critical factor, with the highest shadow prices (IDR 64,420 and IDR 1,886.36), indicating that labor efficiency significantly affects profitability. The policy implication of this study emphasizes the importance of implementing season-based commodity rotation and enhancing labor efficiency through capacity-building programs as adaptive strategies to strengthen the economic resilience of coastal salt farmers. © The Authors, published by EDP Sciences, 2025.

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