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Profit Optimization of Vegetable Farming in Balunijuk Village Using Linear Programming

Optimalisasi Keuntungan Produksi Sayuran Di Desa Balunijuk Kabupaten Bangka Menggunakan *Linear Programming*

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ABSTRACT

Vegetable farming holds considerable potential, offering high economic returns for farmers and remaining a feasible agricultural pursuit. This study was designed to analyze profit optimization in vegetable farming through systematic production analysis. The research subjects were vegetable farmers in Balunijuk Village, Bangka Regency. Specifically, the objectives are to determine the optimal vegetable production combination, calculate the maximum achievable profit (Z) under resource constraints, and evaluate resource slack to compare optimal and actual production conditions. Profit optimization was examined using the simplex method of linear programming, enabling the identification of optimal resource allocation and the maximization of farmers' income. Primary data were collected from farmers in Balunijuk Village through structured interviews, covering one planting season. The dataset represents cross-sectional observations of land use, capital, labor, and production outputs. The findings indicate that Balunijuk Village, despite being a center of vegetable farming, has not yet achieved optimal production. Under optimal conditions, resource utilization changes significantly: labor and capital become binding constraints, while land exhibits surplus capacity. The optimization process reallocates land use by reducing water spinach cultivation and expanding mustard greens, thereby increasing profit by 42.97%.

Keywords: Linear Programming; Profit Optimization; Vegetable Farming

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ABSTRAK

Pertanian sayuran memiliki potensi yang cukup besar karena mampu memberikan keuntungan ekonomi yang tinggi bagi petani dan tetap layak untuk diusahakan. Penelitian ini dirancang untuk menganalisis secara sistematis optimalisasi keuntungan dalam pertanian sayuran melalui analisis produksi. Subjek penelitian adalah petani sayuran di Desa Balunijuk, Kabupaten Bangka. Secara khusus, tujuan penelitian ini adalah menentukan kombinasi produksi sayuran yang optimal, menghitung nilai keuntungan maksimum (Z) yang dapat dicapai dalam keterbatasan sumber daya, serta mengevaluasi slack sumber daya untuk membandingkan kondisi optimal dengan kondisi aktual. Optimalisasi keuntungan dianalisis menggunakan linear programming dengan model simpleks, sehingga memungkinkan identifikasi alokasi sumber daya yang optimal dan peningkatan pendapatan petani. Data primer dikumpulkan dari petani di Desa Balunijuk melalui wawancara terstruktur, mencakup satu musim tanam. Dataset yang digunakan berupa observasi cross-sectional mengenai penggunaan lahan, modal, tenaga kerja, dan hasil produksi. Temuan penelitian menunjukkan bahwa Desa Balunijuk, meskipun dikenal sebagai sentra pertanian sayuran, belum mencapai tingkat produksi optimal. Pada kondisi optimal, pemanfaatan sumber daya mengalami perubahan signifikan yaitu pada tenaga kerja dan modal yang menjadi kendala utama, sementara lahan menunjukkan kapasitas surplus. Proses optimalisasi dengan linear programming mengubah alokasi lahan dengan mengurangi budidaya kangkung dan memperluas budidaya sawi, sehingga keuntungan meningkat sebesar 42,97%.

Kata Kunci: *Linear Programming; Optimalisasi Keuntungan; Produksi Sayuran*

1. Introduction

Horticulture constitutes a crucial component of the agricultural sector, contributing significantly to food security, nutrition, and rural livelihoods. Vegetables, in particular, are essential sources of vitamins, minerals, and dietary fiber and are among the most consumed horticultural commodities in Indonesia. According to Statistics Indonesia (BPS, 2024), vegetable production remains among the top contributors to national horticultural output, with 18 strategic commodities recorded annually. Despite this, per capita vegetable consumption in Indonesia is still below the recommended dietary intake, highlighting the importance of strengthening vegetable production and distribution systems (Maulana & Sayaka, 2005; Arsanti & Perkasa, 2021). The growing demand for vegetables, driven by urbanization and rising middle-income households, underscores their dual role in improving nutritional quality and supporting economic growth. Balunijuk Village, located in Bangka Regency, is recognized as a central hub for vegetable farming, with most households relying on this sector as their primary source of income. Despite its status as a production center, farmers face several structural challenges: average landholdings remain small (approximately 0.25–0.5 hectares per farmer), access to formal capital is limited, labor costs are relatively high compared to local incomes, and market access is largely dependent on regional traders. These constraints reduce production efficiency and highlight the need for optimization strategies to maximize profitability under resource limitations (Agustira et al., Universitas Bangka Belitung, 2020).

For these farmers, the primary source of income comes from the production sector. However, they often face limitations in farming resources, such as small landholdings, limited capital for production inputs, and high labor costs. Despite these constraints, maximizing profit remains a top priority in their short-term goals. Therefore, optimizing the production of individual items and the combination of input use requires special attention (Lina, T. N., et al., 2020). Production management among farmers consistently aims to organize and plan the use of production factors to achieve a certain level of profit while minimizing costs. Hence, it is necessary to formulate a farming plan that combines various inputs under different resource constraints to maximize profits (Rachmatika, R.,2021). Farmers' objectives to maximize profits or minimize production costs can be achieved through optimal production planning.

Optimization is the activity of obtaining the best possible outcome under given conditions. It can be defined as the process of finding conditions that yield the minimum or maximum value of a function (Rachmatika, R.,2021). The calculation of the maximum profit can be performed using linear programming. This research was conducted as a framework to shift farmers' paradigms, supported by the economic aspect of promising agricultural income through an optimization analysis approach, particularly in vegetable farming. Secondly, since vegetable farming was selected as the research focus, the study also responds to farmers' needs for an analysis of their production policies.

Production analysis in horticulture has frequently employed linear programming to optimize resource allocation and maximize profits, with prior studies focusing on commodities such as citrus, cassava, and leafy vegetables in various regions of Indonesia (Sugianto, 2020; Lina et al., 2020; Utami et al., 2020). However, most of these studies have been conducted on relatively larger farming units or in areas with more developed agricultural infrastructure. Limited attention has been given to smallholder vegetable farmers in Bangka Belitung Province, despite their significant role in local food supply. Moreover, few studies explicitly integrate dual analysis to evaluate resource slack and binding constraints, which are critical for understanding efficiency and policy implications. Addressing this gap, the present study applies linear programming with both primal and dual analysis to examine optimal production combinations, maximum profit values (Z), and resource utilization among smallholder vegetable farmers in Balunijuk Village.

2. Research Methods

This study employed a quantitative research design with a case study approach focusing on smallholder vegetable farmers in Balunijuk Village, Bangka Regency. The unit of analysis was individual farming households engaged in vegetable production activities.

Primary data were collected directly from farmers using purposive sampling to capture variations in land size, cropping patterns, and resource availability among farming households. The sample size was determined based on the proportion of households actively cultivating vegetables in the study area. Secondary data were obtained from the Bangka Regency Agricultural Office and Statistics Indonesia (BPS) to support contextual analysis and model validation.

Data collection was conducted during one planting season in 2025 through structured interviews and field observations. The questionnaire captured key production variables, including land use (hectares), capital expenditure (IDR), labor input (person-days), and production output (kilograms). All data collection procedures were standardized to ensure consistency and replicability.

A linear programming model was developed to maximize farm profit. The objective function was specified as:

$$\text{Maximize } Z = \sum c_i x_i \quad (1)$$

where c_i represents the profit coefficient per crop and x_i denotes the decision variable, defined as the land area allocated to crop i.

The model was subject to constraints related to land availability ($\sum x_i \leq M_{land}$), capital ($\sum k_i x_i \leq M_{capital}$), and labor ($\sum l_i x_i \leq M_{labor}$), where k_i and l_i represent the capital and labor requirements per unit area of crop i, respectively.

The coefficients for profit, capital, and labor were derived from field data on average crop yields, market prices, input costs, and labor requirements per crop. The model assumes linear input–output relationships, resource divisibility, certainty about parameter values, and non-negativity of all decision variables.

The linear programming model was solved using the simplex method implemented in LINDO software (version X). Dual analysis was conducted to identify binding constraints and slack resources, while sensitivity analysis was performed to assess the robustness of the results to changes in key parameters, including ±10% variations in crop prices and ±20% adjustments in labor availability. Model validity was ensured by cross-checking estimated coefficients with secondary data from BPS and local agricultural reports.

3. Results and Discussion

The analysis in this study uses both qualitative and quantitative approaches to determine the optimal production level to maximize profit. The production optimization analysis is presented in a mathematical model using linear programming. Data processing was performed using Microsoft Excel and LINDO (Linear Interactive Discrete Optimizer).

The optimal vegetable production combination and the corresponding optimal profit are derived from primal analysis calculations. Primal analysis can be performed once the decision variables, objective function, and constraint functions are defined. Using the LINDO analytical tool, entering the decision variables, objective function, and constraints yields the results of the primal analysis. The output of the primal analysis provides the optimal quantity of each decision variable to be produced in order to maximize the objective function (Z), subject to available resource constraints.

3.1. Primal Analysis

In this study, primal analysis provides information on the combination of vegetable production levels that, when optimized by farmers, yields maximum profit given land productivity. Based on the analysis under optimal land-use conditions, it is possible to determine the appropriate vegetable production combination based on the productivity of each type of vegetable cultivated by farmers. The optimal land scenario serves as a reference for farmers in planning future land allocation to achieve optimal production. In contrast, the optimal vegetable production scenario offers insight into the potential output that could be achieved if farmers adhere to the optimal land-use requirements (Utami, R., et al., 2020).

The visual data presented below are primary data obtained from vegetable farmers in Balunijuk Village, reflecting the profit per kilogram of vegetable production under actual conditions. From this data, optimal production levels will be determined. The results of the optimization analysis reveal varying changes in the production quantity of each vegetable type, depending on the land productivity of each crop. The significant differences in production volume between actual and optimal conditions provide farmers with a clearer picture of the potential for increased production to reach optimal outcomes.

Table 1. Profit per Kilogram of Vegetable Production under Actual Conditions (IDR)

Vegetable	Production Cost (IDR/kg)	Selling Price (IDR/kg)	Profit (IDR/kg)
Spinach	2,000	6,000	4,000
Water spinach	2,500	6,000	3,500
Mustard greens	4,000	9,000	5,000

Source: Primary data, 2025

Based on the information in Table 1, mustard greens yield the highest profit per kilogram, although their production costs are higher than those of spinach and water spinach. The next step is to determine the optimal levels of vegetable production for farmers in Balunijuk Village using linear programming. The results indicate that the total production of the three types of vegetables during one planting season under actual conditions is 5.900 kg, whereas under optimal conditions it increases to 7.700 kg.

Although the linear programming results suggest allocating more land to mustard greens due to their highest profit per kilogram, this conclusion must be interpreted with caution. Vegetable prices are highly volatile across seasons and markets, and the model's deterministic use of constant prices oversimplifies real market dynamics. In practice, household farmers face risks such as post-harvest losses, fluctuating demand elasticity, and dependence on intermediaries, which may reduce the actual profitability of mustard greens. Therefore, while the linear programming model provides a mathematically optimal solution, economic rationality requires incorporating market risks and variability into production planning.

The increase in production volume is not due to an expansion of cultivated land, since the total land area actually decreased from 8.000 m² to 7.500 m² under optimal conditions. Rather, the gain results from a reallocation of land from lower-marginal-profit crops to higher-marginal-profit crops. Specifically, water spinach was eliminated, while the land allocated to spinach and mustard greens was expanded. This shift toward crops with higher profit margins explains the overall increase in production and profitability despite the reduction in total cultivated area. However, the increase in production must be accompanied by market expansion, as the potential for higher vegetable production requires broader market access to ensure that products can be sold and generate greater profit (Yusnaini, A. N., et al., 2019).

Table 2. Comparison of Actual and Optimal Production Land Area (m²)

Land Variable	Vegetable	Actual Area (m²)	Optimal Area (m²)	Change (m²)
L1	Spinach	2,500	3,000	+500
L2	Water spinach	2,500	0	−2,500
L3	Mustard greens	3,000	4,500	+1,500
Total	–	**8,000**	**7,500**	**−500**

Source: Primary data, 2025

Based on Table 2, there is a noticeable change in the combination of vegetable production between actual and optimal conditions. Under optimal conditions, the land area allocated for spinach increased by 500 m², and for mustard greens by 1.500 m². The largest production increase occurred in mustard greens, with an additional 2.500 kg produced. In contrast, there was a significant reduction in water spinach production, which was not cultivated under optimal conditions. This means that, under optimal conditions, not all vegetables necessarily experience an increase in production; they may even decrease or not be produced at all. This is due to the varying resource efficiency and profit potential of each crop. Consequently, vegetables with higher profit potential will be allocated a larger share of production under optimal conditions (Suryanto et al., 2019).

The elimination of water spinach in the optimal scenario is not solely due to its lower profit margin compared to spinach and mustard greens. When analyzed from the perspective of resource efficiency, water spinach requires relatively higher labor input per unit of profit and a less favorable capital-to-profit ratio. In other words, each additional square meter of water spinach requires more labor and capital than it generates in profit. Dual analysis further confirms that labor and capital are binding constraints, meaning crops with lower resource efficiency are excluded under optimal conditions. Spinach and mustard greens, by contrast, provide higher marginal profit per unit of resource, which explains their expanded land allocation. The shadow price analysis indicates that reallocating land to mustard greens yields the highest incremental return, while water spinach's shadow price approaches zero, justifying its elimination despite being profitable under actual conditions.

Table 3. Labor and Capital Efficiency per Commodity

Vegetable	Profit (IDR/kg)	Labor Requirement (Person-days/kg)	Profit per Man-day (IDR)	Capital Requirement (IDR/kg)	Profit per IDR of Capital
Spinach	4,000	0.08	50,000	2,000	2.00
Water spinach	3,500	0.12	29,167	2,500	1.40
Mustard greens	5,000	0.10	50,000	4,000	1.25

Source: Primary data, 2025

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The table of labor and capital efficiency per commodity highlights fundamental differences in resource utilization among vegetable types. Spinach and mustard greens both generate high profit per unit of labor, amounting to Rp50.000 per person-day, making them relatively efficient compared to water spinach, which yields only Rp29.167 per person-day. In terms of capital, spinach demonstrates the highest profit-to-capital ratio (2,0), followed by water spinach (1,4), while mustard greens record the lowest ratio (1,25) due to higher input costs. These findings explain why water spinach is eliminated in the optimal scenario: although it remains profitable, its efficiency in relation to labor and capital is considerably lower than that of spinach and mustard greens. Thus, the table illustrates that the optimal decision is not solely determined by profit per kilogram, but also by the efficiency with which scarce resources are utilized.

The following information explains that the available production land, while a constraint, is not a strict limitation. The varying degrees of land-area adjustments provide farmers with insights for making informed decisions about which vegetables to cultivate, given their limited resources. Production planning will therefore focus more on those vegetable types whose land use should be increased during the planting season in order to maximize profit. The land area allocated to each vegetable under optimal conditions is presented in Table 4.

Table 4. Vegetable Production Parameters under Actual and Optimal Conditions per Planting Season

Parameter	Actual	Optimal
Total Land Area (m²)	8,000	7,500
Total Fertilizer (kg)	225	280
Total Labor (Man-days)	525	600

Source: Primary data, 2025

Profit can be calculated by subtracting total production costs from total revenue. The resulting profit reflects the total earnings from vegetable production over one planting season. To determine the coefficient values in the objective function, it is necessary to calculate the profit per unit for each product (spinach, water spinach, mustard greens). The following table presents the actual and optimal profit values per planting season.

Table 5. Actual and Optimal Profit Levels per Planting Season

Production Scenario	Total Output (kg)	Total Land Usage (m²)	Profit (IDR)
Actual	5,900	8,000	20,000,000
Optimal	7,700	7,500	28,594,000
Profit increase	–	–	**8,594,000**
Percentage increase (%)	–	–	**42.97**

Source: Primary data, 2025

The analysis indicates a difference in profit levels between actual and optimal conditions. Under actual conditions, the total vegetable production amounted to 5.900 kg with a total profit of Rp 20.000.000. In contrast, under optimal conditions, total production increased to 7.700 kg with a total profit of Rp 28.594.000. This reflects a profit increase of Rp 8.594.000 under optimal conditions, with a percentage change of 42.97%.

The reported 42.97% increase in profit represents a theoretical maximum derived from the linear programming model under deterministic price and resource assumptions. In practice, this figure should be interpreted with caution, as it does not account for production risks, additional working capital requirements, or increased dependence on daily labor. Therefore, while the linear programming model provides valuable insights into potential efficiency gains, the results must be contextualized within the realities of household farming. Without such boundaries, the conclusion risks being perceived as an overclaim in policy terms. A more balanced interpretation is that the optimal allocation highlights possible directions for resource reallocation, but actual outcomes will depend on market volatility, labor availability, and capital constraints.

3.2. Sensitivity Analysis

Sensitivity analysis is used to examine how the optimization outcome (optimal profit) changes as key parameters, such as the selling price, input costs, and labor requirements, are varied. The purpose is to ensure that the model results are not only mathematically valid but also realistic in addressing field-level uncertainties.

Table 6. Profit Comparison and Sensitivity Analysis

Scenario	Profit (IDR)	Change (%)	Notes
Actual	20,000,000	–	Baseline production pattern
Optimal (Deterministic)	28,594,000	+42.97	Theoretical maximum profit
Optimal (Price −10%)	25,734,000	+28.67	Reflects market volatility
Optimal (Price +10%)	31,454,000	+57.27	Reflects favorable market conditions
Optimal (Cost −10%)	29,994,000	+49.97	Lower input costs
Optimal (Cost +10%)	27,194,000	+35.97	Higher input costs
Optimal (Labor −10%)	29,494,000	+47.47	Reduced labor requirement
Optimal (Labor +10%)	27,694,000	+38.47	Increased labor dependency

Source: Linear programming simulation and sensitivity analysis, 2025

The 42,97% increase in profit should be interpreted as a theoretical benchmark rather than a guaranteed outcome. Sensitivity analysis reveals that profit gains vary substantially depending on price volatility, input costs, and labor requirements. For instance, a 10% decline in selling prices reduces the profit increase to 28,67%, while higher input costs or labor dependency also erode margins. These results highlight that optimal allocation depends on risk management and resource availability. Therefore, policy implications must emphasize support for farmers in mitigating market volatility, securing working capital, and managing labor constraints, rather than presenting the linear programming outcome as an absolute target.

3.3. Dual Analysis

Dual analysis provides insights into the evaluation of resources used within a linear programming model, as indicated by slack or surplus values. These values are used to assess the extent of resource utilization that leads to the best or optimal solution. A slack/surplus value of zero signifies that the resource is constrained and classified as an active resource. In this study, the dual price associated with a constrained resource indicates that an increase of 1 unit in its availability will raise the objective function value by the amount of its dual price. Conversely, resources with a dual price of zero are considered non-binding or excessive constraints, meaning that any increase or decrease in their availability will not affect the objective function.

Table 7. Dual Price Analysis of Resource Utilization

Constraint	Slack/Surplus	Dual Price (IDR)
Land constraint (m²)	1,125	0
Capital constraint (IDR)	0	5,070
Labor constraint (Man-days)	0	17,721

Source: Secondary data, 2025

Table 7 shows that, according to the dual price analysis, the binding resource constraints are labor and capital. Mathematically, an additional unit of labor, measured in workdays (Man-Days), would increase profit by Rp 17.721, while an additional unit of capital (Rp) would increase profit by Rp 5,07. These shadow prices indicate the marginal contribution of each resource within the optimization model, suggesting that labor is the most critical factor, followed by capital. However, it is important to note that shadow prices represent theoretical marginal values rather than automatic social recommendations. Their practical interpretation requires consideration of whether labor is socially available, whether wages would rise with increased demand, and whether the labor force consists of family members or hired daily workers. Without addressing these socio-economic dimensions, the interpretation of dual prices risks becoming purely technocratic and ahistorical. Therefore, while the LP model highlights labor as the most influential constraint, policy and practical decisions must integrate social availability, wage dynamics, and labor composition to yield realistic, context-sensitive conclusions.

In addition, the land resource constraint shows a slack/surplus value of 1.125 with a dual price of zero. This indicates that 1.125 m² of land remains unused under the optimal allocation, classifying land as a non-binding constraint. In mathematical terms, any increase or decrease in land availability does not affect the value of the objective function. However, the interpretation that farmers should 'reduce land usage' is problematic, since land is not a flexible variable in the short term and cannot simply be abandoned without alternative use. A more appropriate recommendation is to utilize the surplus land through strategies such as diversifying into non-modeled commodities, implementing crop rotation, or adopting intercropping practices. These alternatives ensure that excess land contributes to production resilience and sustainability, rather than being treated as redundant.

4. Conclusion

Balunijuk Village is recognized as a center for vegetable farming; however, current production has not yet reached its optimal level. Based on primary data, the existing cropping pattern consists of three vegetable types, yielding a total output of 5,900 kg and utilizing 8,000 m² of land. Under the optimal model conditions, the cropping pattern shifts to two vegetable types, resulting in an increased production of 7,700 kg while land use is reduced to 7,500 m², leaving a slack of 500 m². In the optimal solution, capital and labor resources are fully utilized, whereas land is identified as a non-binding constraint. Overall, the model indicates a theoretical profit increase of 42.97% compared to actual conditions.

It is important to emphasize that these results are derived from a mathematical optimization model and are based on assumptions of constant prices, linear relationships, and instantaneous reallocability of land and other inputs. Consequently, the findings should not be interpreted as direct operational recommendations without first considering critical prerequisites, including market absorption capacity, access to working capital, and labor availability.

Further research is required to validate the model through a pilot implementation at the farm level, extend the sensitivity analysis to better capture production and market risks, and conduct market assessments to ensure the proposed optimal allocation is both feasible and socially relevant.

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