

# Cultivation Planning for Secondary Plants on Smallholding Oil Palm Plantations Using Linear Programming

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**Abstract**—This study represents research on the determination of appropriate secondary plants at smallholding oil palm plantations in Langkat Regency, North Sumatra, Indonesia. The selection of this research topic is motivated by the fact that land use has changed in Langkat, from predominantly paddies to oil palm plantations. This has caused job loss in the agriculture sector. On oil palm plantations, however, empty spaces appear at the beginning of the planting period due to the nature of plantation work and the oil palm plant. This space can be used for secondary plants (such as horticulture plants), which have competitive prices and high productivity. Here, we use a linear programming model to define the problem of selecting horticulture plants to cultivate in smallholding oil palm plantations. The model is assessed using MS Excel Solver, and the results show that cayenne pepper (*cabai rawit*) and long bean (*kacang panjang*) are the optimum secondary plants to plant.

**Keywords**—cultivation planning, linear programming, land diversification, oil palm plantation

## I. INTRODUCTION

North Sumatra is one of provinces in Indonesia with high number poor residents [1], and Langkat Regency has the second-highest poverty rate in the province [2]. In Langkat, the largest occupations are agriculture, plantation work, forestry, and similar cultivation enterprises. These sectors are also the largest contributors to personal incomes in the community. In an interview, a representative of the Department of Agriculture and Food Security in Langkat Regency reported that people working in agriculture and related sectors generally support themselves on land that is not their own or cultivate leased land. In addition, the community also cultivates paddies with rain-fed systems, indicating high income uncertainty due to the difficulty of predicting yields from rain-fed lowland systems. This causes increasing changes in land use from paddy to plantations.

According to the Langkat Regional Medium-Term Development Plan (RPJMD) 2015–2019, the conversion rate of paddies to plantations (oil palm, rubber, and rambutan, among others) was 11.44% per year in 1998–2007. In an interview with a representative of the Langkat Regency Agriculture Office, it was stated that changes in land use result in the decrease of paddies of 2.3% per year.

Oil palm plantations take up the largest area planting area and have the greatest productivity of all agricultural production in Langkat Regency [2]. Some seed producers [3] recommend that oil palms be planted with a 9.2 m × 9.2 m area around them. Thus, this recommendation calls for a considerable amount of vacant land between oil palm trees, which can be used to cultivate secondary plants and increase income levels.

Horticultural crops are a good alternative for plantation farmers because they can be grown together with plantation crops such as oil palms (Department of Agriculture and Food Security of Langkat Regency). In addition, the prices of certain horticultural crops have risen a considerable amount [4]. This suggests that horticulture cultivation is a real source of income for the community. Analysis is needed to determine what horticulture crops should be planted as the secondary plants in oil palm plantations so that the greatest profit is generated for the surrounding community.

The objective of this study is to determine the optimal allocation of empty space in smallholding oil palm plantation in Langkat for horticulture crops, using a linear programming model. This paper provides recommendations for what farmers in Langkat Regency should plant to maximize profit. The remainder of the paper is arranged as follows. The relevant literature is given in Section 2, and the research methods are discussed in Section 3. The results and discussion are in Section 4, and the conclusions are found in Section 5.

## II. LITERATURE REVIEW

Agricultural produce constitutes a major part of the world economy and is the raw material of many industries products play an important role in the world economy [5]. In particular, they supply diverse consumer demands, including food and biofuels [3]. The productivity of the agricultural sector is dependent on several factors, including seasonality, perishability, security, and traceability along the supply [6, 7]. The agricultural supply chain includes activities of cultivating, harvesting, handling/pre-processing, processing, storing, and transporting/distributing [8]. Cultivation planning refers to the determination of what area will be planted with what crops each year [9] and the distribution of spaces within planting areas [10]. Plant selection and land diversification are

significant tasks that must be considered carefully in cultivation planning.

Basuki et al. [11] show that the foremost basis for the selection of commodities is the existing commodities already being cultivated, their role in the farm household's economy, the market potential, the possibility of further processing, the utilization of the waste generated, and mutually beneficial integration among different cultivated commodities.

Concerning diversification, Wasito [12] states that diversification is achieved in several ways, such as intercropping, diversification on different lands during a single season, and inter-seasonal crop rotation. The success of agricultural-business diversification programs is dependent upon various factors, such as the agricultural environment, the availability of technology, market structure and performance, and government policy [13].

Wasito [12] also states that food diversification involving land use in oil palm plantations plays a very important role. However, diversification has not yet received full support from the government or the plantation sector because diversification is considered as a threat to the potential ability to export palm oil. The types of intercropping plants depend on the available resources and market demand. Factors affecting the cultivation of intercrops among oil palm include: (1) the growing environment of oil palm crops, such as climates and soils, (2) characteristics of oil palm crops, such as species, rooting, stems, and canopy, and (3) characteristics of intercropping plants [14]. Wasito [12] also finds that the selection of intercropping crops to be cultivated between oil palm plants should be based on: (1) the characteristics of the oil palm and the intercropping crops, (2) climate suitability and dispersion of oil palm areas, (3) microclimate conditions prevailing under the palm oil, especially solar radiation, temperature, and humidity, and (4) the climate requirements of the intercropping plant, including solar radiation, rainfall, altitude, temperature, and humidity.

According to Glen [15], the problem in planning plant production is determining which crops to plant, the planting area per plant, and the resources used. Land utilization through planting planning has been discussed in several previous works. According to Dury et al. [16], the plant-cultivation model has been developed by agronomists to investigate crop allocation and resource utilization. Annual crop rotation has been studied by Abdulkadri and Ajibefun [17], Leroy and Jacquin [18], Garcia et al. [19], and other researchers.

### III. RESEARCH METHODS

This study investigates the types of horticulture most suitable for being planted and to determine the land allocations for the selected horticultural crops within oil palm plantations to maximize profit for farmers. According to a representative of the Department of Agriculture and Food Security of Langkat Regency, the use of empty space in oil palm plantation during the early planting period (which can be as long as 2 years from the first planting) for secondary plants does not threaten oil palm plants themselves and may increase farmers' income. The identification of suitable types of horticulture is conducted through an analysis of plant productivity, sale price, and whether horticulture plants can be cultivated in the given area. The model used to determine land allocation for horticulture plants is taken and modified from

that of Filippi et al. [20], a crop optimization model that uses a mixed-integer linear program. This model is used for smallholding oil palm plantation in Langkat Regency to increase farmers' income, and sensitivity analysis is conducted to take changes that may happen in the price of certain crops into account.

The primary data used are collected in interviews with farmers and representatives of local government in Langkat Regency, and the secondary data are taken from Indonesia's Central Agency of Statistics (BPS). Modifications are made to adjust the model to match the conditions prevailing in Langkat. The modifications are as follows: (1) elimination of variables related to transport trucks because horticulture farming in Langkat regency is conducted by hand; (2) removal of binary decision-making variables because they are not relevant to the problem; (3) removal of the parameters associated with the relationship between equipment used and the planting process for the same reason as (1); and (4) replacing processing-time parameters with multiplier parameters. The modified model is then solved using MS Excel Solver.

The main assumptions for the model are the following: (1) the farmers know the area that is available for planting in a given period of time; (2) the planting area has a flat topography overall; (3) the distance between oil palms is 9 m, although only 2 m of the aisle width can be used for planting; (4) the planting area has oil palms that are under 2 years old; (5) the time horizon is six months; (6) the costs for each activity are the sum of wages of workers, equipment leases, and purchases for planting needs; and (7) accurate sale prices for each crop can be obtained through interviews. Notation of indices and parameters is presented in Table I.

TABLE I. INDICES AND PARAMETERS

Index	Description
$m$	Number of plant species
$i$	Types of crops cultivated
$T_i$	Harvest time for plant $i$
<b>Parameter</b>	
$\bar{r}_i$	Estimated revenue (in Rp) from selling product $i$ from one ha of planting area
$c_i$	Variable costs for crop $i$
$FC_i$	Fixed costs for crops $i$
$R_{i,T_i}$	Yield/productivity of each crop during period $T_i$ .
$d_{i,T_i}$	Productivity of crop $i$ at the $T_i$ of plant harvest
$P_{i,T_i}$	The number of crops $i$ planted in period $T_i$
$B$	Budget parameters or amount of funds available during planting timeframe.
$H$	Available planting area (ha)
<b>Decision Variable</b>	
$A_i$	Planting area for plant $i$ (ha)

The model formulations are below:

- Objective function:

$$Z = \text{Max} \left[ \sum_{i=1}^m R_{i,T_i} \bar{r}_i A_i - (\sum_{i=1}^m c_i A_i + FC) \right] \quad (1)$$

- Constraints:

$$\sum_{i=1}^m A_i \leq H \quad (2)$$

$$\sum_{i=1}^m c_i A_i + FC \leq B \quad (3)$$

$$R_{iT_i} \leq d_{i,T_i} P_{i,T_i} \text{ for all } i \quad (4)$$

$$A_i \geq 0 \quad (5)$$

The objective function in this model is to maximize the amount of net profit for all types of plants over a period of time. The net profit is calculated from the difference between the estimated revenue and the costs required to grow the crop. The cost component is divided into variable and fixed costs (denoted by  $FC$ ). The constraint (2) limits the area that can be grown to no more than the total available area. The constraint (3) states that the amount of funds spent on growing a particular crop should be less or equal to the value of budget ( $B$ ), which is set at the beginning of the planting period. Budget  $B$  will cover variable and fixed costs. Constraint (4) limits the production of each plant to not exceed its maximum production capacity at any time (productivity per plant times the number of plants that can be cultivated in a unit area in the planning period). The constraint (5) is a non-negative restriction for decision-making variables.

#### IV. RESULTS AND DISCUSSIONS

Our observations, of planting area for secondary plants indicate what is presented in Table II.

Interviews with farmers show that crop selection is currently conducted with reference to the farmer's own preferences. We first calculate the total profit earned by farmers using the current planting policy. Cayenne pepper and watermelon were chosen as the horticulture plants to be cultivated in the available area, with a land allocation ratio of 1:1 (see Table III).

We then select the type of horticulture plants for consideration in the optimization model based on their productivity, sales price, and suitability for cultivation in Langkat Regency. The plants considered in selection process are determined using data from the BPS in Langkat Regency, which include information on what horticulture plants are grown in Langkat. We rank these plants, with higher ranks assigned to higher productivity or price. Suitability is

determined from interview results with representatives of farmers and local government. In the model, we only consider suitable crops (see Table IV).

The results of Table IV guide the selection of plants to be included in the model, namely, are cayenne pepper, watermelon, corn, tomato, cucumber, and long bean. Then, the optimization model is solved, and the results show that cayenne pepper and long bean are chosen as they result in the greatest profit (see Table V).

The results show that the total profit generated by the model solution is Rp 162,984,628.23 with land allocations of 0.824 ha for cayenne pepper and 0.576 ha for long bean. The increase in profit over the current farmer's planting policy (0.7 ha for cayenne pepper and 0.7 ha for watermelon, with the profit of Rp 135,493,189.77), is about Rp 27.4 M.

We also conduct sensitivity analysis to determine the impact of price changes on results of optimization. Sensitivity analysis is conducted by altering the prices of certain plants that have historically had fluctuating prices, i.e., cayenne pepper, watermelon, and long bean. The sale price of the three crops are reduced by 25% and 50% and then increased by 25% and 50%. The prices used in the sensitivity analysis can be seen in Table VI

The results of sensitivity analysis for cayenne pepper, watermelon, and long bean prices can be seen in Tables VII, VIII, and IX, respectively.

TABLE II. AVAILABLE AREA FOR SECONDARY PLANTS

Aisle length (m)	Aisle width (m)	Total aisle	Total planting area (m <sup>2</sup> )
700	2	10	14,000

TABLE III. AVAILABLE AREA FOR SECONDARY PLANTS

Plants	Cultivation area (ha)	Profit (Rp)
Cayenne pepper	0.7	83,251,840.00
Watermelon	0.7	52,241,349.77
Total	1.4	135,493,189.77

TABLE IV. PLANTS SELECTION

No	Plants	Productivity ranking	Price ranking	Suitability	Total
1	Cayenne pepper	12	2	Yes	14
2	Watermelon	2	3	Yes	5
3	Corn	9	6	Yes	15
4	Cassava	1	5	No	-
5	Tomato	10	1	Yes	11
6	Cucumber	7	5	Yes	12
7	Sweet potato	6	6	No	-
8	Mung bean	13	5	No	-
9	Spinach	3	5	No	-
10	Long bean	11	4	Yes	15
11	Chinese cabbage	5	6	No	-
12	Eggplant	8	4	No	-
13	Water spinach	4	7	No	-

TABLE V. MODEL SOLUTIONS

Plants	Cultivation area (ha)	Profit (Rp)
Cayenne pepper	0.824	97,048,807.60
Watermelon	0	
Corn	0	
Cucumber	0	
Long bean	0.576	65,935,820.63
Tomato	0	
Total	1.400	162,984,628.23

TABLE VI. PRICES FOR SENSITIVITY ANALYSIS

Price reduction/ Increase	Cayenne pepper (Rp)	Watermelon (Rp)	Long bean (Rp)
-50%	3,500	1,500	1,000
-25%	5,250	2,250	1,500
0	7,000	3,000	2,000
25%	8,750	3,750	2,500
50%	10,500	4,500	3,000

TABLE VII. SENSITIVITY ANALYSIS FOR CAYENNE PEPPER PRICES

Price reduction/ Increase	Price of cayenne pepper (Rp)	Plants	Cultivation Area (ha)	Profit
-50%	3,500	Long bean	1.4	151,671,240.00
-25%	5,250	Long bean	1.4	151,671,240.00
0	7,000	Cayenne pepper	0.824	97,048,807.60
	8,750	Long bean	0.576	65,935,820.63
25%	10,500	Cayenne pepper	1.4	201,554,360.00
50%	3,500	Cayenne pepper	1.4	245,654,360.00

TABLE VIII. SENSITIVITY ANALYSIS FOR WATERMELON PRICES

Price reduction/ Increase	Price of watermelon (Rp)	Plants	Cultivation Area (ha)	Profit
-50%	1,500	Cayenne pepper	0.823936	97,048,807.60
		Long bean	0.576064	65,935,820.63
-25%	2,250	Cayenne pepper	0.823936	97,048,807.60
		Long bean	0.576064	65,935,820.63
0	3,000	Cayenne pepper	0.823936	97,048,807.60
		Long bean	0.576064	65,935,820.63
25%	3,750	Cayenne pepper	0.823936	97,048,807.60
		Long bean	0.576064	65,935,820.63
50%	4,500	Cayenne pepper	0.636109	76,028,533.26
		Watermelon	0.421226	49,120,747.85

TABLE IX. SENSITIVITY ANALYSIS FOR LONG BEAN PRICE

Price reduction/ increase	Price of long bean (Rp)	Plants	Cultivation area (ha)	Profit
-50%	1,000	Cayenne pepper	1.4	157,454,360.00
-25%	1,875	Cayenne pepper	1.4	157,454,360.00
0	2,000	Cayenne pepper	0.824	97,048,807.60
25%	10,500	Long bean	0.576	65,935,820.63
25%	3,125	Long bean	1.4	193,671,240.00

The above sensitivity analysis indicates that the results of optimization do not change as the price of cayenne pepper changes. The results show that cayenne pepper and long bean are still selected. Decreases in the price of cayenne pepper results in the entire planting area being allocated to long beans, while an increase in cayenne pepper prices results in the entire area being allocated to cayenne pepper.

The results of the sensitivity analysis of watermelon prices show that the plants are changed only when watermelon prices increase by 50% (to Rp 4,500). This indicates that the model is less sensitive to changes in watermelon prices.

The results of the sensitivity analysis of long bean prices indicate that changes in it do not change the selected plants to change. Decreases in long bean prices result in total land allocation for cayenne pepper, while an increase in long bean prices results in total land allocation to long beans. Thus, it can be concluded that the model is not sensitive to price changes and that the optimization model can be used by farmers to support decision making in their land utilization.

## V. CONCLUSIONS AND RECOMMENDATIONS

The paper presents an optimization model for determining optimal land allocation for secondary plants in smallholding



oil palm plantations in Langkat Regency to increase farmers' income levels and reduce poverty.

The objective function of the model is to maximize profit for farmers. Land allocation is limited by available budgets and planting areas. In addition, the allocation is also limited by the number of plants that can be planted in each unit area because each plant requires different care procedures and has a different planting period. Each plant's yield is adjusted within a 6-month timeframe.

Interviews with farmers show that crop selection is conducted on the basis of each farmer's preferences. This indicates that the policy is less than optimal because farmers do not take the costs and yields of other crops into account. Nor do they account for planting timeframes of each plant. The current planting policy is to cultivate cayenne pepper and watermelon with a land ratio of 1:1 for the two plants.

The model is implemented in smallholding oil palm plantations in Langkat Regency with available planting area for horticulture of 1.4 ha. Interview results and secondary data indicate that horticulture crops, namely cayenne pepper, watermelon, corn, long bean, cucumber, and tomato should be considered in the model. Solutions to the proposed model find that cayenne pepper and long bean should be cultivated in the available area to maximize profit, with an allocation of 0.82 ha for cayenne pepper and 0.58 ha for long bean. The resulting profit is about 20.2% higher than the current planting policy for the farmers.

Sensitivity analyses are conducted by changing prices for some crops (which have fluctuating prices) to take uncertainty in crop prices into account. The results show that the model is relatively robust and not sensitive to changes in cayenne pepper, watermelon, and long bean prices. Thus, the model can be used by farmers to help them obtain optimal land allocation for secondary plants in the oil palm plantation.

This study has limitations. First, the proposed optimization model does not consider any obstacles that may occur in the reality of the management of a plantation, such weather events, weather trends, and pest attacks. Furthermore, in this study, prices are estimated based on interviews with farmers, but they may not accurately reflect actual sales prices. Last, the planting process is considered to be manually performed by farmers (as is true under actual conditions). However, farming equipment can be used to increase crop productivity, which may affect some model parameters.

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