CLSU International Journal of Science and Technology
www.clsu-ijst.org
ISSN 2507 -9638 (online)
The CLSU International Journal of Science and Technology was previously published as CLSU Scientific Journal since 1965.

Profit Optimization Model of Coconut-Cacao Intercrop Farming in the Philippines Using Linear Programming

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Submitted: June 10, 2022. Accepted: February 15, 2023. Published Online: March 31, 2023.

Abstract

Linear programming (LP) has various applications relevant to agriculture aspects such as optimization and simulation. Profit from agricultural production should be maximized due to the limited resources such as certain land areas available for planting, budget for production, and quantity of farm outputs. Intercropping is one way of utilizing land by planting a combination of crops that addresses productivity and environmental concerns. Intercrop farming of coconut and cacao in the Philippines initiates better economic benefits for the farmers. Since profit drives the venture's survival, this study determined the maximum profit along with the optimum number of coconut and cacao trees to be planted by formulating a linear programming model for establishing cost parameters and Microsoft Excel Software for data simulation. Using the data from the Department of Agriculture and up-to-date parameter costs, one hectare intercropping of 135 coconut trees and 500 cacao trees generates an annual average profit of Php 61,940.00. The comparison of profits from monocropping and the optimum solution was performed yielding more than Php 30,000.00 higher profit for intercropping. Lastly, the effect of the change in input cost to optimum profit has been evaluated concluding with a decrease in profit for a unit increase of seedlings and an increase in profit for fertilizer cost not exceeding Php 10,000.00. The developed LP model was designed for the demonstration of determining the most benefits from a 1-hectare intercrop land and can be utilized by doing interpolation to the land size and subjecting to PIC for the values of the inputs.

Keywords: Linear programming, Profit optimization, Intercropping, Coconut-cacao production.

Introduction

Intercropping stands as a pivotal agricultural practice in the Philippines, serving to enhance plant diversity (Zhang et al., 2021). and helps maximize productivity given a limited area (Enarlan & Bulayog, 2020). Characterized by the simultaneous cultivation of two or more crops within a single field during a growing season, contributes significantly to ecological balance and resource utilization. It brings forth benefits such as improved quantity and quality of agricultural products, along with a reduction in damages caused by pests, diseases, and weeds (Mousavi & Eskandari, 2011). This farming method anticipates the risk of price and production uncertainty while optimizing farmers' revenue (Adam et al., 2017).

The Philippine Coconut Authority (PCA) promotes the intercropping method to augment farmers' income, by earning extra income and addressing environmental problems concerning coconut production (Plucknett, 2019). Intercrops shall be shade-loving or shade-tolerant and selected based on site suitability, availability of the market, and other value-adding activities (Bureau of Agriculture and Fisheries Standards, 2008). Davao Region, the top coconut producer, contributed 14.4% to the country's total coconut production for the year 2018 making the country the second-largest producer of coconut products in the world, next to Indonesia (Tacio, 2019c). The 3.565 million hectares of the country's total agricultural land is currently a coconut plantation and the Department of Agriculture urges the farmers to utilize the land by establishing intercrops such as coffee and cacao which are both getting known to the market (Dar, 2016).

Coconut products contributed 43% of the agro-based revenue of the country in 2017 with a total of US$1.8 billion in export value with copra or dried coconut meat as the main product of coconut (Tacio, 2019a). Cacao, on the other hand, has many uses and by-products from the shell, pulp, and beans having the highest antioxidant value of all the natural foods in the world. Also, the Davao Region remained the major producer of cacao with 2.49 thousand metric tons output or 81% share of the country's total cacao production (Mapa, 2021). The economic status had 90% small farm holdings (almost 30,000 farmers engaged), offering more jobs, livelihood, and opportunities, and promoting countryside development reaching over 64,000 hectares of planted area. In 2018, the Philippine government distributed 70 million cacao seedlings to support the growing interest in cacao farming and to upscale the contribution to the global market (Reyes-Lao, 2018). The cacao industry significantly contributes to poverty alleviation since the crop is suitable for intercropping, and year-round harvest. The investment requirement had low start-up costs and a bigger hit is that the cacao has no product substitute and is marked 3rd as the most traded commodity that requires a small monetary investment or capital with early return on investments and generates high profitability of the products (Reyes-Lao, 2018).

The coconut and cacao industry is a vital sector, and predicting the best combination for intercropping using a linear programming model can benefit farmers involved in intercropping practices. A properly arranged high-density cacao under widely spaced coconuts is a profitable farming system (Supanggih & Widodo, 2013). Profit is generated when all costs are already deducted from gross income, which dictates the ability of the venture to withstand adverse conditions. The ideal units of coconut and cacao for a certain area size are not yet clear and identified in the Philippines, thus the utilization of a linear programming model determines the optimal combination that maximizes the income from intercropping activities (Supanggih & Widodo , 2013). Consequently, the objective of the project is to formulate a model that projects the optimum profit from coconut-cacao intercropping practice in the Philippines considering the restrictions on land area, production cost, and the quantity of both coconut and cacao trees. The study aims to demonstrate profit calculation from coconut-cacao intercropping in consideration of whether the farmer already owned a farm or not. The study also includes the comparative analysis of profits derived from monocropping and intercropping, employing linear programming. The paper intends to initiate insights into the economics of intercropping practices and inform strategic decision-making for farmers and stakeholders.

Related Works

The study conducted by Lirag (2021) concluded that engaging in cacao raising and processing is highly feasible with the recorded return on investment of 77.98% and 160%, respectively. A profitability and efficiency ratios of 2.33 and 3.33 were also obtained indicating that cocoa production is profitable and efficient. The lack of research and development programs for cultivating and processing the product and inadequate technological training and information on value-adding and manufacturing development were a few reasons for the insufficient supply of cacao in line with evident heightened demand for chocolate. The recommendation of proper investment in production, processing, and marketing systems plays a significant role in establishing a more dynamic, sustainable, and competitive cacao industry (Lirag, 2021) wherein the current study could be a tool to relay the profit benefits of the cacao growers. The Philippines is among the countries in Asia seen to be a competitive advantage in cacao production given its strategic location and climatic conditions. The two (2) million hectares of coconut farms are ideal for cacao intercropping to supplement the industry's competitive advantage since each farmer has an average land area of 1-3 hectares (Lirag, 2021). One of the problems addressed by intercropping relays to control pest scattering, McBautista (2021) stated that plantation due to pest and disease infestation greatly affects the cacao produced. Also, profit is the primary concern for the farmers followed by livelihood and job creation thus this proposed study aims to display the profit values by considering the data by Philippine Coconut Authority (2007) which has been subjected to an inflation calculator for updated values and to come up with the optimal quantity combination of coconut and cacao trees that yields maximum profit for a given area. The Philippine inflation calculator is a reliable online tool that computes the effects of inflation on prices in the Philippines where consumer price index data are provided by the Philippines Statistics Authority, (2022).

The Philippine agencies established a roadmap for coconut production and cacao production to strengthen and empower the economy with the advantage of an intercropping method (PinoyEntre, 2016), in line with this, the study shows the ideal quantity combination of trees to be planted. Correspondingly, the in-effect market demand cannot deny the growing attraction of farmers to engage in post-harvest activities (Reyes-Lao, 2018), therefore the use of this study helps establish a strong foundation for the industry to benefit the economy in the long run. The report by Mendoza et al. (2018) states that coconut with intercrops such as banana, mangosteen, coffee, and cacao are ideal for farmers to secure growth in the value-added chain of the products since owning 5.0 ha is still not a substantial area if income will be obtained from coconut alone. In addition, most of the coconut farmers own less than 3 ha farms, and the majority of them have no access to appropriate agro-technologies to improve their coconut production (Mendoza et al., 2018).

The standard linear programming (LP) model, also known as linear optimization, is a mathematical optimization technique used to determine the optimal combination of resources to achieve a specific objective, subject to constraints (Chungchunlam, 2021). The LP had various application and use, the same model was utilized by (Malvar, 2018) in generating the maximum possible profit for rice production in Mabitac Laguna, Philippines, and concluded that a unit change in irrigation used per kilogram of seed inputs, cost of fuel and oil give an increase (or decrease) in the optimal solution. As performed effectively in rice production, the basis for the development of a profit optimization model for coconut-cacao production used also an LP model since coconut and cacao were, along with rice and corn, the most traded commodities in the country (Tacio, 2019b). Lastly, farmers used the published brochure from Bhatia and Bhat (2020), which serves as a guideline in the plant spacing for monocropping (cacao) and intercropping (coconut and cacao) while this study objects to show the profit benefits of the farmers whenever the planting method propose from Bhatia and Bhat (2020) was employed.

Some studies have applied linear programming to optimize intercropping for small-scale farmers such as identifying the optimal land use options for different vegetable mixes in Leyte, Philippines which resulted in improved profits across various crop combinations. As suggested from the linear programming analysis, farmers can achieve maximum profit (up to Php 211,887 per 608.97 m2) using the optimal mix of crops, allocating about 551.28m^2 for eggplant production while allocating 57.69m^2 in producing sweet pepper (Enarlan & Bulayog, 2020). The study of Herath (2019) stated that farmer's adoption of intercropping coffee, pepper, and cocoa with coconut on a sustained basis has been very poor then developed a plan using a multi-period linear programming model of the coconut-based farming systems. The inclusion of the farmer's objectives namely profit-maximizing and survival resources and government subsidies as constraints were considered in formulating a linear method employing the value of gross margins of intercropping activities over a 20-year period in Sri Lanka. The LP approach has been shown to be an effective tool for determining optimal crop combinations and maximizing profits in agriculture (Bhatia & Bhat, 2020).

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Materials and Method

Linear Programming Model Formulation

Linear programming (LP) involves solving problems of maximum or minimum value under linear constraints. The researchers used the concept of LP to maximize the profit based on data from the Department of Agriculture regarding the economic views for coconut production and cacao production as decision variables and objective functions for linear programming while the updated data from Tacio (2019c), intercropping coconut and cacao, leads to creating the constraints. The following are the three necessary elements that were used to formulate an LP model;

1. Decision variables are a set of possible values controlled by the decision-maker that affect the problem to be solved (Maiti, 2020). In this paper, variables x and y are used as the quantity for coconut and cacao trees, respectively since these are to be determined in the optimization process

2. The objective function is the basis of determining the solution. It appears as a mathematical equation of decision variables that transforms a solution into numerical output. It strictly contains linear mathematical sentences (Maiti, 2020). Letting z as the projected maximum profit.

3. Constraints are a group of functional equalities and inequalities assigned to decision variables that demand to be satisfied (Maiti, 2020). The constraints included are seedling cost, fertilizer, cost, gross income, area of production, and maximum number of trees.

A. Decision Variables

x- number of coconut trees to be planted (pcs)
y-number of cacao trees to be planted (pcs)

B. Objective function

$$ax + by = z$$

The profit is represented by variable ***z*** and is aimed to maximize. The coefficients of x and y are the collected net income per coconut and cacao tree.

C. Constraints

The following are the limiting conditions:

1. Seedlings cost – Decision variables must provide less than or equal to the computed maximum cost of seeds b_1.

$$a_{11}x + a_{12}y \leq b_1$$

where:
$a_{11},\ a_{12}$ = seedling cost per plant

2. Fertilizer Cost – Decision variables must provide not greater than or equal to the recommended maximum cost of fertilizers b_1.

$$a_{21}x + a_{22}y \leq b_2$$

where:
$a_{21},\ a_{22}$ = fertilizer cost per plant

3. Gross Income – Adding the gross income of cacao and coconut should produce a value that is greater than or equal to the minimum gross income b_2 acquired from the previous feasibility studies. Higher gross return results in a bigger return on investment (ROI).

$$a_{31}x + a_{32}y \leq b_3$$

where:
$a_{31},\ a_{32}$ = gross income per tree

4. Area of Production – The space occupied by the trees should not exceed the total area of production b_4, b_5.

$$a_{41}x \leq b_4$$
$$a_{51}y \leq b_5$$

where:
$a_{41},\ a_{51}$ = area occupied by a tree (ha/plant)

5. Maximum number of trees – Recommended maximum plant densities b_5**,** b_6 recorded in past studies.

$$x \leq b_6$$
$$y \leq b_7$$

The linear programming model was performed using Microsoft Excel Add-in Data Solver. An accessible and user-friendly software used to find the optimal solution (maximum or minimum) to a problem. The solver works by assigning an objective cell that is subjected to constraints, or restrictions, on the values of different formula cells on a worksheet. Cells designated as decision variables were used in treating the formulas in the objective and constraint cells. The solver

DOI: https://doi.org/10.22137/ijst.2023.v7n2.02

modifies the numerical quantities in the decision variable cells to meet the limits on constraint cells and produce the optimum solution for the objective cell (Microsoft. (2022).

Design and Implementation

The design of the project plan is shown in Figure 1. The researchers maximized the profit from coconut-cacao intercropping farming given the limited or available land area to be planted. The inputs such as available plantation area and established assumptions for the intercrops and farming method by BAFS (2008) and PSA (2007) had been gathered and incorporated. The process includes formulating a linear programming model and Microsoft Excel to simulate the data. Hence, from the optimum model, the output includes maximum profit, gross income, and the number of coconut and cacao trees for the output.

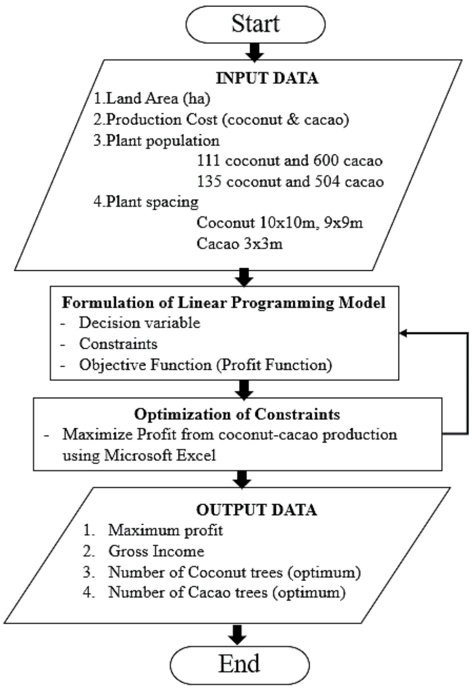

Figure 1. Implementation of the Project

The data used are the initial costs for coconut and cacao production from the Department of Agriculture (2014) as shown in the following tables. To the best of the ability of the researchers, monetary values were dated from 2019 up to 2022 as the latest data acquired for Tables 1, 2, and 3.

Table 1. Parameters for Coconut

Particulars	Values
Seedlings Cost (Php/seedlings)	100
Fertilizers Cost (Php/tree)	25.5
Productivity (kg / tree)	15
Farm Gate Price (Php/kg)	30
Spacing (m)	9,10

Assumptions

1. The coconuts to be planted are tall varieties
2. The fertilizer used is Common Salt (NaCl), applied at 1.5 kg/tree (Maiti, 2020).

Table 2. Parameters for Cacao

Particulars	Values
Seedlings Cost (Php/seedlings)	25
Fertilizers Cost (Php/tree)	12
Productivity (kg / tree)	4
Farm Gate Price (Php/kg)	25
Spacing (m)	3

Assumptions

1. The 80% of the total area is prior to cacao plantation as established by Tacio (2019c).
2. The fertilizers that will be used per plant are 108 g of Ammonium Sulfate (21-0-0), 75 g of Solophos (18% P_2O_5), 86 g of KCl (0-0-60), and 40 g of dolomite (Tacio, 2019c).

Table 3. Summary of 5-year average cost and returns of a 1-hectare cacao production (wet beans)

Particulars	Values
Gross Return (Php/ha)	58,125
Total Costs	26,786
Net Returns	19,714
Net Profit-Cost Ratio (Php)	1.29
Cost per Kilogram (Php)	10.97
Yield per hectare (kg/ha)	2,325.00
Farmgate Price (Php/kg)	25
Return on Investment (ROI, %)	128.57

Result and Discussion

Linear Programming Model

The researchers formulated the linear programming model using the collected data from Maiti (2020) and to minimize error, data acquired from Tacio (2019c) was subject to the Philippine Inflation Calculator (PIC) to utilize updated data (2019 present worth) (Microsoft, 2022). The decision variables in the representation of x for the number of the coconut tree and y for the number of the coconut tree. The objective function sets the optimum profit having a combination of 244 and 58 for coconut and cacao trees respectively. Both the function and constraints were designed for a 1-ha farm which can be interpolated so long as the values for tables 1,2 and 3 are maintained

Decision Variables

x-no. of coconut tree
y- no. of cacao tree

Objective Function

$$244x + 58y = z$$

Constraints

$$100x + 25y \leq 26100$$
$$25.5x + 25.7y \leq 18531$$
$$450x + 100y \leq 105000$$
$$0.0072x \leq 1 \text{(for 9x9m)}$$
$$0.0091x \leq 1 \text{ (for 10x10m)}$$
$$0.000806y000806y \leq 0.80$$
$$x \leq 135$$
$$y \leq 1240$$
$$x, y \geq 0$$

A. *Coconut-Cacao Intercropping Production*

The data gathered has been incorporated from the previously formulated linear programming model. Table 4 shows the optimum values of parameters for intercropping coconut and cacao with a plant spacing of 10 x 10m for coconut and 3 x 3m for cacao. The optimum solution obtained includes 111 coconut and 600 cacao trees, producing a profit of Php 61,652. On the other hand, shown in Table 5 is the solution for intercropping coconut and cacao with 9x9m spacing. As the spacing was reduced between coconuts, the number of coconut trees increased from 111 to 135, thus gaining a net income of Php 61,690 per hectare. With the demonstration from the model, farmers may use the existing spacing for their 1-ha farm and still follow the projected numbers of trees displayed depending on their spacing preference (9x9m or 10x10m).

For the change of input cost, say an increase of a unit cost per seedling of cacao and coconut decreases the optimum profit in both treatments. An amount of Php 1,577 and Php 1,416 was deducted on the net return of 10x10m and 9x9m spacing, respectively. Furthermore, for a Php 10,000 budget for fertilizer with 10x10m spacing, the net income was decreased by Php 722 if there is a unit increase per kilogram of fertilizer. However, in 9x9m spacing, the profit remains constant with fertilizer increase as the optimum solution takes up Php 8942.50 only out of Php 10,000. Adding a unit cost will increase the fertilizer cost to Php 9,645 which is still less than 10,000. Thus, not causing an effect on the optimum yield. A hundred increase in the seedling cost budget will yield an additional Php 232.00 in the optimum solution for both situations. In today's time, a budget of Php 10,000 per ha for fertilizer on intercropping systems is enough to obtain a profitable result.

Table 4. Optimum Solution for 10x10m coconut spacing

Parameters	x	y		
Maximize	244	58		
Seedling Cost	100	25	≤	26000
Fertilizer Cost	25.5	11	≤	10000
Gross Income	450	100	≥	105000
Production Area for Coconut	0.0091		≤	1
Production Area for Cacao		0.000806	≤	0.8
Maximum no. of Coconut Trees per Hectare	1		≤	135
Maximum no. of Cacao Trees per Hectare		1	≤	1240
Solution	**111**	**596**		**61,652**

Table 5. Optimum Solution for 9x9m coconut spacing

Parameters	x	y		
Maximize	244	58	≤	
Seedling Cost	100	25	≤	26000
Fertilizer Cost	25.5	11	≥	10000
Gross Income	450	100	≤	105000
Production Area for Coconut	0.0072		≤	1
Production Area for Cacao		0.000806	≤	0.8
Maximum no. of Coconut Trees per Hectare	1		≤	135
Maximum no. of Cacao Trees per Hectare		1	≤	1240
Solution	**135**	**500**		**61,940**

B. *Feasible Solutions*

The region of the feasible solution was formed upon plotting the equations of constraints in a graph. Figures 2 and 3 show the set of the optimum solution for intercropping coconut and cacao with 10x10m and 9x9m spacing, respectively. The bounded section encloses the set of solutions that satisfies all the constraints.

Figure 2 displays the feasible solution enclosed by the lines of gross income, fertilizer, and area of production for coconut. For the ease of identifying the points included, the point of intersections was identified. The x-axis stands for the number of coconuts and the y-axis for the number of cacaos. The combination of points where the lines meet was (111, 551), (65,758), (78, 728), and (111,596). While, figure 3 shows that the optimum solution is found in the section surrounded by the lines of gross income, fertilizer, and maximum no. of coconut trees. The ordered pairs where the points intersect are (135,443), (65,758), (78, 728), and (135,500).

The lowest profit that was acquired from the feasible solution in Figure 2 was with intercropping 111 coconuts and 551 cacaos gaining a net return of Php 59,042. The optimal solution with a combination of (111,596) produces the highest return amounting to Php 61,652. In 9x9m spacing of coconuts, the lowest gain of Php 58,634 was in the point (135,443). Similar to 10x10m spacing, the highest net income was obtained in the optimum solution (135,500) having a value of Php61,940.

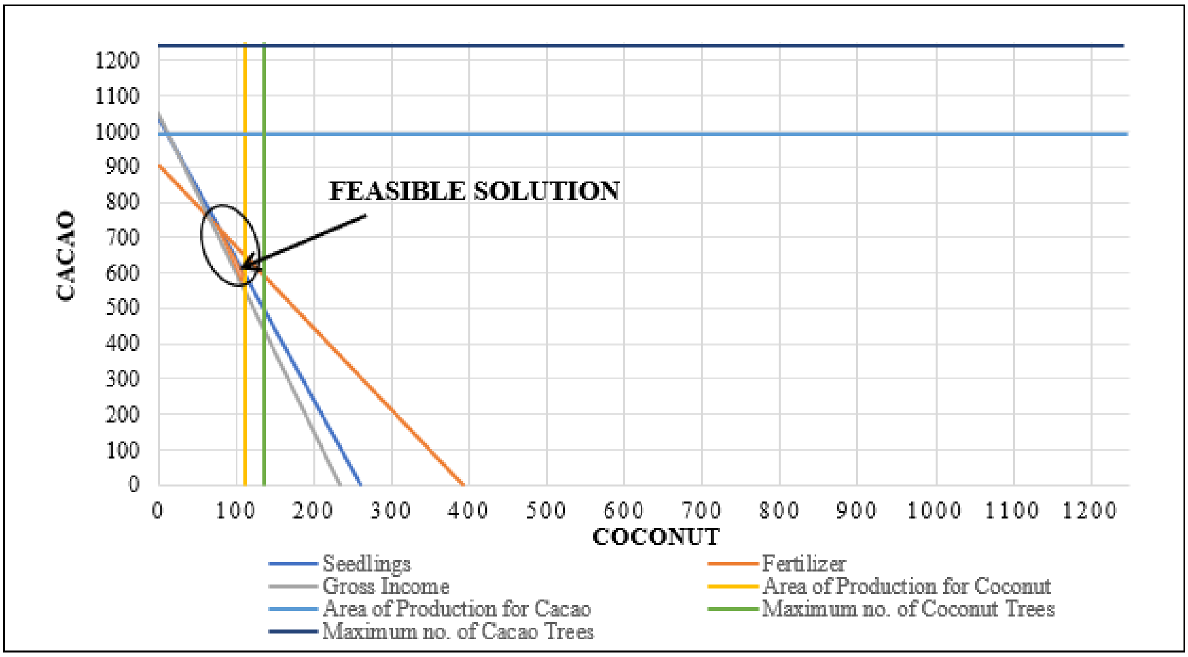

Figure 2. Feasible Solution for 10x10m spacing of Coconut

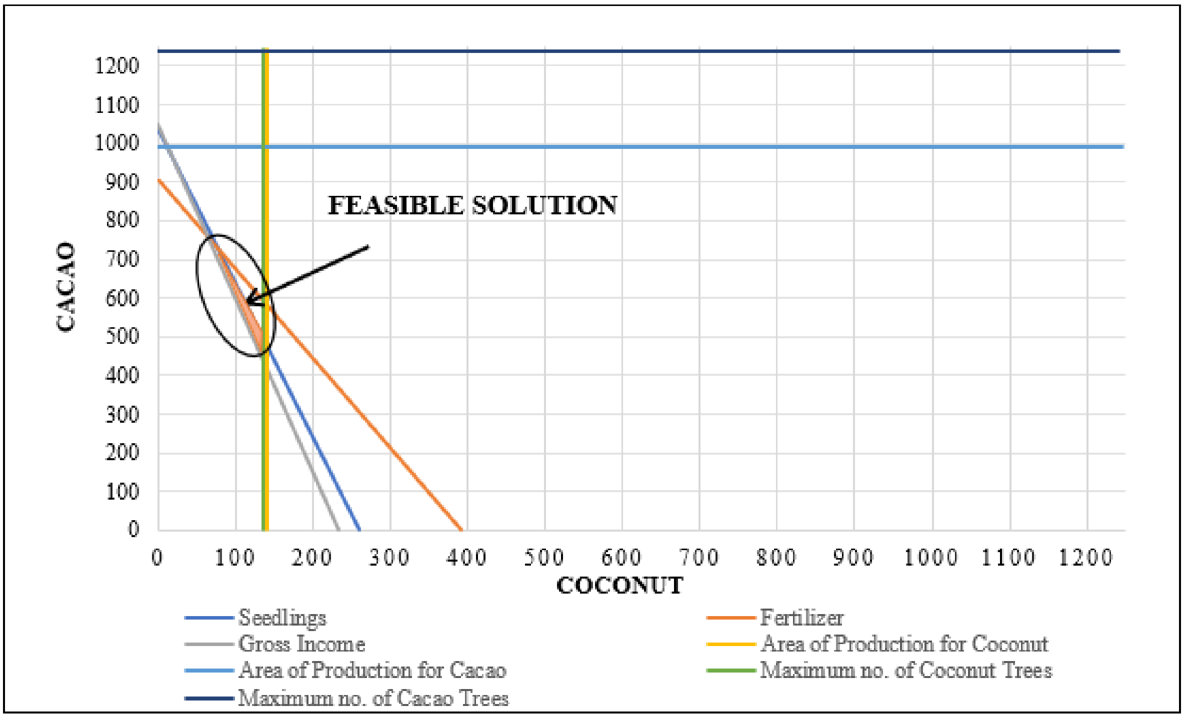

Figure 3. Feasible Solution for 9x9m spacing of Coconut

Table 6. Set of Feasible Solutions for 10x10m Coconut Spacing

No. of Coconut Trees	No. of Cacao Trees	Seedling Cost (Php)	Fertilizer Cost (Php)	Gross Income (Php)	Profit (Php)
111	551	24,863	8,886	105,001	59,042
65	758	25,450	9,996	105,050	59,824
78	728	26,000	9,997	107,900	61,256
111	596	26,000	9,368	109,550	61,652

Table 7. Set of Feasible Solutions for 9x9m Coconut Spacing

No. of Coconut Trees	No. of Cacao Trees	Seedling Cost (Php)	Fertilizer Cost (Php)	Gross Income (Php)	Profit (Php)
135	443	24,575	8,316	105,050	58,634
65	758	25,450	9,996	105,050	59,824
78	728	26,000	9,997	107,900	61,256
135	500	26,000	8,942	110,750	61,940

Table 6 shows that in 10x10m, the generated optimum solution states a budget of Php 26,000 for seeds and Php 9,368 for fertilizer which are sufficient to produce a gross income of 109,550. This is greater than Php 105,000 gross income based on the computed data from Tacio (2019c) as a feasible return. While in a 9x9m spacing, a gross return of Php 110,750 was produced from 135 coconut and 500 cacao trees. The budget for seedling and fertilizer costs are Php 26,000 and Php 8,942, respectively. The model produced such acceptable profit values since the gross income is always higher than the total expenses of the inputs. The potential profit can benefit the farmers in the industry of coconut-cacao intercropping.

Figure 4 displays the profit comparison wherein the highest profit was Php 61,940.00 from intercropping cacao with 9x9m coconut plant spacing followed by Php 61,651.85 for intercropping cacao with 10x10m coconut plant spacing, while Php 34,822.00 from cacao monocropping and the least profit of Php 31,197.00 obtained by coconut monocropping. The numbers produced can be observed by the beneficiaries in decision-making and choosing the farming practice that benefits the most.

Table 8 shows the summarized average cost of the optimum solution. The 9x9 m plant spacing for coconut under intercropping yields higher values of gross income, profit and so as production cost compared to a 10x10 m plant spacing. On the concern of benefit-cost ratio, the farmer will gain profit to either of the optimum spacing.

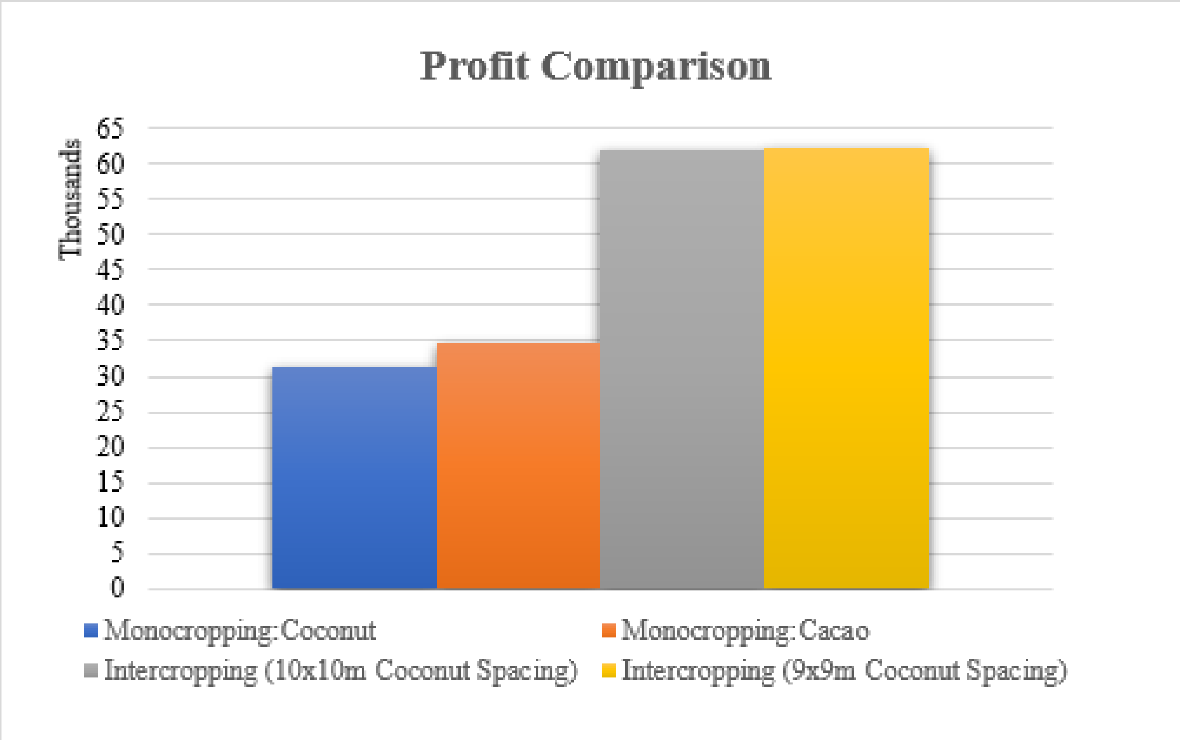

Figure 4. Profit comparison of monocropping and optimum intercropping

Table 8. Summary cost of the optimum solution

Particulars	**Spacing**	
	10x10 m	9x9 m
Gross Income (Php)	109,549.00	110,750.00
Profit (Php)	61,651.85	61,940.00
Production Cost (Php)	47,897.15	48,810.00
Benefit-Cost Ratio	1.3	1.3

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Conclusion

To conclude, the linear programming (LP) model was successfully utilized in generating optimum profit for coconut-cacao intercropping with the considerations of economic parameters in the Philippine setting. The maximum profit was determined together with the optimum number of coconut trees and cacao trees needed for every hectare of land area. The formulated model can be interpolated with the different land areas so long as the parameters do not change. Intercropping coconut and cacao has shown greater benefits compared to monocropping alone. Also, it shall be noted that changes in the values of input cost affect the profit of the optimum solution.

The output of the study displays that both plant spacing of 10x10 m and 9x9 m for coconut and 3x3 m for cacao generated higher profits than monocropping. An amount of Php 61,940.00 for planting 135 coconuts (9x9m) and 500 cacao trees while almost Php 61,652.00 for planting 111 and 596 coconut and cacao trees respectively, for every hectare. The optimum solution determined a profit decrease, Php 1,577.00 (10x10m) and Php 1,416.00 (9x9m), for a unit increase of the seedling cost. An increment of Php 100 will yield an increase of Php 232.00 in profit to either of the optimum solutions. An amount of less than or equal to Php 10,000 for fertilizer is sufficient for a 1-ha intercropping farm.

The generated outputs from the equation can be used by the farmers and stakeholders in the coconut-cacao intercropping industry as guidelines for estimating the quantity of coconut and cacao trees for their farm with respect to the optimum profit. Changes in the value of inputs may occur over time thus, the practicality of the results is limited to the inputs used and to the data subjected to PIC.

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