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Optimization of Croplands for Efficient and Sustainable Resource Use and Management

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Abstract

The farmers in Ilocos Norte, Philippines, produce vegetable crops during the dry season (November to May). During this time, they face simultaneous climatic and resource challenges, which impact their production decisions and threaten food security. Land use decisions at the farm level require trade-offs due to resource constraints and other inherent factors, thus, informed decision-making is called for. This study determines the optimal cropland allocation where farmers can earn the highest income given their level of existing resources and production objectives during the dry season. Only prime agricultural lands were considered, and it excluded livestock production due to resource limitations and more sophisticated models and analytical software required. Production data from 80 farmers were subjected to optimization through linear programming in Microsoft Excel Solver. Results revealed that the farmers should adjust their current production level and cropland areas during the dry season to further maximize profit. Particularly, the farmer-respondents should devote 2.22-ha croplands to tomato production to earn 208.09 percent higher profit, and another 2.90-ha for purple corn and peanut production to generate 41 percent more profit than their existing crop production system. The study provides scientific evidence that maximum income can be attained if the farmers in the study areas change their existing crop production to the identified best alternative. It also offers information that could be a basis for crafting a decision tool for efficient and sustainable agricultural land use and management in the respective areas. Future studies may consider incorporating price volatility, risk preferences of farmers, crop rotation requirements, and non-linear yield responses. Analysis of wider agricultural lands combined with livestock production may also provide a more comprehensive perspective.

Keywords: Agricultural Land, Cropland Allocation, Linear Programming, Optimization, Sustainability

1. Introduction

Agricultural land is a valuable and scarce natural resource for production; therefore, it must be properly managed. Farm-level land use decisions involve trade-offs due to resource constraints and other inherent factors shaped by social, economic, and environmental factors. Particularly, farmers may face sustainability and intensification trade-offs due to varying objectives and priorities [1]. Their choices impact the real efficiency of resource utilization and the degree to which growth-defining, growth-limiting, and growth-reducing forces are present and optimized for the biophysical environment of the farm and a particular crop [2]. Therefore, the farmers' personal priorities and the farm's socio-economic environment strongly affect management decisions. For example, profitability and economic sustainability are twin objectives that motivate farmers and farm enterprises [3]. To realize them, a cropping pattern that carefully considers land suitability, climate and availability of soil and water resources must be determined. Therefore, the importance of efficient land use to achieve high income, food security, and sustainable land use and management cannot be overemphasized.

In Ilocos Norte, a major agricultural province in northwestern Philippines, rice dominates during the wet season (June-October), while high-value crops such as garlic, onion, tomato, and corn are cultivated in the dry season (November-May). It is a major crop-producing area [4], and a significant contributor to food security in the Philippines. However, production is challenged by drought, market fluctuations, and rising input costs, pushing farmers toward crop diversification as a coping mechanism [5]. Cropland allocation has been the focus of researchers for many years in various countries in recognition of its contributions to food security. Numerous studies employed a multi-objective optimization approach in view of competing land uses, such as food production against other alternatives. Some of

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these include biofuel [6], traditional Chinese medicine (TCM), and rubber production [7]. Environmental concerns such as afforestation (fields should be removed from agricultural production/ lack future role for food security) [8], [9], [10], minimizing negative environmental pressures [11], water security [12], climate adaptation [13], and ecosystem services [14] were also integrated. Maximization of farmers' profit was also studied in the context of mixed cropping systems [15], [16], [17], [18], [19]. However, there is an absence of studies that focus on farm-level linear programming (LP) optimization for dry-season diversification conducted in the local setting, which is crucial for data-driven decision-making, identifying bottlenecks, and enhancing sustainability. These have implications for farmers' income, considering that croplands in Ilocos Norte are more affected by increasing temperature [4] and drought [5], and become scarcer due to agricultural land conversions [20].

LP has been proven effective at various scales, from provincial resource mapping to village-level analysis of labor and capital constraints. Empirical evidence suggests that reallocating croplands using LP can more than double farmer profits while simultaneously meeting aggregate food requirements, outperforming conventional allocation methods [6], [14], [16], [17], [21]. In the specific context of Ilocos Norte, farmer decisions regarding cropping patterns are currently driven by reactive factors such as immediate resource availability and fluctuating market prices. There is no existing decision-support tool that ensures the efficient management of natural resources while guaranteeing the highest economic returns for the farmer. This study addresses this localized gap by applying LP optimization to dry-season cropland allocation, providing a scalable model for sustainable and profitable land use.

2. Literature Review

2.1. Global Paradigms in Cropland Allocation and Ecosystem Management

The optimization of cropland allocation has evolved into a multi-dimensional challenge, requiring the integration of biophysical, socio-economic, and environmental variables. Numerous models have been developed to transition from simple yield-maximization to precision farming frameworks that balance crop and water allocation to enhance profitability while maintaining ecological integrity [8],[10], [22]. Recent studies emphasize the necessity of assessing integrated biodiversity alongside socio-economic demands to inform environmental conservation policy [6].

A critical theme in contemporary literature is the trade-off between competing land uses, particularly the tension between biofuel production and food security. Evidence suggests that land-use diversification serves as a superior strategy compared to dedicated food-crop monocultures [7]. Furthermore, life cycle assessments comparing organic and conventional practices across various dietary scenarios (e.g., vegan, vegetarian) have highlighted that crop production generally produces lower environmental impacts such as in water and energy use than livestock production [23], [24]. These global findings underscore a shift toward sustainable intensification and afforestation, where marginal lands are removed from production to safeguard future food security and ecosystem services [9], [11].

2.2. Agricultural Land Use Dynamics in the Philippines

Despite global advancements, there is a significant dearth of empirical studies concerning localized cropland optimization within the Philippine context. Existing research in provinces such as Ilocos Norte has utilized multi-scale land-use optimization to identify high-value cropping patterns. Findings indicate that during the dry season, non-staple crops, specifically watermelon, onion, tobacco, and tomato, yield the highest net income and benefit-cost ratios [15].

Similarly, systemic approaches in rice-based production highlight the potential for increased profitability through the strategic allocation of resources toward garlic and vegetable production during water-scarce periods [12]. Climate change projections for 2035 in Nueva Ecija further suggest a paradigm shift; while land area for staples like rice and onion may decrease, the transition toward more suitable crops like tomato and bitter gourd could maintain economic viability [19]. However, a persistent gap remains such that while the economic potential of dry-season allocation is evident, there is still a lack of localized, farm-level decision-making frameworks to guide farmers in maximizing these benefits.

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3. Methodology

3.1. Research Design and Data Collection

This study adopts a quantitative research design. The information gathered from the farmers through surveys includes their sociodemographic profile, capital and profit for producing the crops, quantity of production inputs and costs, and other relevant data.

According to the High-Value Commercial Development Program (HVCDP) of Ilocos Norte, there are about 79,716 producers (40,072 in District 1 and 15,472 in District 2) of high-value crops. The actual population of farmers diversifying crop production in their agricultural land is yet unknown, hence the Cochran's formula for sample size determination was used. With 95% confidence level and an associated z-value of 1.96, assuming a maximum population variability of 0.50 and a margin of error of 10%, the computed sample size was 96. The stratified random sampling method was used in this study. The practice of multi-cropping was the inclusion criterion, while the practice of monocropping during the dry season was the exclusion criterion. Approval from authorities and informed consent from the participants were sought before the farm surveys. In line with this, out of those who passed the inclusion criterion, only 80 farmers agreed to participate in this study. Hence, all the analyses were for 80 farmers only.

3.2. Study Area

During the dry season in Ilocos Norte, the crops produced in prime agricultural lands are diverse. The most diversified crop-producing towns are Vintar in District I and Badoc in District II. Thus, these were chosen as the study areas as illustrated by the map in figure 1.

Figure 1. Map of the province of Ilocos Norte, Philippines

3.3. Data Analysis

The LP was employed for the quantitative data analysis, particularly for evaluating the optimal allocation of cropland per farmer-respondent, along with cost and returns analysis for profitability assessment to determine the magnitude of benefits for the crop producers. The Microsoft (MS) Excel Solver package was used as an analysis tool since it is user-friendly, yet it can generate reliable results [19], [25]. Cost and returns analysis, particularly gross margin analysis, was done a priori, which excluded fixed costs of production due to its practicality if the focus was small-scale farmers' profits [26]. The revenues were computed based on the quantity produced and the existing market price of each crop. Only the variable costs were deducted from the revenue. The terms gross margin (total revenue less total variable cost) and profit are synonymous in this study. All monetary values were converted into US Dollars (US$) wherein US$1.00 is equal to PhP58.85, the average conversion rate according to the Bangko Sentral ng Pilipinas when this study was completed [27].

3.4. Model Formulation

This study utilizes an LP framework to determine the optimal allocation of land across fifteen dry-season crop varieties (X_1 through X_{15}), as detailed in table 1. The optimization is structured as a technological matrix where cropping activities compete for finite capital, land, and economic resources.

The decision variables (X_j) represent the physical area (in hectares) allocated to each crop. For the model to maintain mathematical and practical validity, it operates under specific linearity assumptions. First, the proportionality denotes that the total profit and resource allocation are assumed to change linearly with the scale of the land area (X_j). Second, the assumption of additivity indicates that the total resource use and profit are the sum of the individual contributions of each crop, assuming no inter-cropping synergies. Third, the assumption of divisibility ensures that the land area variables are treated as continuous, allowing for fractional hectare allocations. Lastly, determinism indicates that the model parameters (a_j, c_{ij}, P, E, L) are assumed to be known and fixed for the duration of the dry season.

The behavioral objective of the model is to maximize the aggregate profit (Y) from dry-season production. The profit coefficients (a_j) are derived from a gross margin analysis, calculated as the difference between total revenue (valued at farmgate prices) and the total variable costs (valued at prevailing market prices and wage rates). The objective function is defined as:

$$Max\ Y = \sum_{j=1}^{15} a_j K_j \tag{1}$$

The feasibility of the production plan is defined by a set of linear inequalities representing financial, economic, and physical barriers. These serve as the structural constraints for the land resource allocation. Access to capital is often the primary bottleneck for smallholder farmers. This financial constraint (Equation 2) ensures that the total capital requirement for the chosen crop mix, such as those covering purchased inputs and credit, does not exceed the total available capital (P):

$$\sum_{j=1}^{15} c_{1j} X_j \leq P \tag{2}$$

To prevent unsustainable intensification, the model includes an economic constraint (Equation 3) based on average variable costs of crop production. This ensures that the chosen combination of crops stays within the maximum allowable expenditure (E) per hectare:

$$\sum_{j=1}^{15} g_{2j} X_j \leq E \tag{3}$$

The physical limitation of the agricultural landscape (Equation 4) dictates that the sum of the hectares allocated to various crops cannot exceed the total available land area (L):

$$\sum\nolimits_{j=1}^{15} r_{3j} X_j \leq L \tag{4}$$

For all decision variables, a non-negativity constraint is applied ($X_j \geq 0$), ensuring the model yields only realistic physical allocations.

Table 1. Description of the Optimization Variables and Parameters

Notation	Definition	Unit
Y	Total profit for dry season crops	US$
X_{1-15}	Land area allocated to crops (garlic, shallot onion, red onion, yellow onion, tomato, finger pepper, sweet pepper, yellow corn, purple corn, watermelon, mung bean, eggplant, lady's finger, peanut, & tobacco)	Hectare (ha)

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$\mathbf{a}_j$	Profit contribution per hectare of crop j	US$/ha
P	Total capital available for production	US$
E	Maximum allowable production expenditure	US$
L	Total available land area	Hectare (ha)
c, g, r	Technical coefficients for capital, cost, and land use	Constant

Subsequently, the sensitivity analysis was done to test what would happen to the earnings per hectare of crop producers if the recommended cropland allocation were affected by other events that may occur in the coming years. It tests the optimization model's effectiveness and the robustness of the results [28], [29]. After the optimal allocation of croplands was determined, three scenarios were assumed to occur in five years. Profitability evaluation methods such as Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit-Cost Analysis (BCA) were utilized to determine how beneficial it would be for the respondents in the study areas to implement the optimal allocation of their croplands. The NPV is the present value equivalent of all cash inflows less all cash outflows associated with the project. If it is greater than zero, a project is worth the investment. If there are alternatives, the project with the greatest NPV should be selected. The IRR is the discount rate that represents the average earning power of the money used in the project over its entire duration. It solves the equation for the discount (interest) rate that makes NPV=0. The project is acceptable if the IRR is positive with the highest NPV and BCR. The BCA measures the ratio between the discounted benefits and discounted costs to evaluate the desirability of a project. It is an important indicator often used for government decision-making and a formal technique for making informed decisions on the use of society's scarce resources [30]. The conceptual framework for this study (figure 2) illustrates how the concepts discussed are interrelated when farmers decide on how to determine the optimal allocation of croplands, given that their objective is to maximize profits.

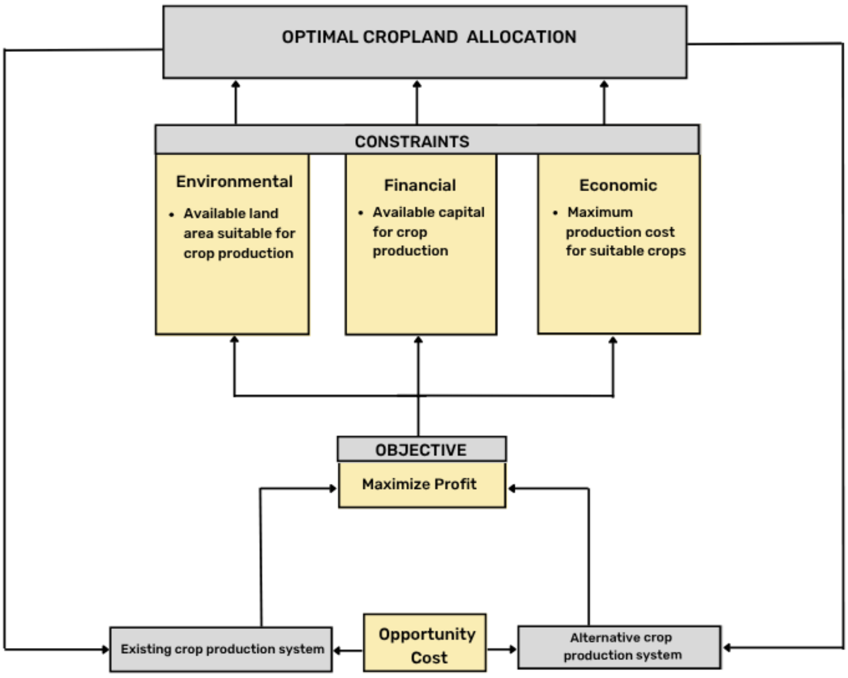

Figure 2. Conceptual framework for optimizing cropland allocation

4. Results and Discussion

4.1. Existing Crop Combinations and Cropland Allocations

The survey revealed rich crop diversity during the dry season in Ilocos Norte, with 45 crop combinations. This supports the findings of Catudan and Martin [5] that Ilocos farmers take pride in growing their own food, and it is deeply ingrained in typical Ilokano farmers' hearts and culture. Most of the farmer-respondents preferred the combination of red onion-garlic (12.50%), both of which belong to the genus of plants called Allium, considered to be the most cultivated crops in the world [31]. These crops have the same production requirements; thus, farmers find it easier to produce them simultaneously.

Average cropland allocation varied, with yellow corn (0.79 ha) and watermelon (0.77 ha) receiving the largest shares, while eggplant occupied the least (0.05 ha) (figure 3). Yellow corn is often used as an ingredient for animal feeds, particularly for broilers and layer chickens. It is the source of the yellow pigment seen in eggs [32]. Data obtained from the Philippine Statistics Authority (PSA) [33] showed that the area planted and price of yellow corn increased by 2% since 2015, on average. Meanwhile, the watermelon production areas are only small, with an average of 184.57 ha. in Ilocos Norte from 2014-2024 [34]. However, watermelon is highly demanded and priced beginning the last week of December until the first week of January. Therefore, many farmers in the area produce the crop despite associated risks such as the occurrence of fungi and diseases [35]. The price of watermelon increased by 6.23% since 2014, on average. On the other hand, eggplant is commonly used for intercropping [36] with rice, other vegetables, and corn [37]. It is one of the basic ingredients of "pinakbet," a vegetable food viand which Ilocos Norte is well known for [38]. According to the PSA [39], Region 1 (where the province is located) is the top producer of eggplant in the Philippines with 60.46 thousand mt or 58.7% share of the total production during the second quarter of 2023. The same data revealed that since 2014, there has been a steady increase in the area planted to eggplant in the province. However, insect pests cause low productivity among farmers [37], and the crop is susceptible to several fungal, bacterial, and viral diseases, negatively affecting eggplant production and profitability [40].

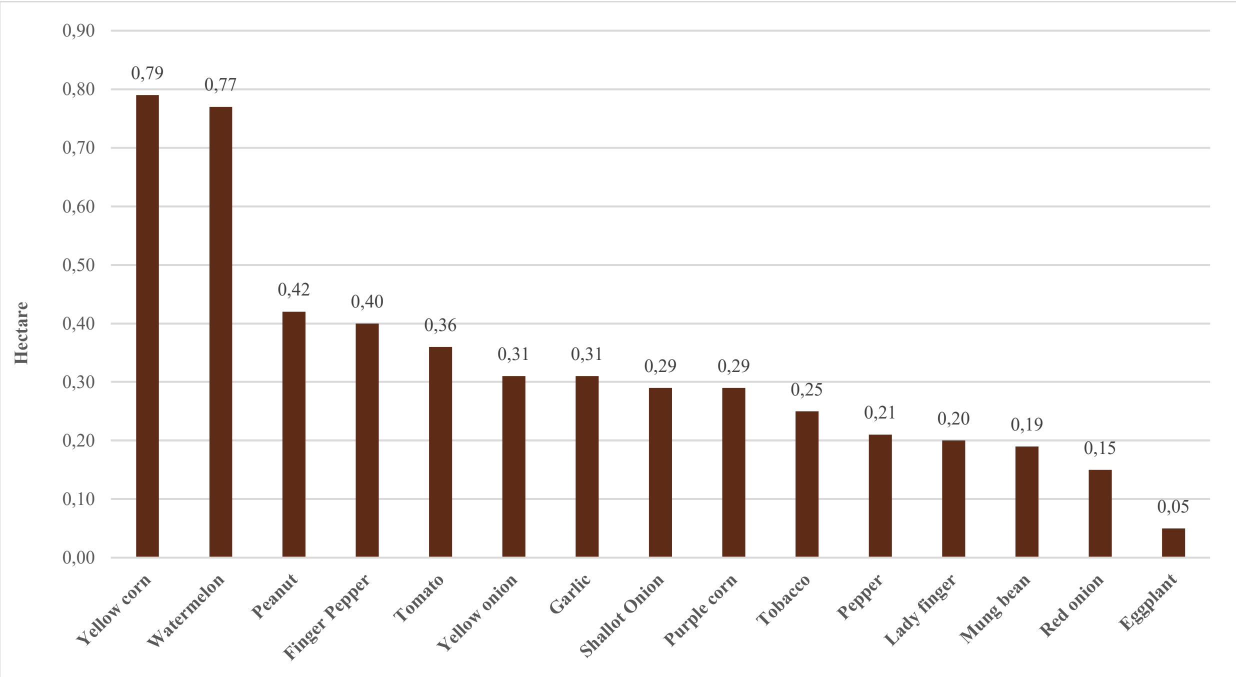

Figure 3. Average Cropland Size (in hectares) in Ilocos Norte, Dry Season, 2025

4.2. Cost and Returns

Tomato, finger pepper, and garlic had the highest gross margins in Badoc per hectare in the town of Badoc, amounting to US$5,979.49, US$4,994.40, and US$4,923.26, respectively. Among the crops produced in the area, garlic and finger pepper had the highest selling prices, which were US$1.14 per kg and US$0.97 per kg, respectively. The average yield and consumption were multiplied by the price per mt (Table 2). In terms of cost, the percentage share of each cost item in the total costs shows notable variations for each crop during the dry season. Sweet pepper had the highest average cash cost amounting to US$3,744.72. This is higher by 66% compared with the estimates (US$2,257.40) of Maghirang, et al [41]. Fertilizers such as urea, complete, ammonium phosphate, and sulphate were the highest contributors to the average costs of garlic, shallot onion, yellow corn, watermelon, and mung bean, which ranged from 18-37%. Meanwhile, sweet pepper had the highest cost share for potassium (23%). These align with the findings of Briones [42] that fertilizers had high utilization rates for crop production in the country, and around 60% goes to food crops, because modern varieties require a large amount of fertilizer for higher yield. Among the crops, finger pepper had the highest seed cost share at 21%, mainly because the inputs for other crops were subsidized by the government, while finger pepper seeds were usually bought by the farmer-respondents. On average, a hectare of production would need 1.96 kg of finger pepper seeds valued at US$339.30. Mung beans had the highest percentage share (58%) of the chemical expenses to total cash costs. The crop has poor competitiveness against weeds [21], therefore, herbicide application was an essential item in the production expenditures. The cost of fungicides for mung beans was high at 43%, due mainly to the high prevalence of fungi in the study area, thus the need for seed treatment [43]. Subsequently, tomato had the highest labor (25%). This is consistent with the findings of Abella et al [19] that tomato production has the highest labor cost among other crops. This may further be due to the duration of fruit harvesting, which typically starts at day 55 up to 100 days after planting. Harvesting can be done weekly, depending on the demand, but can last up to 48 man-days, the highest (19%) among labor activities and costs [44]. Sweet pepper had the highest fuel cost share (29%), which also reflects the high cost of irrigation. In terms of rent for machinery, mung beans had the highest share (10%) of the total variable costs but had the lowest variable cost among the crops before planting (table 2).

Table 2. Cost and Returns for Crop Production Per Hectare (in thousand US$), Badoc, Ilocos Norte, Dry Season, 2025

	Garlic	Shallot Onion	Tomato	Finger Pepper	Sweet Pepper	Yellow Corn	Water-melon	Mung Bean
Revenue								
Production (mt/ha)	7.56	8.36	17.85	9.37	10.40	8.16	9.85	1.38
Price/mt (US$)	1,139.34	538.07	465.96	966.76	601.07	249.61	184	793.64
Prod. Value	8.61	4.50	8.32	9.14	6.25	2.04	1.81	1.10
Home Consumption	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98
Total Revenue	6.63	4.05	7.15	8.14	5.94	2.04	1.61	1.01
Variable Cost*								
Seeds	-	-	0.14	0.67	0.42	0.28	0.09	0.03
			(12)	(21)	(11)	(14)	(8)	(3)
Fertilizers	1.10	1.88	0.38	1.11	1.48	1.19	0.55	0.29
	(64)	(68)	(32)	(35)	(39)	(60)	(45)	(29)
Chemicals	0.37	0.11	0.07	0.69	0.17	0.08	0.24	0.58
	(22)	(4)	(6)	(22)	(4)	(4)	(20)	(58)
Labor	0.09	0.50	0.30	0.29	0.49	0.25	0.18	-
	(5)	(18)	(25)	(9)	(13)	(13)	(14)	
Fuel	0.05	0.19	0.19	0.29	1.09	0.18	0.06	-
	(3)	(7)	(16)	(9)	(29)	(9)	(5)	
Rent and Machineries	0.10	0.10	0.10	0.10	0.10	-	0.10	0.10
	(6)	(4)	(9)	(3)	(3)	-	(8)	(10)
Total Variable Cost	**1.71**	**2.78**	**1.17**	**3.14**	**3.74**	**1.98**	**1.22**	**1.00**
GROSS MARGIN (US$/Ha.)	**4.92**	**1.27**	**5.98**	**4.99**	**2.19**	**0.05**	**0.39**	**0.01**

**The numbers in the parentheses represent the percentage of each item to the total variable costs.*

In Vintar, garlic, yellow onion, and finger pepper had the highest average gross margins per hectare, amounting to US$5,988.35, US$4,578.23, and US$3,769.64. Similarly, in Badoc, the price of garlic was the highest (US$1,695/mt), but purple corn and finger pepper had the highest volume produced at 18.62 mt and 16.98 mt, respectively. In terms of cost, red onion had the highest average cash cost amounting to US$2,965 (53%). This was higher by US$1,212.45 (59%) compared with the findings of Abella et al [19]. The findings in this study concur with the estimates of [45] that the capital investment of farmers is at least around US$1,699.24 for onions. Eggplant and purple corn had the highest

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share in fertilizer, which was equal to 51% and 44%, respectively. This is higher than the findings of Briones [42] that eggplant was one of the crops with the highest cost shares in the total cost of production from 2002 to 2011, ranging from 18 to 28%. Meanwhile, the high fertilizer application for purple corn is in contrast with the no fertilizer application in the uplands [46]. Consequently, the lady's finger (or okra) had the highest seed cost share of 82%, which is similar to that in Badoc. In terms of chemical use, there is a relatively low cost share for all crops, which range from 1 to 16%. Among these, the yellow onions were found to have the highest share due to pesticide use, which accounts for 9% of the total chemical cost. This was slightly higher than the Department of Agriculture-Bureau of Agricultural Statistics (DA-BAS) [47] report for Ilocos Norte pesticide cost share of 7%. Subsequently, finger pepper had the highest cost share for labor (94%). This was much higher than the findings of the DA-Regional Field Unit No. 02 [48], which was 58%. However, such a difference may also be attributed to the wage rate increase in the area since 2017. Eggplant had the highest share in fuel cost (24%), three times higher than the previous estimation of 8% [49], which can perhaps be attributed to inflation. Among the crops produced in Vintar, lady's finger, mung bean, and peanut had the lowest variable costs. Lady's finger only required minimal fuel for irrigation aside from seed cost, and there was no application of fertilizers and chemicals, whereas seeds for mung bean and peanut production were from their previous harvests. Thus, these are non-cash costs that were not accounted for in the gross margin analysis. Moreover, the respondents did not apply any fertilizer, chemical, or irrigation because the crops are known as drought-tolerant and do not require much care. Particularly, mung beans have a short duration, low water requirement, and high nutritional value [50]. Tobacco farmers, on the other hand, did not have much variable cost due to the special support given by the government by virtue of Republic Act 7171 (An Act to Promote the Development of the Farmer in the Virginia Tobacco Producing Provinces) to increase their income and productivity (table 3).

Table 3. Cost and Returns for Crop Production Per Hectare (in thousand US$), Vintar, Ilocos Norte, Dry Season, 2025

	Garlic	**Red Onion**	**Yellow Onion**	**Tomato**	**Finger Pepper**	**Yellow Corn**	**Purple Corn**	**Mung bean**	**Peanut**	**Lady's Finger**	**Eggplant**	**Tobacco**
Revenue												
Production (mt/ha)	4.79	9.67	9.22	5.94	16.98	5.67	18.62	0.88	0.72	0.28	2.53	1.76
Price/mt (US$)	1,695	595.74	647.31	670.88	385.30	321.08	222.19	796.29	1,387	462.36	578	1,233
Prod. Value	8.12	5.76	5.97	3.99	6.54	1.82	4.14	0.70	0.99	0.13	1.46	2.17
Home Consumption/ Fodder	0.32	0.29	0.18	0.20	0.07	0.11	0.12	0.15	0.21	0.03	0.58	-
Total Cash Return	**7.80**	**5.47**	**5.79**	**3.79**	**6.48**	**1.71**	**4.01**	**0.55**	**0.78**	**0.10**	**0.88**	**2.17**
Variable Cost*												
Seeds	-	-	-	0.09	-	-	-	-	-	0.02	-	-
				(9)						(82)		
Fertilizers	0.66	0.74	0.30	0.33	0.03	0.16	0.27	-	-	-	0.22	-
	(37)	(25)	(25)	(33)	(1)	(23)	(44)				(51)	
Chemicals	0.03	0.09	0.20	0.05	0.02	0.02	0.01	-	-	-	0.01	-
	(2)	(3)	(16)	(5)	(1)	(2)	(2)				(2)	
Labor	0.88	1.57	0.42	0.27	2.55	0.46	0.25	-	-	-	-	1.14
	(49)	(53)	(34)	(27)	(94)	(64)	(42)					(82)
Fuel	0.13	0.46	0.20	0.15	-	0.08	0.08	-	-	0.005	0.10	0.15
	(7)	(16)	(16)	(15)		(11)	(13)			(18)	(24)	(11)

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Rent and Machineries	0.10	0.10	0.10	0.10	0.10	-	-	0.10	0.10	-	0.10	0.10
	(6)	(3)	(8)	(10)	(4)			(100)	(100)		(23)	(7)
Total Variable Cost	**1.81**	**2.97**	**1.21**	**1.00**	**2.71**	**0.72**	**0.61**	**0.10**	**0.10**	**0.03**	**0.44**	**1.39**
GROSS MARGIN (US$/HA.)	**5.99**	**2.51**	**4.58**	**2.79**	**3.77**	**1.00**	**3.40**	**0.45**	**0.68**	**0.08**	**0.44**	**0.78**

**The numbers in the parentheses represent the percentage of each item to the total variable costs.*

The existing crop production system of farmer-respondents in Badoc during the dry season is composed of eight crops that generated various levels of profit (figures 4 and 5). Among the crops produced, tomato and finger pepper generated the highest average profit mt/ha at US$146,406 and US$124,894, respectively, even though the land areas devoted to their production were not the largest. This could be attributed to the high production levels of these crops. Tomatoes can be harvested 10-15 times in a series of weeks [51], [52]. Meanwhile, pepper varieties could be harvested by batch [53]. Overall, producing the eight crops generated a total average profit of US$441,971 for a 2.22-ha production area of the respondents in Badoc.

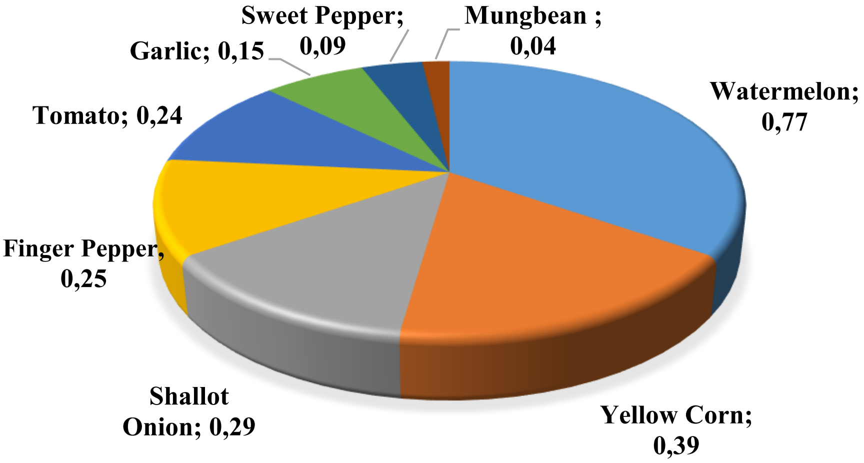

Figure 4. Current Crop Production System (in hectares), Badoc, Ilocos Norte, Dry Season, 2025

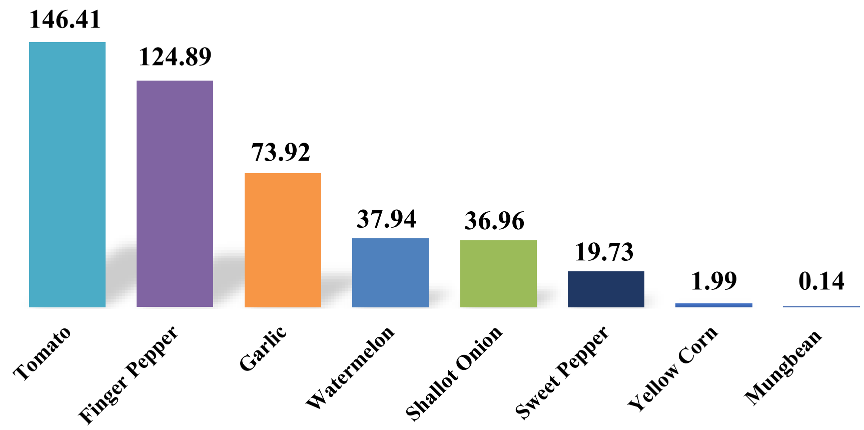

Figure 5. Profit from Current Crop Production System (in thousand US$/ha), Badoc Ilocos Norte, Dry Season, 2025

The existing crop production system of farmer-respondents in Vintar during the dry season, which was composed of 12 crops, generated various total profit levels (figures 6 and figure 7). Among them, finger pepper (US$150,892) and yellow onion (US$141,699) generated the highest average profit mt/ha. Compared with the previous literature, such income levels were both lower by 59.38% for finger pepper [48] and by 55.61% for yellow onion [54]. Notably, the land areas for finger pepper and yellow onion production were both 0.40 ha, second largest cropland area of the respondents. Meanwhile, the yellow onion had the third widest land area among crops produced but finger pepper had the highest production, generating the highest profit. On the other hand, the yellow onion had a high yield of 9.22 mt/ha and a relatively high price as well. This is higher than the average yield of 8.70 mt/ha for the Philippines [55]. Also, the average price was higher than the average by 46.82%, particularly during the off-season [56]. Overall, producing the eight crops generated a total average profit of US$657,060.32 from a 2.90-ha production area of the respondents in Vintar.

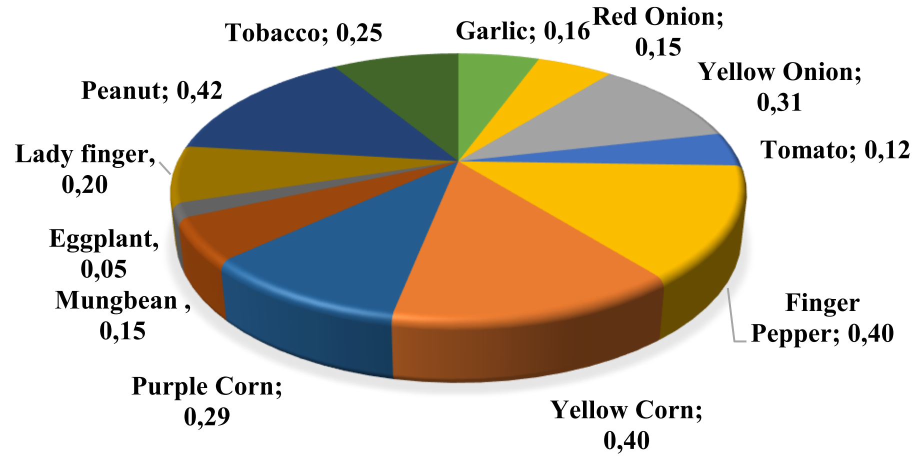

Figure 6. Current Crop Production System (in hectares), Vintar, Ilocos Norte, Dry Season, 2025

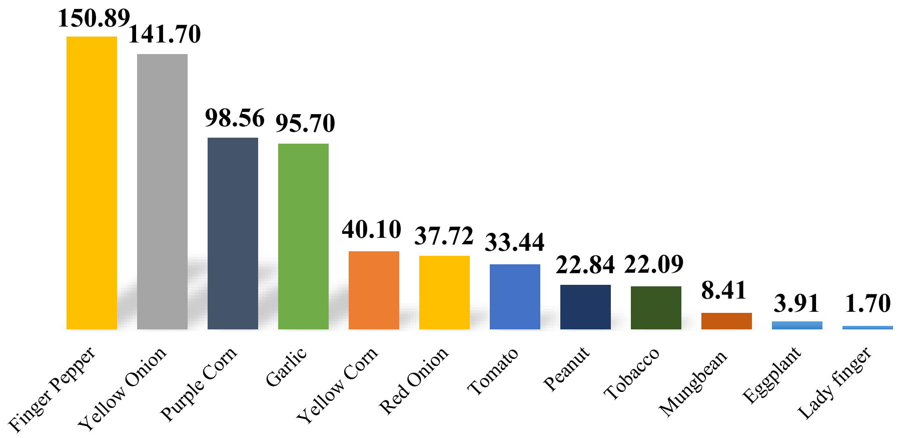

Figure 7. Profit from Current Crop Production System (in thousand US$/ha), Vintar, Ilocos Norte, Dry Season, 2025

4.3. Optimal Allocation of Croplands

Results of the linear programming showed that the respondents in Badoc should devote 2.22 ha to tomato production during the dry season. Thus, they need to make a trade-off and forego producing other crops on a total of 2.22 ha of their agricultural lands. This will generate maximum profit (gross margin) equal to US$13,618.01, a 208.09% increase in profit or a difference of US$9,198.30 compared with the existing crop production system (table 4). It should be noted that maximum profit can still be generated even if the labor cost for tomato production is among the highest cost items. A positive implication of this is in terms of local employment that could be generated for a relatively longer period, especially during harvest time. This is also supportive of and can enhance the relevance and effectiveness of the farm clustering and consolidation program that is currently being advocated by the DA. Under its Administrative Order No. 27, clustered farming "seeks to advance the interest and condition of Filipino small farmers by encouraging them to adopt the strategy of clustering and consolidation of their production, processing, and marketing activities as community business enterprises, including the pooling of assets, labor, and other resources." Such a policy aims to effectively raise the overall productivity and income of Filipino farmers, among others. Recently, the Office of

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Provincial Agriculturist in Ilocos Norte supported clustered farming in various locations for the production of high-value crops, including garlic, onion, mango, mung bean, and peanuts, with a total budget of US$509,770.60 [57]. The policy is aimed at addressing the persistent challenges faced by the dry season farmers, especially market power domination by the traders. However, it may also have implications for the province's food security and production level in the long run. Thus, further evaluation and assessment may be needed in view of effective public policies in the agriculture sector.

Table 4. Comparison of Farmers' Profits Under the Current and Optimized Production Systems (in thousand US$), Badoc, Ilocos Norte, Dry Season, 2025

	Current			Optimized		
Crop	**Area (Ha)**	**Profit/Ha (US$)**	**Total Profit (US$)**	**Area (Ha)**	**Profit/Ha (US$)**	**Total Profit (US$)**
Garlic	0.15	4,927.78	739.17			
Shallot	0.29	1,274.43	369.58			
Tomato	0.24	6,100.25	1,464.06	2.22	6,134.24	13,618.01
Finger Pepper	0.25	4,995.75	1,248.94			
Sweet Pepper	0.09	2,192.01	197.28			
Yellow Corn	0.39	50.98	19.88			
Watermelon	0.77	492.78	379.44			
Mung bean	0.04	33.98	1.36			
Grand Total	**2.22**	**20,067.97**	**4,419.71**	**2.22**	**6,134.24**	**13,618.01**

On the other hand, the respondents in Vintar should devote 2.69 ha of their croplands to purple corn production and 0.21 ha for peanut production during the dry season, increasing their production areas for purple corn and peanuts from their current levels. The recommended alternatives are expected to generate a maximum profit (gross margin) of US$9,141.89 and US$142.74, respectively. Overall, the maximum profit (gross margin) for the respondents in the area will be US$9,284.62, which is a 41% higher profit or a difference of US$2,689.21 compared with the existing crop production system in a total of 2.69 ha farm area (table 5).

Purple corn originated in Peru. In 2023, the price was US$2.00 per kilogram [58], whereas in Malaysia, purple corn had an average market price of US$0.34 per cob. Meanwhile, purple corn costs US$0.85-US$1.36/kg in Southern Philippines [59]. On average, one kilogram contains about 4 cobs, each cob having a mean weight of 258.33 g [46]. Numerous studies indicate that the crop contains anthocyanins, which can benefit human health in various aspects. Therefore, there is a high demand for it. Considering this, the National Nutrition Council in the Philippines also encourages Filipinos to consume the crop. Purple corn has a maturity date of three months or 75 days after its seeds are planted, comparable to hybrid corn, ordinary sweet corn, and white corn [58], [46]. Apparently, the crop is cultivated and conserved in the province of Kalinga, Philippines, because farmers were also aware of its anthocyanin content, which has many health benefits. The farmers produce purple corn without fertilizers, however, it was found that the application of bio-synergy and vermicompost organic fertilizers improve the yield of the purple corn [46].

According to the findings of Kasron et al [60], consumers were willing to pay more at US$1.58 per cob for purple corn due mainly to its anthocyanin content. However, the findings of this study revealed the low selling price for purple corn in Vintar, with an average price of US$0.24/kg or US$222.19/t. Nevertheless, it had the highest average production level, reaching 18.62 mt/ha. It is also the third crop with the highest gross margin among those that are currently produced. At present, it is not widely produced in the province, maybe because the level of awareness of its health benefits is still low. In addition, it is not among the priority investment programs of the government.

Sustaining and expanding peanut production is also recommended in Vintar. Among the crops produced, it had the second-highest selling price at US$1.53/kg or US$1,387.06/t. This was higher by US$0.34 compared with the findings of Balba et al. [61]. According to the data from the PSA, the average price of peanuts in Ilocos Norte was US$0.92/kg in the last five years, and the price fluctuations were relatively small compared with those of other crops. Although the average yield of peanuts was higher in Central Luzon (1,975.76 kg/ha), compared with the yield in Vintar of only 648.00 kg/ha, it should be noted that the farmers in Vintar have a lower production cost due to the crop's tolerance to

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drought and pests. Again, this has implications for the relevance and effectiveness of the farm clustering and consolidation program in Vintar. Since peanuts are part of the high-value crops (HVCs) and priority investments in the province, findings in this study may be considered for planning the cropland area allocation and corresponding interventions.

Although the proposed increase in area for the production of purple corn and peanuts may result in a significant reduction in the area for the production of other crops, the other areas producing the other HVCs in the province may supply the market's needs in the long run. This, however, should also be assessed by the concerned government offices to ensure that food security will be sustained in the province.

Table 5. Comparison of Farmers' Profits Under the Current and Optimized Production Systems (in thousand US$), Vintar, Ilocos Norte, Dry Season, 2025

	Current			Optimized		
Crop	**Area (Ha)**	**Profit/Ha (US$)**	**Total Profit (US$)**	**Area (Ha)**	**Profit/Ha (US$)**	**Total Profit (US$)**
Garlic	0.16	5,981.31	957.01			
Red Onion	0.15	2,514.87	377.23			
Yellow Onion	0.31	4,570.94	1,416.99			
Tomato	0.12	2,786.75	334.41			
Finger Pepper	0.4	3,772.30	1,508.92			
Yellow Corn	0.4	1,002.55	401.02			
Purple Corn	0.29	3,398.47	985.56	2.69	3,398.47	9,141.89
Mung bean	0.15	458.79	68.82			
Eggplant	0.05	441.80	22.09			
Lady's finger	0.2	84.96	16.99			
Peanut	0.42	679.69	285.47	0.21	679.69	142.74
Tobacco	0.25	883.60	220.90			
Grand Total	**2.90**	**26,576.04**	**6,595.41**	**2.90**	**4,078.16**	**9,284.62**

4.4. Sensitivity Analysis

For sensitivity analysis, the first scenario was based on the data from OpenSTAT, that the average price of tomato/kg increases annually by 16% over the past five years. Alongside, analysis of the DA-Fertilizer and Pesticide Authority's reports revealed that the average annual cost of fertilizers such as urea and complete increases by 11% and 14%, respectively. In the second scenario, the simultaneous annual increase in tomato/kg, by 16%, and the wage rate was used because these are the top two cost items according to the cost and returns analysis in Table 2. It is assumed that the local governments would continue to subsidize fertilizers for farmers. Thus, they would not be affected by the fertilizer price increase. The Regional Tripartite Wages and Productivity Board-Ilocos Region has increased the wage rate in the agriculture sector for the last five years at an average of US$0.54 per day, hence, this was the amount used for the analysis. In the third scenario, the simultaneous occurrence of an increase in price/kg, fertilizer cost, and wage rate was used to determine how sensitive the earnings from the optimal crop allocation would be to a simultaneous increase in the cost of important inputs.

The three scenarios revealed that although there will be changes in the farmgate price along with fertilizer cost and/or wage rate, the average profit per hectare for producing tomatoes in Badoc would still be high. Moreover, although there were slight variations in the three profitability indicators, NPV, IRR, and BCA, the results would still be acceptable. Among these, the highest NPV and BCR will be in Scenario 2. The NPV of US$31,029 will be derived by deducting the sum of discounted costs from the sum of the discounted benefits for five years. Meanwhile, the BCR of 7.88 means that the discounted benefits outweigh the discounted costs. In simple terms, for every $1.00 spent on the project, an investor or the farmers, in this case, receive approximately $7.88 in benefits in return. These indicate that increasing tomato crop production area in Badoc is a worthwhile investment, even if an annual increase in farmgate price per kg

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would be accompanied by an annual increase in wage rate for the agriculture sector. Although the scenario's IRR is not the highest, the rate of 2.52% is still positive and acceptable. Moreover, IRR is heavily reliant on projections of future cash flows, which may be inaccurate due to many uncertainties. Therefore, Scenario 2 is the most preferred among others that could potentially generate the highest benefits for the respondents (table 6)

Table 6. Summary of Sensitivity Analysis Results for Optimal Allocation of Agricultural Lands in Badoc, Ilocos Norte, Dry Season

Scenario	Discounted Benefits (US$)	Discounted Costs (US$)	Net Present Value (US$)	Benefit-Cost Ratio	Internal Rate of Return (%)
1: Change in farmgate price and fertilizer costs	29,163.56	2,288.46	8,336.45	1.51	9.00
2: Change in farmgate price and wage rate	37,313.01	4,737.70	31,029.00	7.88	2.52
3: Change in farmgate price, fertilizer costs and wage rate	36,791.68	5,259.03	29,986.35	7.00	3.23

In Vintar, 11% farmgate price increase was used for purple corn. The three scenarios for wider land allocation for purple corn revealed that changes in the farmgate price, along with fertilizer cost and/or wage rate, can still generate high average profit per hectare. In Scenario 1, the average increase in fertilizer cost by up to 14% annually cannot be entirely covered by the 11% average annual increase in farmgate price. This was reflected in the negative IRR (-0.02%), implying that a successive increase in fertilizer price can significantly reduce the income of purple corn producers (Table 7). In Scenario 2, the average annual increase in wage rate can be compensated by the annual average increase in farmgate price. The simultaneous annual increase in farmgate price and input costs in Scenario 3 also revealed that the simultaneous annual average increase in fertilizer cost and wage rate cannot be covered by the corresponding annual average increase in farmgate price. Nevertheless, the projection of the five-year production is still positive. This may be due to the very high production level, thus, income from sales, which can offset the losses from the higher cost of inputs (Table 7). In terms of NPV, IRR, and BCR, Scenario 2 can be the best option among the two alternatives, considering that it had the highest level of NPV and BCR.

There was only one scenario projected for the optimal allocation of land for peanut production due to the very limited factors that can be used. It was found that the annual average farmgate price increase for peanuts was 0.29 percent as per PSA, therefore, it was used for the succeeding analysis. In five years, the production of peanuts can generate an average income of about US$683.79 to US$692.86/ha. Henceforth, for a 0.21-ha production area, the farmer/s can earn about US$143.59 to US$145.49. Also, the annual average farmgate price increase was about US$4.01/mt or US$0.0004/kg. The three profitability indicators revealed that this investment program is also a worthwhile investment because the NPV, BCR, and IRR were high. Therefore, this scenario is more plausible than the base or existing scenario (table 7).

Table 7. Summary of Sensitivity Analysis Results for Optimal Allocation of Agricultural Lands in Vintar, Ilocos Norte, Dry Season

Scenario	Discounted Benefits (US$)	Discounted Costs (US$)	NPV (US$)	BCR	IRR (%)
1: Change in farmgate price and fertilizer costs					
For purple corn production	17,943.52	2,681.59	11,863.46	6.69	-0.02
For peanut production	2,607.63	386.48	1,796.34	6.75	51.00
2: Change in farmgate price and wage rate	18,138.26	2,486.85	12,252.94	7.29	0.004

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3: Change in farmgate price, fertilizer costs and wage rate	17,769.75	2,821.38	11,515.91	6.22	0.01

5. Conclusion

Optimization is a valuable method for efficient cropland allocation and profit maximization. This is very relevant, especially in the context wherein farmers produce diverse crops with limited resources. This study reveals that the selected towns in the province of Ilocos Norte, Philippines, with intensive crop production should reallocate their land to maximize crop production profits. The results show that devoting 2.22 ha to tomato in Badoc could increase income by 208.09%, while allocating 2.69 ha to purple corn and 0.21 ha to peanut in Vintar could raise profits by 41%. These findings confirm that optimized land use can significantly improve farmer earnings under the recognized resource constraints.

Beyond profitability, the study highlights the importance of science-based land use decisions for sustainability. Integrating optimization tools into extension programs and supporting farm clustering will further strengthen income gains and food security. Thus, this can be a basis in crafting a decision-making tool for policymakers and farm organizations in the respective study areas.

Future research should expand to other towns and provinces and incorporate climate and market risks into optimization models to guide long-term agricultural strategies. Moreover, the limitations of the linear programming approach (e.g., price volatility, risk preferences of farmers, crop rotation requirements, and non-linear yield responses) that were not sufficiently included in this study should also be further analyzed because these could also significantly affect the practical implementation of the proposed land allocation. The analysis of agricultural lands combined with livestock production can also be done for a more comprehensive perspective.

6. Declarations

6.1. Author Contributions

Conceptualization: M.C.P.P., J.A.D., and A.J.Q.; Methodology: M.C.P.P., J.A.D., and A.J.Q.; Software: A.J.Q. Validation: M.C.P.P., J.A.D., and A.J.Q.; Formal Analysis: M.C.P.P., J.A.D., A.J.Q., and D.B.A.; Investigation: M.C.P.P.; Resources: M.C.P.P.; Data Curation: M.C.P.P.; Writing Original Draft Preparation: M.C.P.P.; Writing Review and Editing: M.C.P.P., J.A.D., A.J.Q., and D.B.A.; Visualization: M.C.P.P., J.A.D, and A.J.Q. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

Following the Data Privacy Law of the Philippines, the data presented in this study will be made available with the informed consent of the respondents.

6.3. Funding

The main author received financial support for the research and its dissemination from the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), a non-profit organization established in 1966 by the Southeast Asian Ministers of Education Organization (SEAMEO). Also, the Mariano Marcos State University (MMSU), a premier higher education institution in Ilocos Norte, Philippines, where the main author is affiliated, provided financial support for the publication of this article.

6.4. Institutional Review Board Statement

The University of the Philippines Los Baños Research Ethics Board (UPLB REB) Review Panel 1A has reviewed and approved the study protocol of this study, titled “Optimal Allocation of Croplands During Dry Season in Selected Towns of Ilocos Norte, Philippines,” for implementation on December 4, 2024. (The complete document is available. It can be provided upon request.)

6.5. Informed Consent Statement

This document is available. It can be provided upon request.

6.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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