AN OPTIMIZATION MODEL FOR CROP ALLOCATION TO MAXIMIZE PROFIT UNDER CARBON TARIFFS AND INTERNATIONAL CARBON CREDIT MARKETS

MÔ HÌNH PHÂN BỔ CÂY TRỒNG NHẰM TỐI ĐA LỢI NHUẬN TRONG BỐI CẢNH THUẾ QUAN CARBON VÀ THỊ TRƯỜNG TÍN CHỈ CARBON QUỐC TẾ

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Abstract - In response to global climate change challenges, many agricultural-importing countries have tightened environmental policies, notably through the implementation of carbon tariffs to control greenhouse gas (GHG) emissions. To address this issue, the research team developed a linear programming (LP) optimization model to determine an efficient crop structure that maximizes profits under carbon tariff constraints. To evaluate the feasibility of this model, a simulation scenario based on reference data in the Mekong Delta (MD) was proposed as a representative case study. The results indicate that the model not only improves land-use efficiency and profitability but also expands opportunities for participation in the international carbon credit market. This research provides practical insights for promoting sustainable agriculture and enhancing the competitiveness of Vietnamese agricultural products in the international market.

Key words - Carbon tariffs; Linear programming (LP); crop allocation; sustainable agriculture; Carbon credits.

Tóm tắt - Trước thách thức toàn cầu về biến đổi khí hậu, nhiều quốc gia nhập khẩu nông sản đã siết chặt chính sách môi trường, đặc biệt là áp dụng thuế quan carbon nhằm kiểm soát phát thải khí nhà kính (GHG). Nhằm tìm ra giải pháp thích ứng, nhóm nghiên cứu đã xây dựng mô hình tối ưu hóa tuyến tính (LP) giúp xác định cơ cấu cây trồng hợp lý và tối đa hóa lợi nhuận trong điều kiện chịu tác động của thuế carbon. Để đánh giá tính khả thi của mô hình này, một kịch bản giả lập theo dữ liệu tham khảo ở vùng Đồng bằng sông Cửu Long (ĐBSCL) được đề xuất làm trường hợp nghiên cứu điển hình. Kết quả cho thấy mô hình không chỉ nâng cao hiệu quả sử dụng đất và lợi nhuận, mà còn góp phần mở rộng cơ hội tham gia thị trường tín chỉ carbon. Nghiên cứu mang ý nghĩa thực tiễn trong việc định hướng phát triển nông nghiệp bền vững và tăng khả năng cạnh tranh của nông sản Việt Nam trên thị trường quốc tế.

Từ khóa - Thuế quan carbon; tối ưu hóa tuyến tính; cơ cấu cây trồng; nông nghiệp bền vững; tín chỉ carbon.

1. Introduction

The Mekong Delta (MD) is a key agricultural production area in Vietnam, accounting for 33.5% of the country's total fruit cultivation area. Benefiting from favorable climatic conditions and an extensive irrigation system, this region plays a pivotal role in ensuring both national and international food security. In 2024, the export value of agricultural products reached a record USD 7.12 billion, with the MD making significant contributions, especially with fruits such as durian, dragon fruit, banana, mango, and jackfruit. China is the largest consumer market, followed by the United States, the EU, Japan, and South Korea.

However, fruit export activities in Vietnam in general and the MD in particular are facing an urgent need for transformation to adapt to increasingly stringent environmental regulations from international markets. The rise in greenhouse gas (GHG) emissions has prompted many importing countries to implement control measures such as carbon tariffs. Although these barriers currently do not exert excessive direct pressure, they signal a tightening trend in the near future. This requires Vietnam's agricultural sector, especially enterprises with limited resources, to gradually transition to sustainable production models to maintain export advantages and enhance long-term competitiveness.

In this context, carbon credits are receiving increasing attention, and the exploitation of carbon credits in agriculture is emerging as a promising direction. Besides forests, fruit trees in the MD, particularly perennial species such as durian, mango, and star apple, have the capacity to absorb CO_2 and participate in the carbon credit market if sustainable cultivation practices are adopted. This not only helps the agricultural sector mitigate costs associated with carbon tariffs but also creates additional revenue streams, enhances product value, and increases the competitiveness of Vietnamese agricultural products in the global market.

Therefore, this study proposes a linear programming (LP) optimization model ([1],[2]) for allocating areas to potential crops, integrating emission and carbon credit factors to maximize profit on a given land area and help enterprises better adapt to changing market requirements.

2. Literature review

2.1. Crop allocation using traditional cultivation methods

Crop allocation has long been a concern, primarily in the context of traditional cultivation, with the goal of efficient land use to maximize yield and profit for farmers. In summary, several key factors such as crop variety, soil conditions, and management practices have been identified as having significant impacts on productivity, forming the foundation for subsequent modern research directions [3].

Building on this, recent studies have approached the issue quantitatively and through technological applications. For example, a study in Northeast China employed a multi-criteria evaluation (MCE) method combined with GIS to determine the suitability of rice, soybean, and maize under local natural conditions, thereby proposing a crop rotation model to improve land-use efficiency and ensure food security [4]. Additionally, researchers have focused on optimizing crop diversity by applying mathematical models such as linear programming and optimization algorithms to assist farmers in making rational decisions regarding crop type, timing, and planting area, thus enhancing production efficiency [5], [6].

2.2. Crop allocation following sustainable trends

Amid the growing need for optimizing agricultural land use, sustainable crop allocation is becoming an important orientation in agricultural planning and development. Various land suitability assessment methods, such as the FAO framework, MCDA, AHP, and GIS, facilitate the selection of crops compatible with natural conditions, optimizing economic efficiency and protecting soil resources [7]. Moreover, crop optimization models play a crucial role in rational land allocation, not only increasing profits but also reducing resource dependency, thereby promoting sustainable cultivation [8].

Linear programming (LP)-one of the most widely used tools in crop optimization models-enhances land allocation efficiency and fosters sustainable cultivation. For instance, Sofi et al. applied the simplex method to adjust the allocation of wheat, rice, beans, and maize, expanding the area from 2,409 to 2,752.56 acres, resulting in higher profits [9]. Similarly, Bhatia and Bhat utilized an LP model to optimize crop structure, achieving an income of 156,499 Rs by switching from a mixed crop of wheat, grapes, and mustard to peas [10]. In 2020, Bhatia and Rana proposed two scenarios combining crop and livestock farming, improving land allocation efficiency to 68% on farm 1 and 16.5% on farm 2, while also enhancing soil quality and reducing production costs [11]. Additionally, research by Alotaibi and Nadeem highlighted the role of LP in identifying high-value crops and efficiently allocating area to maximize profit [12].

2.3. Crop allocation considering carbon emissions

A study was conducted by integrating life cycle assessment (LCA) with the Monte Carlo method to estimate the carbon footprint of rice, maize, and soybean production in various cities in Northeast China. The research proposed crop allocation strategies combined with staged fertilization [13]. In Turkey, Başer et al. investigated land fragmentation in hazelnut cultivation, revealing that fragmented farms have 11.74% higher GHG emissions than non-fragmented ones, emphasizing the importance of land management to minimize emissions [14]. Furthermore, a study on soil CO_2 flux changes indicated that cultivating soybeans and eucalyptus could be a low-carbon farming strategy, reducing environmental impact and supporting carbon neutrality goals in agriculture [15].

2.4. Carbon credits and markets

Recent studies on sustainable agriculture not only focus on profit optimization but also open up opportunities to participate in the carbon credit market. Meena et al. demonstrated that conservation agriculture, agroforestry, and land conversion could reduce CO_2 emissions by 20–30%, while providing opportunities to earn income from carbon credits [16]. Other studies also affirm that carbon credits can promote emission reductions and increase income, but simplifying measurement and providing financial support for farmers are essential for effective participation, although technical and financial barriers remain [17].

The current carbon market includes two main types: mandatory markets, such as Emissions Trading Systems (ETS), and voluntary markets, where businesses purchase carbon credits to offset emissions and meet ESG standards. Regions like the EU, China, and several US states have implemented these systems, promoting sustainable production and mitigating climate change impacts. In Vietnam, the carbon market is being developed under Decree 06/2022/NĐ-CP, with a pilot planned for 2025 and official operation in 2028. Currently, carbon credit transactions mainly occur in the voluntary market due to the absence of an official trading platform. Participation in the carbon credit market also creates new financial opportunities through the sale of carbon credits from sustainable agricultural activities [18].

Challenges from the carbon market also present significant opportunities as low-emission farming models are deployed. In the MD, the project for one million hectares of high-quality, low-emission rice aims to reduce 5–10 tons of CO_2/ha/year, equivalent to 5–10 carbon credits, generating profits of USD 50–100 [19]. In Đắk Lắk, a similar model helps reduce about 3.5 tons of CO_2/ha, increase yields, and improve farmers' incomes through carbon credit sales and reduced production costs [20].

2.5. Crop allocation considering the impact of carbon tariffs

Although relatively new, research on the impact of carbon tax policies and land-use changes on GHG emissions is gaining attention, reflecting a growing global awareness of agriculture's role in climate change mitigation.

Climate simulation models show that combining increased crop productivity with the implementation of global carbon tariffs can limit the expansion of cultivated land, thereby effectively reducing emissions. Additionally, research in Chile indicated that imposing sector-specific taxes on agriculture leads to significant economic losses and low emission reduction efficiency, whereas comprehensive carbon taxes combined with forestry subsidies achieve higher environmental effectiveness with minimal impact on growth. These findings suggest that carbon taxes are only truly effective when implemented synchronously with appropriate support policies, in which crop allocation strategies must consider both economic benefits and environmental objectives [21]. These two goals should be pursued in parallel in the long-term development strategies of agricultural enterprises.

2.6. Contribution of the study

Table 1. *Review of related literature*

Year	Author	Crop Allocation Model					Method and Algorithm
		A	B	C	D	E	
2005	Donal J Mead	✓					Literature Review, Modeling and Forecasting
2011	Nordin Mohamad	✓					LP
2012	Wankhade	✓					LP, Push – Pull System
2013	Ruohong Cai	✓					Stochastic Modeling, Dynamic Optimization Model
2014	Davies Barnard	✓		✓	✓		Hadley Centre Global Environment Model version 2 – Earth System
2015	Sofi		✓				LP
2016	Chiranjit Singha		✓				Literature Review
2017	Sara Osama		✓				LP, GA
2017	Mohammadi		✓	✓			LP, Interger Linear Programming
2019	Mahak Bhatia		✓				LP
2020	Mahak Bhatia		✓				LP
2020	Cristian Mardones				✓		CGE (Computable General Equilibrium)
2021	Alanoud M Alotaibi		✓				LP, Parametric Programming
2021	Ge Song	✓	✓				Agent-based Land Allocation Modeling, Multi-Criteria Evaluation (MCE)
2022	Nimanthika Lokuge			✓		✓	Qualitative Analysis, Literature Review
2023	Hoàng Đông			✓		✓	MRV (Measurement, Reporting and Verification)
2024	Jin Sai Chen		✓	✓			Monte Carlo, Life Cycle Assessment
2024	Paulo Eduardo Teodoro		✓	✓			Principal Component Analysis
2024	Uğur Başer		✓	✓			Life Cycle Assessment, Partial Budgeting Analysis
2024	Ram Swaroop Meena			✓		✓	Quantitative Analysis, Qualitative Analysis, Literature Review

***A**: Conventional Approach; **B**: Sustainable Approach; **C**: Carbon-Conscious Planting; **D**: Incorporates Tax Policy; **E**: Integrates Carbon Credit Mechanisms*

Based on the studies summarized in Table 1, it can be seen that most current research focuses on the relationship between crop allocation and emission reduction, without fully integrating factors such as profit, carbon tariffs, and carbon credits. The lack of such integrated analyses creates a gap in the development of comprehensive decision-making models. In particular, key factors such as carbon emissions, the impact of tariffs on crop structure, and trading opportunities for optimizing profits have not been thoroughly considered.

Driven by these practical requirements, the proposed optimization model aims to enhance the efficiency of fruit crop area allocation, thereby maximizing profit for producers. The model simultaneously incorporates emerging factors such as carbon tariffs in major export markets, helping enterprises to proactively adapt to policy changes. Additionally, the model considers the CO_2 absorption capacity of perennial fruit trees, opening up pathways for accessing the carbon credit market as a supplementary source of income.

3. Model development

3.1. Problem description

This study develops a linear programming (LP) optimization model [12] for planning the cultivation area of export-oriented crops in the context of international economic integration and the need to improve agricultural resource management efficiency. As the global market imposes stricter environmental standards, especially regarding carbon emissions from imported agricultural products, agricultural production organizations face the challenge of balancing economic efficiency with environmental responsibility.

The crop allocation model is described in the overview diagram in Figure 1. Harvested products from these areas can be distributed in two main directions:

- Exporting fruits to consumer markets, ensuring minimum and maximum demand compliance.
- Selling carbon credits when environmental requirements are met (i.e., net carbon absorption exceeds emissions), opening opportunities for additional income.

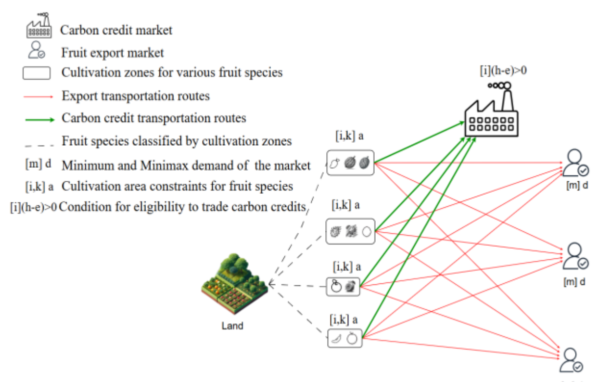

Figure 1. *Problem description diagram*

This study focuses on developing an optimization model for allocating crop areas over a specific time period (Figure 2), aiming to:

- Maximize profit from fruit exports.
- Ensure carbon emission standards and leverage the carbon credit market.
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Model assumptions:

- Ensure carbon emission standards and leverage the carbon credit market.
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- Profit from carbon credits is calculated by multiplying net positive CO_2 absorption by the carbon credit price. Since Vietnam's mandatory carbon market is not yet officially operational, this study uses reference prices from the international voluntary carbon market. Specifically, data are sourced from the Verra – Verified Carbon Standard (VCS) system and the State of the Voluntary Carbon Markets 2024 report by Ecosystem Marketplace [22].
- The model calculates profit based on nominal annual values without discounting cash flows to present value, to simplify the comparison of alternatives during the initial implementation phase.

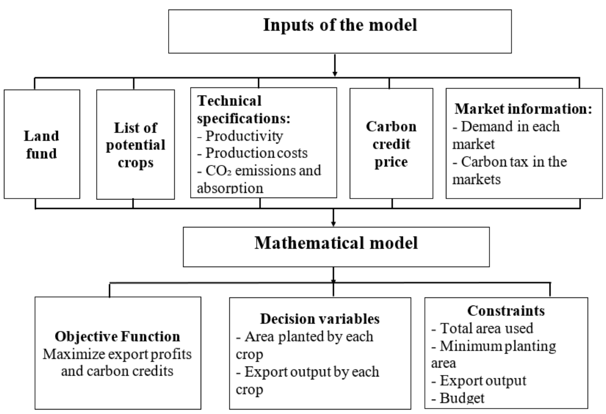

Figure 2. *Mathematical Model Development Flowchart*

Parameters:

a_k Total area of region k.

$dmax_{i,t,m}$ Maximum export demand for crop i in year t in market m.

$dmin_{i,t,m}$ Minimum export demand for crop i in year t in market m.

$l_{i,m,t}$ Export profit for crop *i* in year *t* in market *m*.

$q_{i,t,m}$ Carbon tariff for crop *i* in year *t* in market *m*.

$p_{i,t}$ Carbon profit for crop i in year t.

$c_{i,t}$ Cultivation cost for crop i in year *t*.

$r_{i,t}$ Yield of crop *i* in year *t*.

s_i Minimum area required for crop *i* to achieve economic efficiency.

$v_{i,t,m}$ Export cost for crop i in year *t* in market *m*.

$w_{k,i}$ Assigned value of *1* if crop *i* is suitable for region *k*, otherwise 0.

Decision variables:

$X_{k,i}$ Area of crop i in region k.

$Y_{i,t,m}$ Export output of crop i in year t in market m.

Objective function:

The objective function is to maximize profit from fruit exports and carbon credit sales. Specifically, the problem seeks the optimal values for the area allocated to each crop and export output.

$$Max: Z = \sum_{t=1}^{T}\sum_{i=1}^{I}\left(\sum_{m=1}^{M}((l_{i,t,m} - q_{i,t,m}\right)Y_{i,t,m}) + \sum_{k=1}^{K} X_{k,i}.(p_{i,t} - c_{i,t})) \quad (1)$$

Constraints include:

Land area limitation:

$$\sum_{i=1}^{I} X_{k,i} \leq a_k, \forall k \quad (2)$$

The total area allocated to all crops *i* in region *k* must not exceed the available area a_k.

Land allocation in each region:

$$w_{k,i}s_i \leq X_{k,i} \leq w_{k,i}a_k, \forall k,i \quad (3)$$

The area for crop *i* must not be less than the minimum required s_i for economic efficiency and must not exceed the total available area in region *k*.

Export output limitation:

$$\sum_{m=1}^{M} Y_{i,t,m} \leq r_{i,t}\sum_{k=1}^{K} X_{k,i}, \forall i,t \quad (4)$$

The total export output of crop *i* to all export markets must not exceed the actual harvested yield.

Market demand:

$$dmin_{i,t,m} \leq Y_{i,t,m} \leq dmax_{i,t,m}, \forall i,m,t \quad (5)$$

Export output must meet the minimum requirement to maintain market share but not exceed the maximum demand.

Budget constraint:

$$\sum_{k=1}^{K}\sum_{i=1}^{I}(c_{i,t}X_{k,i}) + \sum_{m=1}^{M}\sum_{i=1}^{I} Y_{i,t,m}(q_{i,t,m} + v_{i,t,m}) \leq b_t, \forall t \quad (6)$$

Ensures that the total production and export costs in year *t* do not exceed the available budget b_t.

Non-negativity of decision variables:

$$X_{k,i}, Y_{i,m,t} \geq 0, \forall i,k,t,m \quad (7)$$

4. Experimental results

4.1. Case study description

The case study is based on an agricultural cooperative in the Mekong Delta (MD), which owns a land fund of 350 hectares divided into four areas with distinct characteristics, each suitable for different crop types. The harvested products are exported to three major markets: the United States, the EU, and China. The model is designed to plan crop cultivation over a 10-year period with the objective of maximizing profit.

Table 2. *Crop allocation and land use per region*

Land type	Area (ha)	Crops
Alluvial soil along rivers	140	Mango, Durian, Jackfruit
Sandy loam soil along rivers	105	Dragon fruit, Coconut, Passion fruit
Elevated well-drained land	70	Banana, Star apple
Slightly saline and acidic alluvial soil	35	Pomelo, Orange

4.2. Experimental results

The optimization model was solved using IBM ILOG CPLEX 12.6 software, executed on a computer with a Core (TM) i5-11320H 3.20GHz processor and 8.00 GB RAM. The results show that the objective function value reached VND 1,244 billion, with the following breakdown:

- Carbon tax cost: VND 48.33 billion;
- Cultivation cost: VND 636.54 billion;
- Export profit: VND 1,895 billion;
- Carbon credit profit: VND 33.85 billion.

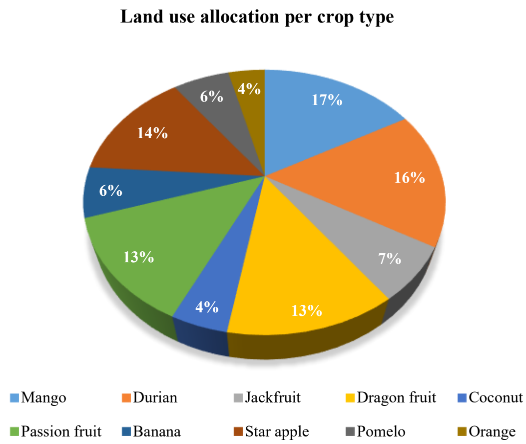

Figure 3. *Land use allocation per crop type*

Figure 3 illustrates the allocation of land area for each crop type. The results indicate that mango and durian are prioritized, occupying the largest areas (17% and 16%, respectively), followed by dragon fruit, passion fruit, and star apple, which have similar proportions. This reflects the high economic efficiency and strong adaptability of these crops to their respective soil types.

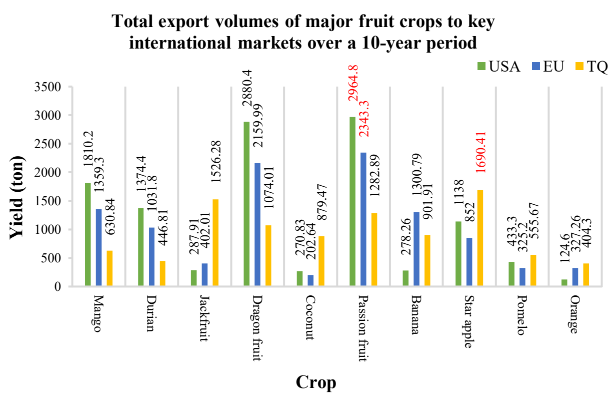

Figure 4. *Export volumes of fruit crops by market*

Differences in consumption levels and carbon tariff rates across markets are reflected in the allocation of export output. Figure 4 shows that the model optimizes crop structure and output distribution to maximize market advantages: passion fruit and dragon fruit are prioritized for export to the US and EU due to higher selling prices and carbon credit opportunities, while crops such as jackfruit, star apple, pomelo, and orange are focused on the Chinese market, which has more accessible requirements. Allocating output according to market characteristics enables enterprises to proactively optimize profits by leveraging high prices, favorable carbon tariff rates, and regional consumer preferences.

4.3. Sensitivity analysis

Sensitivity analysis was conducted to assess the impact of key parameters on the optimal results, including export profit, carbon profit, carbon tax, cultivation cost, yield, minimum and maximum demand. This analysis supports effective decision-making in the context of constantly changing real-world conditions. The analysis focuses on:

- The individual impact of each factor on the objective function value.

- The combined effect (when multiple factors change simultaneously) on the objective function value.

Table 3 presents the analysis data, which were developed based on three scenarios for each factor: Low – Medium – High.

Table 3. *Key factors incorporated in sensitivity analysis*

Factor	Adjustment scenarios		
	Low (Derease)	Medium	High (Increase)
Export profit	20%	-	20%
Carbon profit	20%	-	60%
Carbon Tariffs	20%	-	60%
Farming cost	20%	-	20%
Maximum demand	20%	-	20%
Minimum demand	20%	-	20%
Productivity	20%	-	20%

Due to the large number of full factorial combinations ($3^7 = 2{,}187$), the research team used a fractional factorial design. After removing outliers and duplicates, 29 representative experiments remained. Analysis was performed using Minitab 17 software.

Table 4. *Analytical results*

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Export profit	7	1.58950E+24	2.27072E+23	1648.24	**0.000**
Carbon profit	1	7.96049E+23	7.96049E+23	5778.28	**0.000**
Carbon Tariffs	1	1.94069E+21	1.94069E+21	14.09	**0.001**
Farming cost	1	2.11879E+21	2.11879E+21	15.38	**0.001**
Maximum demand	1	1.23268E+23	1.23268E+23	894.77	**0.000**
Minimum demand	1	3.71365E+20	3.71365E+20	2.70	0.116
Productivity	1	3.02911E+20	3.02911E+20	2.20	0.153
Export profit	1	3.18425E+23	3.18425E+23	2311.35	**0.000**
Error	21	2.89308E+21	1.37766E+20		
Total	28	1.59239E+24			

Model Summary

S	R-sq	R-sq (adj)	R-sq (pred)
1.17374E+10	99.82%	99.76%	99.62%

After analysis, the key factors influencing the objective function value are: export profit, carbon profit, carbon tax, cultivation cost, and yield. The model demonstrates high statistical significance with a clear linear relationship between input variables and the objective function. The R^2 index reached 99.82%, indicating that the model explains most of the variance in the dependent variable. The adjusted R^2 (99.76%) confirms that all included variables contribute significantly without causing noise.

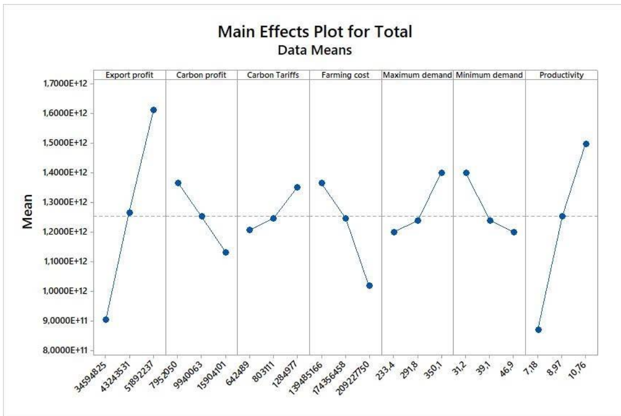

Figure 5. *Main effects plot of key factors on the objective function*

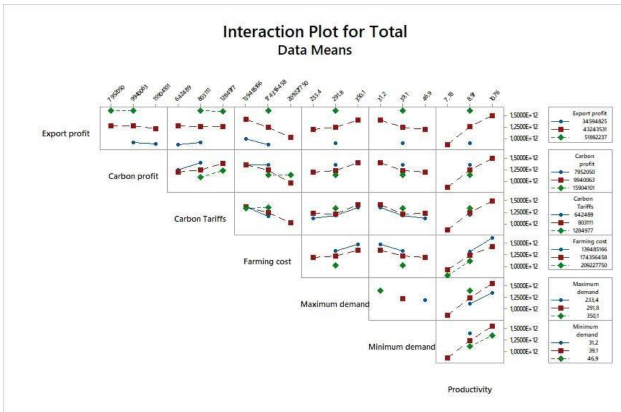

Figure 6. *Interaction plot of factor means for the objective function*

Figure 5 shows the impact of each factor on the objective function value. Export profit and yield exhibit a strong positive correlation with profit, while cultivation cost has a negative impact. Carbon tax and carbon profit have moderate effects, whereas minimum and maximum demand show little to no significant difference. Figure 6 illustrates the interaction between pairs of factors. Pairs such as cultivation cost–carbon tax and yield–carbon profit have non-parallel lines, indicating relatively clear interaction-meaning the effect of one factor depends on the value of the other. In contrast, pairs like maximum demand–minimum demand have nearly parallel lines, indicating little or no interaction.

Based on the analysis results, three recommendations are proposed for enterprises in planning crop structure to meet market and international environmental policy requirements:

- Prioritize crops with high yield and export profit, suitable for demanding but high-profit markets.
- Combine cost control in cultivation with emission reduction to mitigate the dual impact of carbon tariffs.
- Leverage opportunities from carbon credits by selecting perennial crops with CO_2 absorption capacity and implementing MRV systems.

4.4. Model effectiveness evaluation

The traditional model was built with 10 crop types allocated across 4 cultivation regions, each corresponding to the crop types in the optimal model's case study. However, the traditional model selects only the most suitable crop for each region based on production experience and common cultivation practices. Crop allocation does not consider emissions or carbon credit potential, focusing solely on maximizing profit from crop yield per soil type.

Table 5. *Results of the optimized model compared to the traditional model*

Comparison Criteria	Traditional Model	Optimized Model
Total Profit	VND 977.91 billion	VND 1,244 billion
Profit from Carbon Credits	VND 0	VND 33.85 billion
Cultivation Cost	VND 655.20 billion	VND 636.54 billion
Carbon Tax	VND 468.97 billion	VND 48.33 billion
Carbon Emissions	11,646 tons of CO_2	10,126 tons of CO_2

One of the most notable differences between the two models lies in the ability to access and capitalize on the carbon market mechanism, as evidenced by the simultaneous reduction in emissions and the creation of new revenue streams. Specifically, the optimal model reduces CO_2 emissions by approximately 13% compared to the traditional model, while generating nearly VND 34 billion from carbon credits-a revenue source previously untapped. As a result, total profit increased significantly, with a difference of 27.21%, demonstrating improved efficiency stemming from cost reduction and the addition of non-traditional revenue sources.

5. Conclusion and recommendations

This study developed an optimization model for crop area allocation with the goal of maximizing export profit, leveraging carbon credits, and complying with international carbon tariff regulations. The results show that the model not only enhances economic efficiency but also serves as a decision-support tool for enterprises, helping to select optimal crop allocation plans under practical constraints.

Several recommendations to increase practical applicability include: (1) pilot implementation in potential regions and building local experimental databases to calibrate the model; (2) comparison with traditional cultivation methods; (3) establishment of appropriate financial and technical support mechanisms such as green credit and subsidies to encourage enterprises and farmers to transition. In the future, the model can be expanded in the following directions: (1) planning raw material regions to serve export value chains integrating logistics and processing; (2) optimizing the combination of crops, livestock, and multi-resource use (land, water, labor); (3) planning renewable energy and developing low-emission agriculture in conjunction with sustainable regional economic spatial design.

REFERENCES

[1] A. Charnes, W. W. Cooper, and R. O. Ferguson, "Optimal estimation of executive compensation by linear programming", *Management Science*, vol. 1, no. 2, pp. 138–151, 1955.

[2] G. B. Dantzig, "Maximization of a linear function of variables subject to linear inequalities", in *Activity Analysis of Production and Allocation*, T. C. Koopmans, Ed. New York: Wiley, 1951, pp. 339–347.

[3] D. J. Mead, “Opportunities for improving plantation productivity. How much? How quickly? How realistic?”, *Biomass and Bioenergy*, vol. 28, no. 2, pp. 249–266, 2005.

[4] G. Song and H. Zhang, “Cultivated Land Use Layout Adjustment Based on Crop Planting Suitability: A Case Study of Typical Counties in Northeast China”, *Land*, vol. 10, no. 2, p. 107, 2021.

[5] N. H. Mohamad and F. Said, “A mathematical psrogramming approach to crop mix problem”, *African Journal of Agricultural Research*, vol. 6, no. 1, pp. 191–197, 2011.

[6] M. O. Wankhede and H. S. Lounge, “Allocation of Agricultural Land to The Major Crops of Saline Track By Linear Programming Approach: A Case Study”, *International Journal of Scientific & Technology Research*, vol. 1, no. 9, pp. 21–25, 2012.

[7] Singha and K. C. Swain, “Land suitability evaluation criteria for agricultural crop selection: A review”, *Agricultural Reviews*, vol. 37, no. 2, pp. 125–132, 2016.

[8] S. Osama, M. Elkholy and R. M. Kansoh, “Optimization of the cropping pattern in Egypt”, *Alexandria Engineering Journal*, vol. 56, no. 4, pp. 557–566, 2017.

[9] N. A. Sofi, A. Ahmed, M. Ahmad, and B. A. Bhat, “Decision Making in Agriculture: A Linear Programming Approach”, *International Journal of Modern Mathematics Sciences*, vol. 13, no. 2, pp. 160–169, 2015.

[10] M. Bhatia and G. M. J. Bhat, “Linear Programming Approach Application in Agriculture”, *Journal of Emerging Technologies and Innovative Research*, vol. 6, no. 5, pp. 155–157, 2019.

[11] M. Bhatia and A. Rana, “A mathematical approach to optimize crop allocation – A linear programming model”, *International Journal of Design & Nature and Ecodynamics*, vol. 15, no. 2, pp. 245–252, 2020.

[12] A. Alotaibi and F. Nadeem, “A Review of Applications of Linear Programming to Optimize Agricultural Solutions”, *Information Engineering and Electronic Business*, vol. 13, no. 2, pp. 11–21, 2021.

[13] J. S. Chen *et al.*, “Greenhouse gas emissions and mitigation potential of crop production in Northeast China”, *European Journal of Agronomy*, vol. 161, p. 127371, 2024.

[14] U. Başer, “The effects of land fragmentation on hazelnut farming in Türkiye: Environmental, economic, and policy perspectives”, *Applied Fruit Science*, vol. 66, no. 5, pp. 1987–1996, 2024.

[15] P. E. Teodoro *et al.*, “Soil CO2 emissions under different land-use managements in Mato Grosso do Sul, Brazil”, *Journal of Cleaner Production*, vol. 434, p. 139983, 2024.

[16] R. S. Meena *et al.*, “Potential of Indian agriculture for capturing atmospheric CO2 and monetizing carbon credits to the farmers: an overview and policy framework”, *Advances in Agronomy*, vol. 188, pp. 101–206, 2024.

[17] N. Lokuge and S. Anders, “Carbon-credit systems in agriculture: a review of literature”, *The School of Public Policy Publications*, vol. 15, 2022.

[18] N. N. K. Linh and N. D. Thanh, “Laws on mandatory carbon credit markets in some countries worldwide and suggestions for Vietnam”, *HUL*, no. 60, pp. 30, 2024.

[19] H. Dong, “Selling carbon credits earns millions of USD from sustainable rice cultivation”, *TheLeader.vn*, Oct. 5, 2023. [Online]. Available: https://theleader.vn/ban-tin-chi-carbon-thu-loi-hang-trieu-usd-tu-trong-lua-ben-vung-d7056.html [Accessed Feb. 25, 2025].

[20] H. Ly, “Dak Lak farmers increase profits from green rice production with reduced emissions”, *VOV.VN*, May 23, 2024.[Online]. Available: https://vov.vn/kinh-te/nong-dan-dak-lak-tang-loi-nhuan-tu-san-xuat-lua-xanh-giam-phat-thai-post1096862.vov [Accessed Feb. 26, 2025].

[21] T. Davies Barnard, P. J. Valdes, J. S. Singarayer, and C. D. Jones, “Climatic impacts of land-use change due to crop yield increases and a universal carbon tax from a scenario model”, *Journal of Climate*, vol. 27, no. 4, pp. 1413–1424, 2014.

[22] Ecosystem Marketplace, "State of the Voluntary Carbon Market 2024: On the Path to Maturity”, *A Forest Trends Initiative*, 2024. [Online]. Available: https://www.ecosystemmarketplace.com/publications/2024-state-of-the-voluntary-carbon-markets-sovcm/ [Accessed July 18, 2025].