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BUILDING REASONABLE AGRICULTURAL LAND-USE STRUCTURE WITH OPTIMAL MATHEMATICAL MODEL

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Abstract. This study applies the optimal mathematical model to develop a rational agricultural land-use structure that brings economic, social, and environmental benefits to Que Son district, Quang Nam province. We utilized the method of focus group discussions and household interviews. One hundred and twenty-five households directly engaging in agricultural production in five communes of the district participated in the study. The model was used to build the agricultural land-use structure with the following conditions: limiting the cultivated area, ensuring food security, and guaranteeing labour in the agriculture sector. The results indicate that Que Son district needs to reduce 29.1 ha for peanuts and 8.8 ha for vegetable cultivation while increasing 387.6 ha for maize, 190.1 ha for sweet potato, and 190.1 ha for sesame cultivation.

Keywords: agricultural land-use structure, optimal mathematical model, Que Son district

I Introduction

Under the pressure of urbanization and population growth, agricultural land is at risk of declining quantity and quality [13]. Humans have exploited too much but have not had reasonable measures to protect the land. Rational land use, building clean agriculture, producing various quality products, and ensuring a stable ecological environment and sustainable development are global problems [2, 3].

The conflict between the exploitation and the use of land resources in socio-economic development is increasing, creating fierce competition between land use purposes. Therefore, making land use arrangement decisions that satisfy the goals and high economic efficiency, adapt to the requirements of the whole society, and minimize the negative impact on the environment is a complex problem that decision-makers (managers, planners, etc.) are facing [4].

Optimal mathematical model is a method of calculating functions with limited conditions so that the target function reaches the optimum level [12]. Currently, the application of optimal problem models with the help of computers has been one of the methods with numerous advantages. It is deployed in most fields, such as economic, technical and land management [14].

In land use, the goals are often conflicting; besides, the limited conditions of capital, labour, land area, and market pose such a huge problem that if one can meet one goal, he will not meet the other. Therefore, applying the optimal mathematical model to determine the appropriate land-use structure is essential in guiding economic development [10].

Que Son is a midland district of Quang Nam province, where the majority of people rely on agricultural production. The area for agricultural production land in 2019 accounts for 52.79% of the total agricultural area of the district with 11,173.5 ha [11]. Therefore, using an optimized mathematical model to develop a scientific and reasonable agricultural land-use structure is vital.

2 Methods

2.1 Collecting data

Secondary data: Secondary data on statistics, land inventory, land use plans, and documents regarding natural conditions and socio-economic conditions were collected at the District People's Committee, Department of Natural Resources and Environment, Statistical Office, and Agriculture Division.

Primary data: Primary data were gathered through surveys of agricultural land users in the district through a pre-designed questionnaire form relating to agricultural land use, economic efficiency, and factors affecting the economic efficiency of agricultural land-use types.

Based on natural conditions, socio-economic situation and agricultural land use, we can divide Que Son district into three distinct agricultural production regions.

- Region 1, bordering Dien Ban district, consists of mostly flat terrain; these are Que Xuan 1, Que Xuan 2, Que Phu, and Huong An communes.
- Region 2, located in the middle of the terrain with flat but high and rugged areas, includes

Table 1. Distribution of the survey by district administrative unit

Study sites	Number of questionnaires
Que Phu Commune	25
Que Xuan 2 Commune	25
Que My Commune	25
Que Thuan Commune	25
Que Phong Commune	25
Total	**125**

Que My, Que Thuan, Que Hiep, Que Chau communes and Dong Phu Town.

- Region 3, a highland area bordering Nong Son and Hiep Duc districts, consists of mountainous communes: Que Phong, Que Minh, Que Long, and Que An.

We conducted interviews in five communes representing these three regions:

- Que Phu and Que Xuan II communes (Region 1),
- Que My and Que Thuan communes (Region 2),
- Que Phong commune (Region 3).

The sample size (n) was determined from the Cochran formula [1]:

$$n = \frac{pqz^2}{e^2} \tag{1}$$

where p is the probability selected; $p = 1 - q = 0.5$ is the maximum probability; z is the threshold value of the normal distribution corresponding to the confidence level; e is the tolerance.

Generally, $e = 0.1$, and $z = 1.96$. Therefore, the sample size for the study is 96. However, to increase the reliability of the data and avoid cases where the interviewees did not provide enough information or misunderstood the questions, we distributed some more questionnaires and received 125 valid answers (Table 1).

Sampling method: the respondents were selected randomly from the lists of farmers classified by commune via the RAND() function of the MS Excel software.

2.2 Data processing and analysis

– *Comparison method*: The quantified economic indicators and phenomena with similar content and properties were compared to determine the trend and the volatility. In the research, this method was used to evaluate the optimization results of land-use structure through mathematical modelling and actual results.

– *Optimal mathematical modelling*

Objective function

$$Z = \sum_{j=1}^{n} C_j X_j \ \rightarrow \ \text{Maximum}$$

Binding functions

$$\begin{cases} \displaystyle\sum_{i=1}^{m} a_{ij} X_j (\leq, =, \geq) b_i, & \text{where } i = 1, 2, \dots, m \\ X_j \geq 0, & \text{where } j = 1, 2, 3, \dots, n \end{cases}$$

where C_i is the income from one hectare of crop per year and calculated as the total revenue minus the total costs; X_i is the area of each crop (ha); n is the number of crops in the objective function; m is the number of crops in the binding function; a_{ij} is binding constants; b_i is the limit value of the binding function i. The sign "≤" is used to represent the limited conditions of resources, such as land area, labor, investment capital, fertilizers and self-produced animal feed, etc.; the sign "=" is used to represent the strict control conditions, such as inorganic fertilizers, pesticides and animal feed to be purchased, loan amount needed, number of employees to be hired, etc.; the sign "≥" is used to denote the conditions that ensure the production of certain necessary products.

The binding function shows the interaction among the factors, the production activities, the demand, and the ability to respond to each product in the region. Therefore, the more the binding functions and the determined parameters, the more thoroughly the problems are solved with high reliability.

3 Results and discussion

3.1 Overview of the study area

Que Son is the midland district of Quang Nam province. The land area of the district is 25,746.1 ha. It is located 30 km northwest of Tam Ky City and 40 km southwest of Da Nang City (Figure 1). The district has 13 administrative units: Que Xuan 1, Que Xuan 2, Que Phu, Huong An, Que My, Que Thuan, Que Chau, Que Hiep, Que Minh, Que Long, Que Phong, Que An communes and Dong Phu town.

Que Son is oriented to be the development centre for the second East and Central Corridor of Quang Nam province. With this position, Que Son plays an essential role in connecting Thang Binh and Duy Xuyen districts, forming a dynamic cluster in the East and acting as a hub linking Quang Nam with the Central Highlands, South Quang Nam, Chu Lai – Dung Quat, Southern Laos, and Northeastern Thailand.

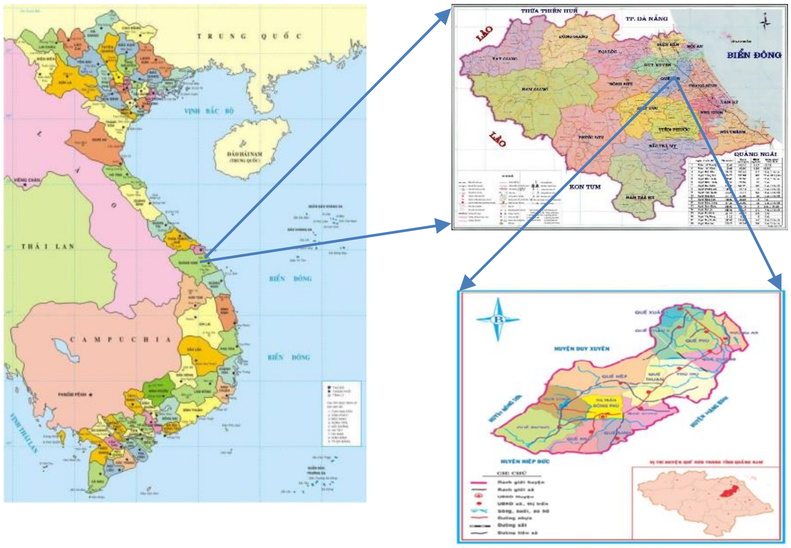

Figure 1. Geographical location diagram of Que Son district, Quang Nam province

3.2 Current agricultural land use in Que Son district

According to the statistical data in 2019, the agricultural land area of the district is 21,164.4 ha. Agricultural land for crops accounts for more than half of the district's agricultural land with 11,173.5 ha, of which land for annual crops is 6,860.7 ha (32.42%) and land for perennial crops 4,312.9 ha (20.38%). Forestry land accounts for 47.10%, with 9,969.2 ha. The remaining land is for aquaculture and other purposes (Table 2).

3.3 Optimal mathematical model for arrangement of crop structure

The size, structure, and scale of the appropriate agricultural land use need to be calculated together for each crop to maximize farmers' total income. The model was constructed as follows:

Table 2. Current agricultural land use in Que Son district in 2019

No.	Land type	Land area (ha)	Proportion of land type's area (%)
	Agriculture land	**21.164,4**	**100,00**
1	**Land for agriculture production**	***11.173,5***	***52.79***
1.1	Annual crop land	6.860,7	32.42
1.2	Perennial crop land	4.312,9	20.38
2	**Forestry land**	**9.969,2**	**47.10**
3	**Aquaculture land**	**10,3**	**0.05**
4	**Other agricultural land**	**11,4**	**0.05**

Source: [11]

Selecting variable

The variables X_j (j = 1, 2, …, n) of the model are the area of the crops. The farmers reported in the questionnaires that they had eight main types of land use with main crops (spring rice, seasonal rice, cassava, sesame, vegetables, sweet potatoes, corn, and peanuts), and corn, sweet potatoes and vegetables can be grown in two crops. Therefore, 11 variables were identified for 11 crops. The variables for the crop area are as follows (measured in ha):

X_1 is the land area of spring rice;

X_2 is the land area of seasonal rice;

X_3 is the land area of cassava;

X_4 is the land area of spring peanut;

X_5 is the land area of spring corn;

X_6 is the land area of seasonal corn;

X_7 is the land area of sesame;

X_8 is the land area of spring sweet potato;

X_9 is the land area of seasonal sweet potato;

X_{10} is the land area of winter vegetable;

X_{11} is the land area of spring vegetable.

Setting up the objective function

Based on the results of the farm household survey combined with the investigation of the agricultural land use status, we determined the objective function as follows:

$$Z = \sum_{j=1}^{11} C_j X_j \rightarrow \text{Maximum}$$

where C_j is the income obtained per crop area unit (million VND/ha) corresponding to X_j.

So the objective function is as follows:

$$Z = 23.05 \times X_1 + 23.37 \times X_2 + 29.73 \times X_3 + 30.33 \times X_4 + 25.01 \times (X_5 + X_6) + 23.87 \times X_7 + 23.62 \times (X_8 + X_9) + 22.26 \times (X_{10} + X_{11}) \rightarrow \text{Maximum}$$

Binding functions

Cultivated area limitation

Four bring high economic efficiency and meet the market demand while protecting natural resources and a sustainable environment, the district had the orientations as follows:

– Making the most of the cultivated area for intensive farming to increase crops, ensuring food for people.

– Stepping up the transformation of low-yield cultivated land into production types with higher economic efficiency, specifically shifting the area of vegetable and seasonal rice land to the production of cassava and peanuts.

According to these orientations, Que Son district determined the demand for land use for each kind of crop in Land use planning 2019.

1. $X_1 \leq 4{,}052.8$

2. $X_2 \leq 3\ {,}228.7$

3. $X_3 \leq 1{,}370.1$

4. $X_4 \leq 934.95$

5. $X_5 \leq 453.8$

6. $X_6 \leq 325.9$

7. $X_7 \leq 73.8$

8. $X_8 \leq 173.6$

9. $X_9 \leq 168.7$

10. $X_{10} \leq 450.9$

11. $X_{11} \leq 454.8$

Labour guarantee conditions

According to the provided data, the number of labourers in agricultural production in the district is 19,356, and a farmer worked for 220 labor days a year. Therefore, the total number of labour days is 19,356 × 220 = 4,258,320.

Equation of working conditions is

12. $24 \times X_1 + 212 \times X_2 + 142 \times X_3 + 190 \times X_4 + 186 \times (X_5 + X_6) + 115 \times X_7 + 200 \times (X_8 + X_9) + 258 \times (X_{10} + X_{11}) \leq 4{,}258{,}320$.

Proportional correlation conditions

In the spring crop, farmers cultivated cassava, peanuts, corn, spring sweet potatoes, and vegetables; so,

13. $X_3 + X_4 + X_5 + X_8 + X_{11} \leq 2{,}807.9$

In the winter season, farmers cultivated cassava and winter vegetables; so,

14. $X_3 + X_{10} \leq 6{,}860.7$

In seasonal crops, farmers cultivated corn, sesame, and sweet potato; so,

15. $X_6 + X_7 + X_9 \leq 3{,}632.0$

Non-negative conditions of all variables

16. All $X_i \geq 0$ with $i = 1, 2, 3, \ldots, 11$.

Mathematical modelling results for optimal plant structure arrangement

After running the optimal mathematical model on MS Excel, we came to the agricultural production types corresponding to variables from X_1 to X_{11} (Table 3).

3.4 Efficiency of land use resulting from optimal mathematical model

Economic efficiency

The results of comparing the land area of land-use types determined according to the optimal plan and the actual layout in Que Son district are shown in Table 4.

Table 3. Cultivated area according to optimal mathematical model

No.	Variables	Crop types	Area (ha)	Proportion (%)
1	X_1	Spring rice	4,052.8	35.34
2	X_2	Seasonal rice	3,228.7	28.16
3	X_3	Cassava	1,370.1	11.95
4	X_4	Peanut	934.5	8.15
5	$X_5 + X_6$	Corn	856.3	7.47
6	X_7	Sesame	73.8	0.64
7	$X_8 + X_9$	Sweet potato	379.7	3.31
8	$X_{10} + X_{11}$	Vegetable	571.5	4.98
		Total	**11,467.38**	**100.00**

Source: Summary of data processing results, 2020

Table 4. Comparing cultivated area in Que Son district currently with the optimal mathematical model

Unit: ha

No.	Crop types	Status in 2019	Optimal mathematical modeling	Difference
1	Spring rice	4,052.8	4,052.8	0
2	Seasonal rice	3,228.7	3,228.7	0
3	Cassava	1,360.1	1,370.1	10
4	Peanut	963.6	934.5	–29.1
5	Corn	468.7	856.3	387.6
6	Sesame	62.7	73.8	11.1
7	Sweet potato	189.6	379.7	190.1
8	Vegetable	580.3	571.5	–8.8
	Total	**10,906.5**	**11,467.4**	**506.9**

Source: Summary of data processing results, 2020

Table 4 shows that the crop land area used in Que Son district when the optimal mathematical model was applied increased by 506.9 ha compared with the status in 2019. The area for growing corn increased by 387.6 ha; the sesame cultivation area increased by 11.1 ha, and the sweet potato cultivation area increased by 190.1 ha. In contrast, the peanut cultivation area decreased by 29.1 ha, and the vegetable area decreased by 8.8 ha. Only the rice cultivation area did not change when applying the mathematical model.

The comparison results in Table 5 show that if applying the optimal mathematical model, the revenue and income increase compared with the status in 2019.

Specifically, the revenue value increased by 7,926.75 million VND, and the total income increased by 14,055.75 million VND. Therefore, it was very reasonable to build an optimal model to scientifically and rationally build the crop structure to increase income and use agricultural land effectively for the district.

Social efficiency

Social efficiency is a part of the category that is difficult to explain. The study evaluated social efficiency through the following indicators:

- Average food expenditure/person/year,
- Income for an agricultural worker/year.

The application of the optimal mathematical model did not change the area of paddy land in Que Son district and still ensured a food safety level of 500 kg/person/year. The average income of the farmers increased significantly from 13.89 to 14.61 million VND/person/year. This increase contributed to improving farmers' lives.

Table 5. Comparison of economic efficiency between the current state and the optimal model

Unit: million VND

No	Type	Status in 2019	Optimal mathematical modeling	Difference
1	Total cost	192,916.04	199,045.04	6,129.00
2	Revenue	467,804.81	475,731.56	7,926.75
3	Total income	268,759.77	282,815.52	14,055.75

Source: Summary of data processing results, 2020

Table 6. Social efficiency indicators according to the optimal model

Indicators	Unit	Value
Average food yield	kg/person	500
Average income per agricultural worker	million VND/labour/year	14.61

Source: Summary of data processing results, 2020

Environmental efficiency

Air environment

The air environment is mainly affected by industrial activities and less affected by agricultural activities. The air was the most affected when spraying pesticides on plants. Applying the optimal problem model, we saw that the crops are diverse. They were spring rice, sweet potatoes, vegetables, and peanuts. Thus, the cultivated area spread evenly throughout the district with different growth times. The time of spraying plant protection products was also different and separated from each other. Therefore, the potential for polluting the air environment was significantly reduced compared with what happened in the current cultivation of some crops with similar growth times. If applying the results of the optimal mathematical model in determining the structure of agricultural land use in Que Son district, the air environment in the agricultural production area had a concentration of toxic gases CO, CO_2, NO_2, SO_2, NH_3 within the permitted standards.

Water environment

The primary source of water pollution was the residue of pesticides and fertilizers. Also, due to intercropping and diversification of crops, the timing and location of fertilizer and pesticide spraying were different. Therefore, the chemicals penetrating the soil had time to be assimilated, reducing toxicity, and the water environment was not polluted.

Soil environment

Soil degradation was unlikely to occur if the optimal mathematical modelling results were applied because intercropping crops, such as peanuts and vegetables, could improve soil fertility. Besides organic fertilizer, agricultural residues, such as rice straw, rice husk, and corn stover, were used to increase soil health. These residues partly minimized the soil from becoming poor, acidic, and dry while increasing the amount of humus.

4 Conclusion

The results of research on building the optimal mathematical model of the rational agricultural land-use structure for Que Son district, Quang Nam province, are the basis for proposing land-use plans in the direction of efficiency, savings, and meeting the general development requirements. The optimal model for a rational structure of agricultural land was built on the basis of data on the areas of major crop types combined with other conditions (cultivated area limitation, food safety, and agricultural labour). The results of the model show that it was necessary to reduce the area of peanut (29.1 ha) and vegetables (8.8 ha) while increasing the area of corn (387.6 ha), sweet potato (190.1 ha), and sesame (11.1 ha). Applying the optimized model resulted in the arrangement of agricultural production land and brought about good economic, social and environmental benefits for Que Son district.

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