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Optimization Research on Crop Planting Strategies Based on Linear Programming Model

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Abstract: Under the condition of limited cultivated land resources, optimizing crop planting strategies is of great significance for increasing the yield and quality of crops, ensuring national food security, and promoting the sustainable development of agriculture. This paper focuses on the crop planting problem and establishes a linear programming model. The mathematical form of the objective function is determined. The model takes the maximization of the total revenue of crops as the objective function, taking into account factors such as the limitations of plot types, the restrictions on continuous cropping of crops, the rotation requirements of leguminous crops, the constraints on planting area, and the prevention of overly dispersed planting areas. Through sensitivity analysis, the impact of the minimum planting area is evaluated. This model can effectively solve the problem of crop planting optimization and provides a theoretical basis for scientific planting plans.

1. Introduction

In the process of globalization and modernization, agricultural production faces various challenges. With the growth of the population and the development of the economy, the demand for food is increasing day by day. However, the limited cultivated land resources and the intensification of environmental problems make the traditional agricultural production mode unsustainable. Therefore, it is of great significance to explore how to utilize the limited cultivated land resources to improve agricultural production efficiency, protect the environment, and promote the sustainable development of agriculture. Through literature research, summarization, and analysis [1, 2], it is found that traditional planting methods often lack scientific and systematic approaches, and it is difficult to adapt to the ever - changing market demands and resource conditions. Therefore, it is necessary to establish a scientific model to optimize crop planting strategies to improve production efficiency [3-5]. This paper assumes that various data of crops will remain stable compared to 2023 in the next few years, and analyzes the following two scenarios, and presents the optimal crop planting plans from 2024 to 2030 respectively.

Scenario 1: The excess part is unsalable and causes waste.

Scenario 2: The excess part is sold at 50% of the sales price in 2023.

This paper comprehensively considers multiple constraints, including crop sales prices, yield per mu, planting costs, and others, to establish a linear programming model. Based on this model, we analyze the two aforementioned scenarios and solve the objective function of profit maximization. Additionally, sensitivity analysis is conducted to ensure the accuracy of the results. The study provides a rigorous and scientifically grounded planting strategy for agricultural crops, addressing the need to enhance agricultural production efficiency and economic benefits, while contributing to improved crop yield and quality. This work holds significant implications for safeguarding national food security and fostering sustainable agricultural development.

2. Material and Methods

2.1 Data Acquisition and Pre-processing

2.1.1 Data Acquisition

This paper collects data such as the sales prices, planting areas, per - mu yields, and planting costs of various crops. These data are sourced from the open - source website (https://cumcm.cnki.net/).

2.1.2 Data Pre-processing

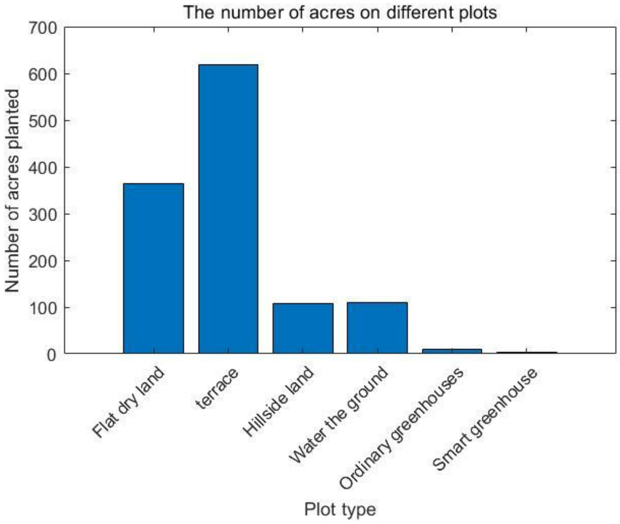

Figure 1 Proportion of Different Plots

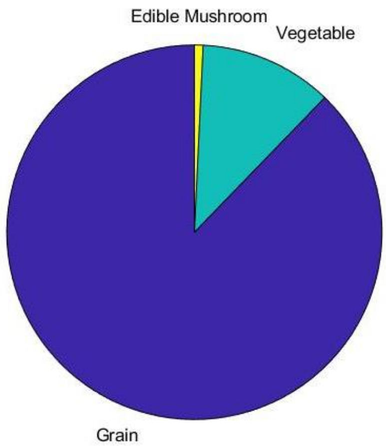

Figure 2 Proportion of Planting Areas of Different Crops

This paper conducts visualization processing on the relevant data, including the proportion of different plots, the proportion of planting areas of different crops, and the distribution of crop planting areas, as shown in Figure 1, Figure 2, and Figure 3.

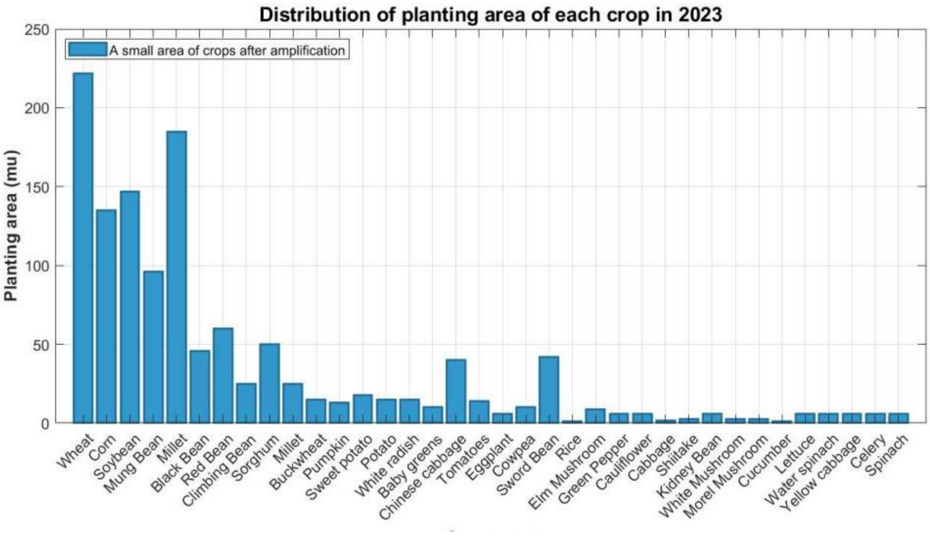

Figure 3 Distribution of Crop Planting Areas

2.2 Method Introduction

This paper takes into account the restrictions such as the planting patterns and conditions of different plots or greenhouses, and combines the different characteristics of various crops to optimize the planting plan, aiming to maximize the profit. A linear programming model is established in this paper. The objective function is set to maximize the profit. According to the information provided by the open - source website, this paper will comprehensively consider multiple constraint conditions, and the decision variables are selected as: The area of crop j planted on plot i in the k-th year.

3. Model Establishment and Solution

3.1 Introduction to Linear Programming

Generally speaking, problems of finding the maximum or minimum value of a linear objective function under linear constraint conditions are collectively referred to as linear programming problems. Decision variables, constraint conditions, and the objective function are the three key elements of linear programming. The general mathematical model of a multi - objective linear programming problem is described as a multi - objective linear programming problem with r objectives, m decision variables, and n constraint conditions, and its general mathematical model is:

$$MaxZ = c * x \tag{1}$$

$$S.t \begin{cases} Ax \leq b \\ x \geq 0 \end{cases} \tag{2}$$

Among them,

$$Z = (Z_1, Z_2, \cdots Z_r)^T \tag{3}$$

And

$$Z_i = c_{i1}x_1 + c_{i1}x_1 + \cdots + c_{im}x_m \qquad (i = 1, 2, \cdots r) \tag{4}$$

$$A = \begin{pmatrix} a_{11}a_{12} \cdots a_{1m} \\ a_{11}a_{12} \cdots a_{1m} \\ a_{11}a_{12} \cdots a_{1m} \end{pmatrix} \tag{5}$$

$$b = (b_1 b_2 \cdots b_n)^T \tag{6}$$

$$x = (x_1, x_2, \cdots, x_m)^T \tag{7}$$

Solving the target model can obtain the solution to the linear programming problem, which demonstrates strong optimality and practicality. Moreover, it can provide the most reasonable solutions for our daily lives. The methods for constructing the mathematical model of a linear programming problem are as follows: First, list the objective function and constraint conditions. Second, represent the feasible region represented by the constraint conditions. Finally, find the optimal solution of the objective function within the scope of the feasible region.

3.2 Determination of the Objective function

The goal is to maximize the total revenue from the planted crops. Therefore, the objective functions can be established separately according to the above - mentioned two scenarios:

(1) The part exceeding the expected sales volume is directly wasted, that is, the revenue from this part is not considered. The objective function is determined by the following formula:

$$Maximize \ \sum_{k=2024}^{2030} \sum_{i=1}^{n} \sum_{j=1}^{m} (min\,(Y_j \times x_{i,j,k}, S_j) \times P_j - x_{i,j,k} \times C_j) \tag{8}$$

Among them, P_j represents the price of the crop, Y_j is the per - mu yield of the crop, S_j is the expected sales volume of the crop, and C_j is the planting cost of the crop.

(2) If the part exceeding the expected sales volume is sold at 50% of the original price, the objective function is determined by the following formula:

$$\sum_{k=2024}^{2030} \sum_{i=1}^{n} \sum_{j=1}^{m} [min(Y_j \times x_{i,j,k}, S_j) \times P_j + max(0, (Y_j \times x_{i,j,k} - S_j)) \times 0.5 \times P_j - x_{i,j,k} \times C_j] \tag{9}$$

3.3 Establishment of Constraint Conditions

Based on the information provided by the open - source website, several constraint conditions are comprehensively considered:

(1) Restrictions on single - season grain crops in flat dry land, terraced fields, and hillside land: Only one season of grain crops (excluding rice) can be planted annually in flat dry land, terraced fields, and hillside land.

$$\sum_{j \in \{Grain\ crops\}, j \neq \text{rice}} x_{i,j,k} \leq A_i \ \ \forall i \in \{Flat\ dry\ land, terraced\ field, and\ hillside\ land\}, k \tag{10}$$

(2) Irrigated land can be used to grow one season of rice or two seasons of vegetables：

$$\sum_{j=rice} x_{i,j,k,\,\text{I}} + \sum_{j=vegetables} x_{i,j,k,\,I} \leq A_i \ \ \forall i \in \{Irrigated\ land\}, k \tag{11}$$

Among them, $x_{i,j,k,1}$: represents the area of planting crop j in the i- th piece of irrigated land in the k- th year.

And Ⅰ represents the first season, and Ⅱ represrnts the second in the following text.

If two seasons of vegetables are planted, in the first season, multiple types of vegetables (excluding Chinese cabbage, white radish, and red radish) can be planted, and in the second season, only Chinese cabbage, white radish, or red radish can be planted.

(3) Restrictions of ordinary greenhouses and smart greenhouses:

$$\sum_{j\in\{Excluding\ Chinese\ cabbage, white\ radish\ and\ red\ radish\}} x_{i,j,k} \le A_i \ \ \forall i \in \{Ordinary\ greenhouse, smart\ greenhouse\} \quad (12)$$

$$x_{i,edible\ fungus,k,\mathrm{II}} \le A_i \ \ \forall i \in \{Ordinary\ greenhouse\}, k \quad (13)$$

(4) Restriction on continuous cropping of crops: The same crop cannot be planted on the same plot of land for two consecutive years to prevent continuous cropping.

$$x_{i,j,k} \times x_{i,j,k+1} = 0 \ \ \forall i,j,k \quad (14)$$

(5) Rotation requirements for legume crops: Each plot of land should be planted with legume crops at least once within three years.

$$\sum_{k=k_0}^{k_0+2} x_{i,beans,k} \ge \epsilon \ \ \forall i \quad (15)$$

Among them, ϵ represents a threshold value to ensure that a certain area of legume crops is planted on this plot of land within three years.

(6) Area constraint: The planting area of each plot of land shall not exceed its total area.

$$\sum_{j=1}^{m} x_{i,j,k} \le A_i \ \ \forall i,k \quad (16)$$

(7) Regional non-dispersion: It is required to avoid the planting areas of each crop from being too scattered. A binary variable can be introduced to restrict the planting areas from being overly dispersed.

$$\sum_j z_{i,j,k} \le M_i \ \ \forall i,k \quad (17)$$

Among them, $z_{i,j,k}$ represents a binary variable indicating whether crop j is planted on plot i; $z_{i,j,k} = 1$ represents that crop j is planted on plot i in the k-th year; $z_{i,j,k} = 0$ represents that crop j is not planted on this plot; M_i represents the maximum number of plots on which crop i is allowed to be planted in the k-th year.

This constraint can control that a certain crop can only be planted on some plots of land, thus avoiding overly scattered planting. At the same time, in order to ensure that the crops are planted concentratedly on larger plots of land, a minimum planting area can be set for each plot.

$$x_{i,j,k} \ge A_{min} \times z_{i,j,k} \ \ \forall i,j,k \quad (18)$$

Among them, A_{min} represents the minimum planting area of this crop on each plot of land to ensure that the planting area will not be too small. When $z_{i,j,k} = 1$, it means that at least A_{min} mu must be planted on this plot of land; otherwise, the planting area is 0.

Since the setting of the minimum planting area may have a significant impact on the results of the model, as it directly affects the distribution of crops, the utilization efficiency of the plots of land, and the overall performance of earnings. Therefore, it is necessary to conduct a sensitivity analysis on the area of the minimum planting region.

For each set minimum planting area $A_{min}^{(n)}$, run the optimization model respectively. Use the ‘intlinprog’ function in MATLAB to adjust the constraints on the planting area and record the optimal solutions output by the model.

The steps are as follows:

1) Model construction: Input components such as the objective function, decision variables, and constraints into the MATLAB code, and make adjustments for different values of the minimum planting area.

2) Run the model: Use the ‘intlinprog’ optimization algorithm to solve the optimization problems under each different setting.

3) Record the results: Record the total revenue, crop distribution, and management costs after each

run.

4) Compare and analyze the results.

3.4 Model Solving

In this paper, we will use the built-in MATLAB function ‘optimvar’ to define decision variables, and the ‘optimproblem’ function to define an optimization problem that incorporates various constraints for solving. Some of the results generated by the MATLAB code are presented in Table 1 and Table 2.

Table 1 Results obtained in Scenario 1

Crop name	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6
soybean	0	0	0	0	0	0	0	0	0	0	25	0
Black beans	0	0	0	0	0	0	0	0	0	0	0	0
Red beans	0	0	0	0	0	0	0	0	0	0	0	0
mung bean	0	0	0	0	0	0	0	0	40	0	0	0
ClimbingBean	0	0	0	0	0	0	0	0	0	0	0	0
wheat	0	0	0	0	68	0	0	0	0	0	0	0
corn	0	0	0	0	0	0	0	46	0	0	0	0
millet	0	0	0	0	0	0	0	0	0	0	0	0
sorghum	0	0	0	0	0	0	0	0	0	0	0	0
millet	0	0	0	0	0	0	0	0	0	0	0	0
buckwheat	80	55	0	0	0	0	0	0	0	0	0	0
pumpkin	0	0	35	0	0	55	0	0	0	0	0	0
sweet potato	0	0	0	0	0	0	0	0	0	28	0	86

Table 2 Results obtained in Scenario 2

Crop name	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6
soybean	0	0	0	0	0	0	0	0	0	0	0	0
Black beans	80	55	0	72	68	55	0	0	0	28	25	86
Red beans	0	0	0	0	0	0	0	0	0	0	0	0
mung bean	0	0	0	0	0	0	0	0	0	0	0	0
ClimbingBeans	0	0	35	0	0	0	60	0	0	0	0	0
Wheat	0	0	0	0	0	0	0	0	0	0	0	0
corn	0	0	0	0	0	0	0	0	0	0	0	0
millet	0	0	0	0	0	0	0	0	0	0	0	0
sorghum	0	0	0	0	0	0	0	0	0	0	0	0
millet	0	0	0	0	0	0	0	0	0	0	0	0
buckwheat	0	0	0	0	0	0	0	0	0	0	0	0
pumpkin	0	0	0	0	0	0	0	0	0	0	0	0
sweet potato	0	0	0	0	0	0	0	46	40	0	0	0

Among them, A1-B6 represent different plots of land.

By comparing the model results of the two scenarios, significant differences in planting structures and revenue under distinct sales strategies are observed. In Scenario 1, the planting strategy is conservative, dominated by low-risk crops such as soybean and wheat. For example, soybean is only planted in plot B5, while black beans and red beans are not cultivated. Although economic crops like pumpkin and sweet potato are partially planted, their total areas remain limited, reflecting a preference to avoid overproduction waste.

In contrast, Scenario 2 adopts a more aggressive strategy. Black beans are widely cultivated across multiple plots, with significantly expanded total planting areas. This indicates that partial revenue from excess production incentivizes the expansion of high-value crops. Additionally, concentrated planting of climbing beans in A3 and B1, as well as sweet potato in B4 and B6, further demonstrates profit-driven optimization.

4. Conclusions

This paper focuses on the difficult problem of crop planting in the practical context of limited cultivated land resources, and has achieved remarkable results through the construction of a linear programming model. Guided by the goal of maximizing the total revenue of crops, the mathematical form of the objective function, combined with various restrictive factors such as plot types, continuous cropping of crops, rotation of leguminous crops, planting area, and the degree of dispersion of the planting area, comprehensively and accurately reflects the complex constraints in the actual planting scenarios. By evaluating the impact of the minimum planting area through sensitivity analysis, the practicality and reliability of the model have been further enhanced. The results of the model operation show that, on the basis of meeting various practical requirements, it can plan a scientific and reasonable planting scheme for farmers or agricultural production departments, and effectively achieve the core goal of improving the yield and quality of crops, thus laying a solid foundation for ensuring national food security.

In conclusion, the linear programming model established in this paper provides a powerful theoretical support and practical guidance tool for the optimization of crop planting. It is expected to be widely promoted and applied in a broader agricultural production field, contributing to the new journey of sustainable development of China's agriculture, and continuously promoting the upgrading of the agricultural industry and the improvement of the food security guarantee system.

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