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Research on the Optimization of Crop Planting Strategies Based on a Multi-Factor Comprehensive Analysis Model

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Abstract. This paper examines crop planting strategies from 2024 to 2030 in a rural village in the mountainous areas of North China to address the challenges posed by climate change and market volatility. Due to its special geographical location and climatic conditions, crop cultivation in the mountainous areas of North China is susceptible to drought and water shortage, which puts forward higher requirements for the optimization of planting strategies. The study considers two market scenarios: Scenario 1 assumes that the excess crop is completely unsalable, and Scenario 2 considers the excess crop being sold at half price. By simulating market fluctuations through the Monte Carlo algorithm and finding the optimal planting combination combined with the greedy algorithm, this paper seeks the optimal planting plan under different market conditions to maximize the net return. The results show that the optimization strategy can significantly improve the net income of crop planting, reduce the risk caused by market fluctuations, and help promote the sustainable development of rural economy. These optimization strategies have important theoretical and practical significance for improving the economic benefits of crop planting, enhancing the ability of agriculture to resist risks, and promoting the sustainable development of rural economy. Analyzing and optimizing crop planting strategies through scientific methods can not only ensure food security, but also promote agricultural modernization and achieve harmonious development of agriculture and the environment.

Keywords: Crop Planting Strategies; Linear Programming; Monte Carlo Simulation; Greedy Algorithm.

1. Introduction

Under global warming and resource scarcity, the efficient use of arable land is crucial for the sustainable planting of crops [1], affecting food security and the rural economy [2]. The growth of China's population and changes in consumption patterns have increased the demand for crops, while arable land is limited. Optimizing planting strategies, improving land efficiency, and reducing risks are key to sustainable agricultural development. This paper provides a scientific planting scheme for a rural area in the North China Mountain Area through mathematical modeling methods, aiming to improve efficiency, reduce risks, and promote sustainable economic development.

Crop planting strategies have always been a research hotspot in academia, and recent literature has discussed the issues related to crop planting strategies. Li Yanbin et al. established a multi-objective agricultural planting structure optimization model based on an improved particle swarm algorithm by introducing inertia weight decay and particle mutation strategies [3]; Zhang Lili utilized extreme learning machines to establish a drone hyperspectral diagnosis model for rice sheath blight and optimized it using particle swarm optimization algorithms [4]; Jia Yinjian et al. developed a crop classification method based on an improved random forest algorithm, optimizing the distribution of crop planting [5].

This paper first employs linear programming methods to solve for the maximization of net revenue for crop planting strategies under two different scenarios, while setting constraints such as plot area limitations and crop rotation rules. Next, the Monte Carlo algorithm is used to perform random simulations on various planting strategies to seek the optimal solution. Finally, in conjunction with the greedy algorithm, effective responses to various uncertainties encountered during the crop planting process are addressed. (Data Source: https://www.mcm.edu.cn/html_cn/node/a0c1fb5c31d43551f08cd8ad16870444.html)

2. Net Profit Maximization Model Based on Monte Carlo Algorithm

For the optimization problem of crop planting strategies in 2023, it is necessary to consider the deviation between expected sales volume and actual planting volume, construct a net revenue maximization model, and set constraints such as plot and rotation. In response to different scenarios of unsold goods, the Monte Carlo algorithm is employed to find optimal solutions through random simulation of various strategies, ensuring stable and reliable results.

The optimization of crop planting strategies for a village in the North China Mountain Area from 2024 to 2030 aims to maximize economic benefits and minimize losses from unsold goods. Specific strategies need to carefully consider two scenarios of unsold goods: direct waste and discounted sales. Given the rich variety of cultivated land in the village, which includes flat dry land, terraced fields, hillside land, irrigated land, as well as ordinary and smart greenhouses, the suitable crops for different plots and greenhouses vary. Therefore, the optimization plan must comprehensively assess crop yield, planting costs, market demand, the crop rotation system (especially the three-year rotation requirement for leguminous crops), and the specific irrigation constraints of irrigated land. Through scientific planning and efficient management, ensure that crop planting strategies not only conform to ecological principles but also significantly enhance economic benefits.

2.1. Net Profit Maximization Model under Loss from Unsold Goods Construction

In this optimization model, the focus is on precisely planning the planting strategies of crops, aiming to maximize the total net revenue of rural areas. The core of the model lies in clearly defining the types of crops planted and their areas on each plot of land in different seasons as decision variables. Considering the potential risks of unsold goods and the economic losses they bring, the objective function is set to maximize total net revenue.

(1) Variable Definition

Decision Variable: The j area of i crops planted on the plot of land.$x_{i,j}$

(2) Objective Function

Maximize net revenue, considering yield, selling price, and loss from unsold goods. It is assumed that unsold crops yield no revenue.

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Objective Function:

$$\text{Maximize}: Z = \sum_{i,j}\left(P_i \cdot Y_{i,j} \cdot A_{i,j} - C_{i,j} \cdot A_{i,j} - L_{i,j}\right) \tag{1}$$

P_i: Selling price per unit of the i crop; $Y_{i,j}$: Yield per mu of the i crop on the j plot; $A_{i,j}$: Planting area of the i crop on the j plot; $C_{i,j}$: Planting cost per unit of the i crop on the j plot; $L_{i,j}$: Loss from unsold goods, calculated as the yield exceeding the expected sales volume multiplied by the unit price.

(3) Constraints

Plot area constraint: The total area planted with crops on each plot cannot exceed its available area:

$$\sum_i A_{i,j} \leq S_j \forall j \tag{2}$$

Where, S_j is the area of the j plot.

Minimum planting area constraint: The planting area of each plot cannot be too small, assuming the minimum area is 10% of the total plot area.

$$A_{i,j} \geq 0.1 \times S_j \forall i,j \tag{3}$$

Crop rotation constraint: Each crop cannot be planted continuously on the same plot, and each plot must plant leguminous crops at least once within three years.

$$\text{if} A_{i_0 j_0} > 0, \text{then} A_{i_1 j_0} = 0 \tag{4}$$

$$\text{count}\left(\sum_{\text{year}=1}^{3} A_{ij_0}\right) \geq 1 \forall i \in \text{legume} \tag{5}$$

Irrigated land restriction: If rice is planted in the first season, no other crops can be planted in the second season.

$$\text{if} A_{\text{rice},j} > 0, \text{then} A_{i,j} = 0 \forall i \in \text{Season } 2, j \in \textit{irrigable land} \tag{6}$$

2.2. Monte Carlo Model Solution

The Monte Carlo algorithm**错误!未找到引用源。**[6] is an algorithm that simulates complex systems through random sampling, which can be used to handle uncertainty and random variables in optimization problems. Applying the Monte Carlo algorithm to optimize crop planting strategies allows for the introduction of random factors (such as climate change, market demand fluctuations, etc.), simulating planting strategies under different scenarios, and finding the optimal solution through extensive random sampling.

When using Monte Carlo for solving, the objective function remains the maximization of net revenue (including losses from unsold goods), meaning the form of the objective function remains unchanged, but randomness is introduced. In each iteration, the $A_{i,j}$ (planting area) is randomly generated, thereby affecting the calculation of net revenue.

First, initialization is performed by inputting plot types, crop data, and planting rules, followed by determining the N number of simulations. Next, iterative random simulation is conducted, where in each simulation, planting strategies are randomly generated based on crop adaptability, crop rotation rules, and plot area, resulting in a random combination generated for each plot $A_{i,j}$; Then, for each plot, the corresponding yield $Y_{i,j}$ and planting cost $C_{i,j}$ are calculated, and losses $L_{i,j}$ from unsold goods are computed based on market demand constraints. Next, calculate the objective function, computing the net revenue Z for each simulation result, that is:

$$Z = \sum_{i,j}\left(P_i \cdot Y_{i,j} \cdot A_{i,j} - C_{i,j} \cdot A_{i,j} - L_{i,j}\right) \tag{7}$$

The loss $L_{i,j}$ from unsold goods is calculated based on the excess yield:

$$L_{i,j} = \max(0, Y_{i,j} \cdot A_{i,j} - S_i) \cdot P_i \quad (8)$$

Where is the expected sales volume of the crop.S_ii

Subsequently, filter the results, perform the next N random simulation, record the net revenue Z for each iteration, and select the planting strategy corresponding to the maximum revenue. Finally, output the optimal plan; after numerous random simulations, select the plan with the highest net revenue Z as the optimal crop planting plan.

2.3. Model Iteration Output

(1) Model Convergence Iteration

This paper optimizes crop planting strategies through random sampling simulated by the Monte Carlo algorithm, ensuring compliance with land types, crop rotation, and seasonal requirements to maximize revenue. After 200 iterations, the best plan was selected to ensure optimal planting benefits from 2024 to 2030.

(2) The optimal planting plan for crops in this village from 2024 to 2030

After optimizing the crop planting strategies for 2024 to 2030, the annual revenue results were obtained. According to the calculations, the target values for 2024 to 2030 are shown in Table.1.

Table 1. Target Values for Scenario One

Year	First Quarter Revenue	Second Quarter Revenue	Total Revenue
2024	6186006.95	2873401.58	9059408.53
2025	6524165.29	2873936.04	9398101.33
……	……	……	……
2030	6214866.75	2866052.01	9080918.76

From Table 1, it can be seen that the total revenue in 2025 is the highest, reaching 9,398,101.33, while the total revenue in 2028 is relatively low, at 8,975,609.60. The overall trend shows that there will be significant fluctuations in revenue every other year, which may be related to adjustments in soybean planting strategies and the handling of unsold portions.

3. Establishing a multi-factor crop planting planning optimization model based on the greedy algorithm

This model aims to optimize the crop planting plan for a certain village from 2024 to 2030 based on the trends and uncertainties in expected sales volume, yield per Mu, planting costs, and selling prices of future crops. It specifically involves changes in various factors, such as the expected sales volume growth of wheat and corn, the rise in vegetable prices, the decline in edible mushroom prices, and the increase in crop planting costs.

3.1. Construction of the Net Profit Maximization Model under Random Fluctuations

To capture these uncertainties, the model randomly generates key parameters for different crops each year, including sales volume, yield per mu, planting costs, and selling prices, thereby establishing a dynamic optimization scheme. This model uses linear programming to find the optimal solution and simulates different risk scenarios through random variables.

3.1.1. Model Objective.

Optimize the allocation of planting areas for crops, maximize the net revenue of crops, and address the issue of unsold crops exceeding sales volume, ensuring that the planting combinations for different plots comply with the actual plot types, seasonal constraints, and crop rotation requirements.

3.1.2. Variable Definition.

Decision Variables: $x_{i,j}$ Represent the planting area of the i crops on the j plot. Each combination of plot and crop forms a decision variable, representing different planting plans.

3.1.3. Objective Function.

The goal is to maximize net revenue while considering the normal sales of crops and the discounted sales of the portion exceeding the expected sales volume. The expression for net revenue is as follows:

$$Z = \sum_{i,j} \left(P_{i,t} \cdot Y_{i,j,t} \cdot A_{i,j,t} - C_{i,j,t} \cdot A_{i,j,t} + \max\left(0, \left(Y_{i,j,t} \cdot A_{i,j,t} - S_{i,t}\right) \cdot 0.5 \cdot P_{i,t}\right) \right) \quad (9)$$

$P_{i,t}$: Selling unit price of the i crop in the t year; $Y_{i,j,t}$: Yield per Mu of the i crop in the t year; $A_{i,j,t}$: Planting area of the i crop on the j plot; $C_{i,j,t}$: Planting area of the i crop in the t year; $S_{i,t}$: Expected sales volume of the i crop in the t year; The last item seeking the maximum indicates that if the planting volume exceeds the expected sales volume, that portion of the crop will be sold at a 50% discount based on the 2023 selling price.

(4) Introduction of Random Factors [8]

In this model, the sales volume, yield per mu, planting cost, and selling price of crops will change randomly each year:

Expected sales volume: For staple crops such as wheat and corn, it is assumed that the annual growth rate of expected sales volume ranges from 5% to 10%, and the annual sales volume update formula is:

$$S_{i,t+1} = S_{i,t} \times (1 + r) \quad (10)$$

Where r is the annual growth rate, randomly selected from the range of 5% to 10%. For other crops, the annual sales volume will fluctuate by ±5% compared to the year 2023:

$$S_{i,t+1} = S_{i,t} \times (1 \pm 0.05) \quad (11)$$

Where values are randomly selected within the ±5% fluctuation range.

Yield per Mu: The yield per mu of crops is affected by external factors such as climate, and there will be a fluctuation of ±10 each year, with the formula being:

$$Y_{i,j,t+1} = Y_{i,j,t} \times (1 \pm 0.10) \quad (12)$$

The fluctuation range can be dynamically generated by a function.random_range

Planting cost: The planting cost of all crops increases by 5% each year, calculated as follows:

$$C_{i,j,t+1} = C_{i,j,t} \times (1 + 0.05) \quad (13)$$

The prices of grain crops remain relatively stable:

$$P_{i,t+1} = P_{i,t} \quad (14)$$

The prices of vegetable crops increase by 5% each year:

$$P_{i,t} = P_{i,t} \times (1 + 0.05) \quad (15)$$

The prices of edible fungi crops decline year by year, randomly decreasing by 1%-5%:

$$P_{i,t} = P_{i,t} \times (1 - r) \quad (16)$$

Where r is randomly selected from a value between 1%-5%. If it is morel, the price decreases by 5% each year.

3.2. Solving with Greedy Algorithm

The Greedy algorithm**错误!未找到引用源。错误!未找到引用源。** is a strategy that incrementally selects the currently seemingly best solution to construct a global solution. It aims to select local optimal solutions at each step, expecting that the final overall plan will approach the global optimal solution. Although the greedy algorithm does not guarantee finding the global optimal solution, its simplicity and efficiency make it applicable under certain constraints.

First, for each plot, select crops according to the following greedy strategy: for each suitable crop, calculate its net revenue; If the crop's yield exceeds the expected sales volume, calculate the revenue from the discounted portion; by combining the net revenue from normal sales and discounted sales, obtain the total revenue. For each plot, select the crop with the highest total revenue as the crop to be planted in the current plot.

Next, allocate based on plot area, ensuring that the crop area for each plot does not exceed the total area of that plot. When the selected crops exceed expected sales, allocate the plot area as much as possible to the crops with higher revenue. If a certain crop cannot cover the entire plot area, continue to select suboptimal crops to fill in.

Then, address crop rotation and seasonal constraints. Ensure compliance with crop rotation rules and seasonal planting requirements based on the type of each plot, season, crop suitability, and other constraints. Especially in irrigated land where rice is planted, if rice is grown in the first season, no other crops can be planted in the second season. Leguminous crops must be planted at least once within three years.

Finally, perform iteration. For each year from 2024 to 2030, repeat the above steps, selecting the best crop for each plot every year, while addressing the seasonal constraints and crop rotation requirements of the plots.

3.3. Model Iteration Output

The greedy algorithm progressively optimizes crop planting strategies, selecting the crop combinations that yield the maximum revenue at each step, ensuring that the crop choices for each plot not only meet the plot type, crop rotation rules, and seasonal requirements but also maximize the overall revenue from crop planting. Ultimately, determine the highest planting plan from the optimal choices of each plot as the optimal solution, ensuring that the crop planting plan for 2024 to 2030 reaches the best state. Taking a certain village as an example, design an optimal revenue plan for multi-season crop planting, setting the number of iterations to 200.

The optimal planting plan for crops in this village from 2024 to 2030 is shown in Table.2.

Table 2. Target Values Considering Multiple Factors

Year	First Quarter Revenue	Second Quarter Revenue	Total Revenue
2024	275580841.14	49616307.89	325197149.03
2025	293652098.06	48698324.93	342350422.99
……	……	……	……
2030	329555660.47	56145904.77	385701565.23

According to the calculations, the target value shows a trend of annual increase, especially with a significant increase in revenue between 2028 and 2030. The highest annual total revenue occurs in 2029, reaching 390,292,580.49, followed closely by 2030 and 2028, which are 38,701,565.23 and 386,054,638.17, respectively. These results indicate that from 2024 to 2030, the optimization of planting strategies gradually reveals higher revenues, demonstrating a stable growth trend, particularly in the years 2027 and beyond, where adjustments in crop planting strategies have led to a significant enhancement in economic benefits.

4. Conclusion

This research focuses on optimizing agricultural planting strategies for specific villages in the North China Mountain Area, aiming to maximize revenue and minimize losses caused by unsold products during the period from 2024 to 2030. The research results indicate that:

(1) The model constructed in this paper comprehensively considers the substitution and complementary relationships between crops, as well as the interconnections between prices and costs, thereby aligning more closely with the complexities of actual agricultural production.

(2) The model constructed in this paper can dynamically adjust planting strategies over time to adapt to market changes and crop growth cycles, thereby enhancing the flexibility of the strategies.

(3) This paper comprehensively considers the risks of unsold products and price fluctuations, effectively reducing the risks in the agricultural production process.

(4) By employing Monte Carlo simulation techniques and the greedy algorithm, the model not only improves solving efficiency but also ensures the global optimality of the results.

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