Statistical Analysis and Modeling Research Based on Crop Planting Strategies in Rural Areas

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Abstract. According to specific rural conditions, rational planning of organic farming, selection of crops and fine management of planting play a key role in promoting the long-term stable growth of local economy. This paper focuses on the development of agricultural planting in North China, and establishes a planting structure optimization model based on global search for the planting problems of agriculture of different plot types, combined with price reduction, uncertainties and potential risks. By considering the changes of economic parameters such as expected sales volume, planting cost, yield per mu and sales price of crops, this paper constructs a target planning model to maximize economic returns, and uses a global search optimization algorithm based on dynamic programming and greedy algorithm to solve the problem. The results show that the economic benefits of crop planting can be improved by rationally adjusting the planting structure, while avoiding food waste and protecting food security. In addition, this paper also considers the fluctuations of crop yield, cost and selling price in the future, as well as the sales growth trend of different crops, and establishes an uncertainties-based crop planting structure optimization model to adapt to market fluctuations and climate instability, and ensure considerable economic benefits in a volatile environment.

Keywords: Crop Cultivation, Uncertainty, Global Search, Dynamic Programming.

1. Introduction

In today's increasingly intensive and intelligent agricultural production, how to efficiently arrange crop planting to achieve maximum economic benefits has become the key to agricultural research. Appropriate crop planting strategies are essential to improve agricultural production efficiency, increase farmers' income, and ensure food security, which can help to make rational use of land resources, reduce waste, and reduce planting risks through scientific planning [1].

Academics have conducted multifaceted research on the issue of crop cultivation. In terms of changes in agricultural planting structure, Liu Dan et al. studied the planting structure of rice under rice-oil rotation, and the results showed that with climate warming, the planting range of rice under different planting patterns is constantly changing, and the planting mix of rice varieties in different regions is also different [2]. As for the influencing factors of cropping structure, Song Yu and Liu Weiping studied the influencing factors and multiple paths of the evolution of cultivated cropping structure based on the fuzzy set qualitative comparative analysis method, and analyzed seven factors affecting the planting structure [3]. In terms of crop planting strategy optimization, Ma Jiatong established a multi-objective agricultural planting structure optimization model based on improved particle swarm optimization algorithm, adjusted the planting ratio of grain crops and cash crops, and improved the comprehensive benefits [4]. The above scholars have studied crop planting from different aspects, but have not given much consideration to the impact of crop sales and uncertainties and potential risks on crop planting structure. This paper focuses on the development of agricultural planting in North China, and in view of the planting problems of agriculture of different plot types, combined with price reduction, uncertainties and potential risks, a planting structure optimization model based on global search is established, and a crop planting scheme with high economic benefits is proposed, so as to promote the innovation and development of agricultural science and technology in North China, and provide a scientific basis for policy formulation to deal with global food and environmental challenges.

2. Research on optimal planting scheme based on the change of economic parameters of crop planting

Data source: https://www.mcm.edu.cn/index_cn.html.

2.1. Preparation of the model

To simplify the model and calculation results, this paper takes the average value of its sales unit price as the sales unit price of crops in the seven years of 2024~2030. The expected sales volume for each of the seven years can be calculated from the two columns of "planting area / mu" and "mu / jin" in the crop planting situation and related statistics in 2023, and the expected annual sales volume of different planting terrains is shown in Figure 1.

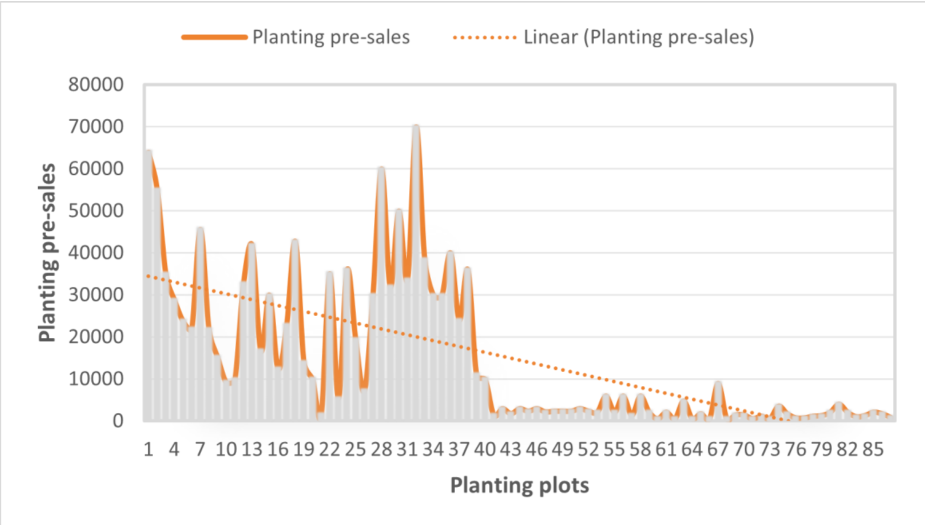

Figure 1. Expected annual sales volume by planting topography

2.2. Establishment of the model

Based on the analysis and processing of the data, this paper constructs the following optimization model: the excess crops are sold at a price reduction of 50%. The goal of optimizing the production system of crop farming must be efficient and stable. After clarifying the objectives, based on the current situation of the rural planting industry, this paper establishes a single-objective optimization model with the largest profit for the above optimization model, and its objective function is expressed as:

$$MaximizeW' = \sum_{i=1}^{54}\sum_{j=1}^{41}\sum_{t=1}^{2}(R_j \cdot \min\{U_{total}, P_j \cdot A_i\} \cdot K_{i,j,t} + 0.5 \cdot R_j \cdot (P_j \cdot A_i - U_{total}) \cdot K_{i,j,t} - D_{i,j} \cdot A_i \cdot K_{i,t,j}) \tag{1}$$

where R_j represents the unit price of crop j, P_j represents the yield per unit area of crop j, A_i represents the area of plot i, and $K_{i,j}$ is the decision variable representing the unit cost of planting crop j in plot i in season t, and representing the unit cost of crop j planted in plot i.

Constraints are mainly based on species diversity, geographic feasibility of planting, arable land demand, and crop yield [5]. The production of planting in this rural area is constrained by various conditions, and the expected sales volume, non-continuous replanting, legume crop rotation, minimum planting area, and food security are mainly taken as the basic constraints.

(1) Constraints on expected sales volume: Since the expected sales volume is not specified in the data, this article assumes that the sales volume is 95% of the total production.

$$U_{total} = 0.95 \cdot A_i \cdot P_j \cdot K_{i,t,j} \tag{2}$$

where U_{total} represents the pre-sale volume.

(2) Constraints on not being able to plant the same crop consecutively [6]: To avoid a reduction in yield caused by successive planting of the same crop, each plot cannot be planted with the same crop in adjacent years.

$$E_{i,t-1} \neq E_{i,t} \tag{3}$$

where $E_{i,t}$ indicates that the crop was planted in year t on plot i.

(3) Legume crop rotation [7] requires that each plot be planted at least once in three years. The set of legume crops is, if a fast field has not been planted with a legume crop in the last three years, it must be planted in that year.

$$\sum_{m=t-2}^{t} 1\{D_{i,m} \in J\} \geqslant 1 \tag{4}$$

where j is the set of legume crops, $D_{i,m}$ is the crop of the first plot of land in year m, and 1 is the indicator function that indicates whether the legume crop is planted or not.

(4) Minimum planting area constraint: To avoid too fragmented planting, the minimum planting area of each crop on a single plot of land is set to be 5% mu of the total area of the plot.

$$S_{i,j} \geqslant 0.05 \cdot A_i \tag{5}$$

where $S_{i,j}$ represents the planting area of crop D_i on plot R_i, and A_i represents the area of plot i.

(5) Food security constraints: food security is the premise of realizing the adjustment of planting structure, and the optimization and adjustment of planting structure should be carried out on the premise of ensuring that local food meets the minimum needs of local residents.

$$\sum_{i=1}^{m} x_i c_i \geq Y_i \tag{6}$$

Among them: x_i represents the planting area of the i crop (10,000 mu), c_i represents the yield per mu of the crop / jin, and Y is the minimum consumption demand of grain (jin).

In summary, a single-objective optimization model for maximizing total profit is established:

$$Maximize W \tag{7}$$

$$s.t\begin{cases} U_{total}=0.95\cdot A_i\cdot P_j\cdot K_{i,t,j} \\ E_{i,t-1}\neq E_{i,t} \\ \sum_{m=t-2}^{t} 1\{D_{i,m}\in J\}\geqslant 1 \\ S_{i,j}\geqslant 0.05\cdot A_i \\ \sum_{i=1}^{m} x_i c_i\geqslant Y_i \end{cases} \tag{8}$$

In this paper, a global search optimization algorithm based on dynamic programming and greedy algorithm is adopted, and the goal of the model is to optimize the planting strategy from 2024 to 2030 and maximize the planting income under the premise of satisfying the planting constraints. If the total crop production exceeds the expected sales volume, the excess is sold at 50% of the normal price, which affects the calculation of earnings.

2.3. Results

In this paper, the "expected sales volume" and "sales price" are determined according to the known economic parameters of crop planting, and the income of the excess part is 2,479,000 yuan, and the total profit is 46,788,000 yuan. From the above results, the economic profit is larger when the excess part has income, so if there is an excess part of the total annual output, it can be sold at a reasonable price according to the market demand, which not only avoids food waste and protects food security, but also can improve the economic income of rural crop planting.

3. Research on crop planting structure based on uncertainty

This paper argues that the price of food crops is stable and does not consider its uncertainty [8] but the increase of its planting cost may lead to a certain degree of reduction in the economic benefits of food crops, so the impact of food crops should still be considered. Considering the fluctuations of yield, cost and selling price of some crops in the future, as well as the sales growth trend of different crops, on the basis of the above research, the factors of "uncertainty and potential planting risk" are further considered, the objective function of achieving the maximum output value of planted crops is determined, and the crop planting structure optimization model based on uncertainty is established to change the fluctuation range of expected sales volume and yield, optimize the planting plan, and adapt to market fluctuations and climate instability.

3.1. Preparation of the Model

To optimize the yield potential of each plot over the ensuing seven-year period,this research meticulously contemplates the temporal evolution of crop yield, planting cost, selling price, and expected sales volume. Simultaneously, strict adherence is maintained to the agronomic principles of crop rotation and the avoidance of continuous cropping. In an effort to more accurately mimic these multifaceted changes, a bespoke function named "change_parameters" has been developed. This function is engineered to fine-tune parameters such as price, yield, cost, and expected sales volume on a crop-specific and year-by-year basis. The following amendments have been methodically applied to the relevant parameters within the model:

(1)The sales volume of grain crops increased by 5% to 10% per year.

$$S_{j,t}=S_{j,0}\cdot(1+r)^{t-2023},r\in[-0.05,0.10] \tag{9}$$

(2) Yield adjustment per mu: The yield per mu of all crops fluctuates by 10% per year.

$$S_{j,t}=S_{j,0}\cdot(1+r)^{t-2023}, r\in[-0.05,0.05] \quad (10)$$

(3) Yield adjustment per mu: The yield per mu of all crops fluctuates by 10% per year.

$$P_{i,t}=P_{i,0}\cdot(1+r)^{t-2023}, r\in[-0.10,0.10] \quad (11)$$

(4) Planting cost adjustment: increase by 5% per year.

$$D_{i,j,t}=D_{i,j,0}\cdot(1+r)^{t-2023}, r\in[-0.10,0.10] \quad (12)$$

(5) Adjustment of sales prices: the prices of grain crops remain unchanged; vegetable crop prices are rising by 5% per year; the price of morels is falling by 5% per year; prices of other edible mushroom crops are falling by 1 to 5 percent per year.

Vegetable prices:

$$R_{j,t}=R_{j,0}\cdot(1+0.05)^{t-2023}, r\in[-0.10,0.10] \quad (13)$$

Morel mushroom prices:

$$R_{j,t}=R_{j,0}\cdot(1-0.05)^{t-2023}, r\in[-0.10,0.10] \quad (14)$$

3.2. Establishment of the model

This article mainly considers the fluctuations in the expected sales volume, yield per mu, planting cost and selling price of various crops. Under the influence of these uncertain factors, the planting strategy is optimized to maximize profits and control risks. Based on this, the following optimization model is constructed in this article: The decision variables are defined as the types of planted crops and the proportion of the planted area in each year, each quarter, each plot and each part. That is, x_{ijk} represents the type of crop planted on the plot numbered k in the j-th quarter of the i-th year, and a_{ijk} represents the proportion of the area of the crop planted on the plot numbered k in the j-th quarter of the i-th year. A single-objective optimization model for maximizing profit is established, and its objective function is expressed as:

$$MaximizeM=\sum_{i=1}^{54}\sum_{j=1}^{41}\sum_{t=1}^{2}(R_j\cdot P_j\cdot A_i\cdot K_{i,t,j}-D_{i,j}\cdot A_i\cdot K_{i,t,j}) \quad (15)$$

Where P_i designates the selling price of the i-th crop, y_{ij} represents the per-mu yield of the j-th crop on plot i and c_i denotes the planting cost associated with the i-th crop.

(1)Constraint against Continuous Cropping: To preclude the phenomenon of yield reduction consequent to consecutive cultivation of the same crop variety, it is stipulated that each plot must not host the same crop during adjacent years. Mathematically, this is denoted as:

$$E_{i,t-1}\neq E_{i,t} \quad (16)$$

Among them, $E_{i,t}$ represents the crop planted on the i -th plot in the t -th year.

(2)Requirements for legume crop rotation: Each plot of land needs to plant legume crops at least once within three years. The set of legume crops is denoted as J.If a certain plot has not planted legume crops in the past three years, legume crops must be planted in that year.

$$\sum_{m=t-2}^{t} 1\{D_{i,m} \in J\} \geqslant 1 \tag{17}$$

Where $D_{i,m}$ represents the crop on the i-th plot in the m-th year, and 1 is an indicator function indicating whether legume crops are planted.

(3)Minimum planting area constraint: In order to avoid overly scattered planting, the minimum planting area of each crop on a single plot is set to 5% of the total area of that plot.

$$S_{i,j} \geqslant 0.05 \cdot A_i \tag{18}$$

Where $S_{i,j}$ represents the planting area of crop D_i on plot R_i and A_i represents the area of the i-th plot.

(4)Food security constraints: food security is the premise of realizing the adjustment of planting structure, and the optimization and adjustment of planting structure should be carried out on the premise of ensuring that local grain meets the minimum needs of local residents.

$$\sum_{i=1}^{m} x_i c_i \geq Y_i \tag{19}$$

In summary, a single-objective optimization model for maximizing total profit is established:

$$Maximize E \tag{20}$$

$$s.t \begin{cases} E_{i,t-1} \neq E_{i,t} \\ \sum_{m=t-2}^{t} 1\{D_{i,m} \in J\} \geqslant 1 \\ S_{i,j} \geqslant 0.05 \cdot A_i \\ \sum_{i=1}^{m} x_i c_i \geqslant Y_i \end{cases} \tag{21}$$

Considering that the fluctuation of uncertainty factors will obviously affect the final result, and more uncertainties will significantly increase the computational cost of the problem, this paper uses the Monte Carlo model [9] to reduce the uncertainty scenario, and uses the global search algorithm based on dynamic programming and greedy algorithm [10] to solve the model. This paper assumes that the range of uncertainties varies as follows: expected sales of wheat and corn will increase by 5% to 10% per year; expected sales of other crops vary by ±5% per year; the yield per mu of crops varies by ± 10% per year; the cost of cultivation increases by an average of 5% per year; prices of food crops remained stable; vegetable crop prices are rising by 5% per year; the price of morels is falling by 5% per year; the price of other edible mushrooms is falling by 1% to 5% per year.Considering these uncertainties, this paper combines the rapid iterative elimination technique based on probabilistic distance to reduce the scene. Expectation of Maximizing Total Profit:

$$Maximize E \tag{22}$$

This objective function is designed to balance the maximization of planting returns, with constraints such as crop rotation and avoidance of stubble, legume crop planting constraints, area constraints, etc, to ensure that the planting scheme is feasible in practice.

3.3. Results review

Analyzing the above solution process, the total annual income from 2024~2030 is shown in Figure 2:

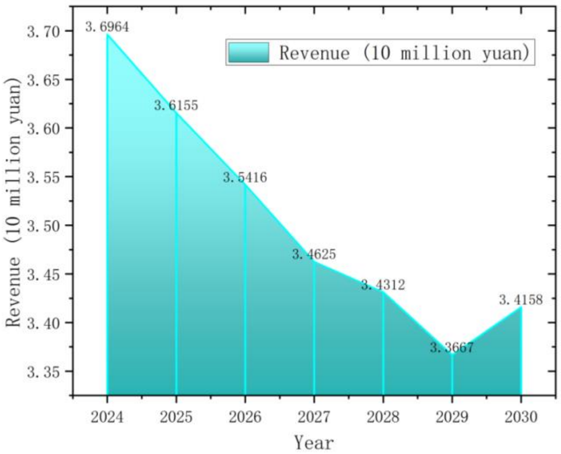

Figure 2 Visualization of the total annual income from 2024~2030

From the above chart, it can be seen that the total income in 2024~2030 shows a downward trend in 7 years, and this paper speculates that it may be due to the increase in planting costs, yield decline, and stable or even declining sales prices due to factors such as climate and market conditions in actual agricultural production and life, and some potential planting risks such as natural disasters, weed competition, and demand changes affect the economic benefits of crops.

4. Conclusions

In this paper, two types of planting structure optimization models are constructed based on crop planting in North China: first, in the constant parameter model, the relevant data from 2024 to 2030 are predicted based on the data of 2023, and a single-objective model with the largest multivariate constrained profit is set up, and the dynamic programming and greedy algorithm are used to search and solve the problem globally; second, the uncertainty model considers the fluctuations of crop economic indicators and market changes, constructs a single-objective model with the largest profit, and uses Monte Carlo simulation and other methods to solve it. The above-mentioned optimization model is concise, practical, accurate, efficient, stable and universal. Future research can further explore the impact of climate change on crop planting structure, optimize the algorithm to adapt to more complex uncertainties, and combine machine learning technology to improve the accuracy and adaptability of model prediction. It will lay a solid theoretical foundation for regional agricultural development, guide the direction of planting, and vigorously promote the improvement of economic benefits and food security.

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