Research On Crop Planting Planning Based on Multiple Constraints

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Abstract. It is very important to plan the planting situation of different crops in different periods, types of cultivated land, and other limiting factors reasonably. In recent years, the problem of crop planting planning has not been common. This article aims to gradually increase the constraints from general to special situations, and ultimately complete a crop planting plan that is close to daily life. In this article, this model is gradually complicated in specific situations to make it as much as possible in line with actual planting conditions. In the end, a long-term planting plan for 41 small crops under the three major categories of vegetables, grains, and fungi on four types of farmland and two types of greenhouses was achieved. Specifically, this method uses an approximate exponential sigmoid function to fit the unit selling price and total yield of crops. At the same time, when refining the consideration of the problem, multiple functions are defined for analysis, such as using the tanh function to fit the area efficiency function, and simulating uncertain changes using the Brownian motion model. On the other hand, the Delphi method and the Independent Weight Grey Relational Analysis method are comprehensively used in determining weights. In the final search for the optimal solution, the Monte Carlo method is used to randomly select several planting scenarios and continuously optimize until the optimal solution is found.

Keywords: Planting strategy, Linear programming, Monte Carlo method, Independent Weight Grey Detection method.

1. Introduction

A reasonable crop production plan can not only help farmers achieve maximum income, but also guide them on how to reasonably divide land for cultivation to reduce objective factors such as human input and avoid some natural disasters. In recent years, there have been some articles on the rational planting of crops, with the most common being the use of multi-objective optimization models. For example, Pan Yue et al. planned river irrigation planting and the rational use of water resources in agriculture [1], while Wu Menghan et al. planned river irrigation problems from three perspectives: economy, ecology, and water consumption [2]. Chen Lei and others conducted comprehensive multi-objective planning by taking into account factors such as meteorological conditions, irrigation treatment, and fertilizer management [3]. Zhang Pengfei's team takes Shanxi Province as the research area, uses water footprint and energy consumption accounting models to analyze the water and energy consumption characteristics of major crops, and constructs a multi-objective programming model with water resources, energy, food and other constraints to optimize the planting structure of major crops[4]. Li Yanbin et al. introduced two change factors, inertia weight decay and particle variation, in their articles [5]. Feng Guangliang and others used particle swarm optimization algorithm to solve the problem in their article [6]. Yang Yijiang et al. introduced the dynamic programming method in their article, discussing the relationship and differences between dynamic programming and linear programming [7]. Zhang Fan and others discovered the dual interval characteristic in the calculation of agricultural water resources, so they used the dual interval theory to characterize and calculate the agricultural water resources. The constructed model was applied to optimize the planting structure in five hydrological years (dry year, relatively dry year, normal year, relatively abundant year, and abundant year) in Ganzhou District, Linze County, and Gaotai County of Zhangye City, Gansu Province in the middle reaches of the Heihe River. The optimization results were compared with the planting structure and economic benefits in the current level year [8]. Luodan et al. proposed a multi-objective particle swarm biogeography algorithm to solve the tomato planning model for the uneven supply of tomato raw materials during the tomato sauce season. By combining the Pareto fast non dominated sorting method with the operational mechanism of particle swarm optimization and bio-geography algorithms, the global search performance of the algorithm can be better enhanced. Construct three objective functions for tomato planning: minimizing economic losses for enterprises, maximizing total net income for growers, and minimizing planting area [9].

In contrast, this article mainly considers how to plan for long-term rather than just one-year planting situations. Therefore, a precise and reasonable cycle was provided based on the objective conditions of soil planting. In this way, it is only necessary to plan the situation within one cycle and then promote it according to the "cycle". For the establishment of the model, this article first considers functions that conform to objective conditions, such as using the traditional activation functions sigmoid and tanh functions in neural networks, and utilizing their good saturation to fit related functions such as the relationship between crop production and price. Then, modify some parameters in the function to meet the needs of practical problems. For non data related influencing factors such as crop distribution, relevant functions such as "divergence function" and "area efficiency function" are defined to convert the impact of these factors into accurate data for comparison. For weight allocation, Delphi method and independent weight grey test method are used to comprehensively determine the weights based on subjective and objective factors. For random variables, use Brownian motion to simulate them. Brownian motion objectively has randomness, rather than subjectively giving arbitrary data that is "pseudo-random". Finally, for the solution of the model, the Monte Carlo method is used to randomly search for several planting scenarios as samples, and then continuously optimize to find the optimal solution.

2. Problem analysis

2.1. Problem Description

After investigating a specific area, it was found that there are 1201 acres of arable land scattered across 34 different sizes. The cultivated land includes four types: flat dry land, terraced land, hillside land, and irrigated land. In addition, there are 16 ordinary greenhouses and 4 smart greenhouses. The crops grown include grains, vegetables, and the use of fungi. According to the survey, there are 41 crops suitable for planting in the region, including soybeans, black beans, red beans, mung beans, climbing beans, wheat, corn, millet, sorghum, millet, buckwheat, pumpkin, sweet potatoes, naked oats, barley, rice, cow peas, knife beans, kidney beans, potatoes, tomatoes, eggplants, spinach, green peppers, cauliflower, cabbage, oil lettuce, bok choy, cucumber, lettuce, chili, spinach, celery, Chinese cabbage, white radish, red radish, elm mushroom, shiitake mushroom, white spirit mushroom, and morel mushroom.

According to the growth pattern of crops, each crop cannot be planted continuously on the same type of land, and all land requires the planting of leguminous crops every three years to fix nitrogen. Natural factors also have the following requirements for crop cultivation: (1) Flat dry land, terraced fields, and hillside land are suitable for planting one season of grain crops (excluding rice) per year. (2) Watered land can be planted with one season of rice or two seasons of vegetable crops per year. (3) If two seasons of vegetables are planted on a certain irrigated land, multiple vegetables can be planted in the first season (excluding Chinese cabbage, white radish, and red radish); In the second season, only one of Chinese cabbage, white radish, and red radish can be planted (for easy management). (4) According to seasonal requirements, Chinese cabbage, white radish, and red radish can only be planted in the second season of irrigated land. (5) Ordinary greenhouses plant two seasons of crops per year. In the first season, a variety of vegetables can be planted , and in the second season, only edible mushrooms can be planted. (6) Due to the adaptability of edible fungi to growing in lower and suitable temperature and humidity environments, they can only be planted in ordinary greenhouses in the second season. (7) The smart greenhouse can plant two seasons of vegetables every year .

Finally, the average yield per mu, planting cost, sales price, and current planting situation of each crop under different soil conditions in 2023 were obtained through investigation.

For specific planning, this article aims to solve the problem in two steps. Step 1: Assuming that the planting situation in 2023 reaches an objective optimum (i.e. the expected sales volume after 2023 is equivalent to the actual production in 2023), assuming that the expected sales volume, planting cost, yield per mu, and sales price of subsequent crops do not change relative to 2023 (one mu refers to 666 square meters), only considering the impact of "overproduction". The first step is also considered from two aspects: (1) the excess production part is sold at 50% of the original price. (2) Excessive production leads to unsold and wasteful products.

Step 2: After in-depth investigation, confirm that the excessive impact generated in step 1 is determined as "selling at 50% of the original price", and assume that there will be the following data changes within one cycle: expected sales volume: wheat and corn (belonging to grain) sales are expected to increase by 5% -10% annually, while other crops only change by around 5% annually. Per acre yield: Each crop has an annual variation of up to 10%. Planting cost: Each crop increases by 5% annually. Sales price: average annual increase of 5% for vegetables; The grain category remains basically unchanged; Fungi decrease by 1% -5% annually, with the largest decrease in morel mushrooms being 5% per year. Simultaneously consider management factors: the land area for planting each crop should not be too small, the planting of the same crop should not be too scattered, and finally consider the impact of natural disasters.

2.2. Planting plan based on long-term

Based on objective conditions such as' crops cannot be planted continuously 'and' bean crops must be planted once every three years on each piece of land ', this indicates that the optimal solution cannot be obtained by planning only for one year and then extending it to subsequent years. Meanwhile, if the specific planning year (such as a specific ‘n’ year) is determined and then planned as a whole, it will make the model too complex and lack generality (because the planning for n and n+1 or n-1 years may differ). Therefore, it is necessary to find a suitable cycle for planning. Note that according to the statistical results for 2023, exactly one-third of the land has been planted with legumes. Therefore, we consider setting the cycle to 3 years and first divide all land into the following categories: record all land that has been planted with legumes in 2023 as M1 (including A4, A5, B2, B3, B4, B4, B5, B11, C3, C6, D5, D6, E1, E7, E8, E9, E10, E11, F3, F4). For the remaining land, it will be divided into two categories M2 and M3 based on the "basic average" area, but the areas of land types with the same properties in M2 and M3 should be approximately the same. According to the land characteristics obtained from the survey, it is known that land types A, B, and C (arid land, terraced fields, and hillside land) have the same properties, while land types D, E, and F have different properties. Therefore, M2 and M3 land meet the following requirements:

$$\min|S2_A + S2_B + S2_C - S3_A - S3_B - S3_C| \tag{1}$$

$$\min|S2_D - S3_D| \tag{2}$$

$$\min|S2_E - S3_E| \tag{3}$$

$$\min|S2_F - S3_F| \tag{4}$$

where $S2_j$ and $S3_j$ denotes the area of the ‘j’th type of land in M2 or M3. Based on the above optimization problems, M2 (A1, A2, A3, A6, B1, B6, D1, D4, D8, E2, E3, E4, E5, E6, F1) and M3 (B7, B8, B9, B10, B12, B13, B14, C1, C2, C4, C5, D2, D3, D7, E12, E13, E14, E15, E16, F2) can be obtained. Therefore, the specific planning situation for three years is T1, T2, and T3, requiring each year's planning to reach the optimal solution (maximizing benefits) under the current year's constraints. After considering the constraints, the specific planning is as follows: in the first year, follow the planting situation in 2023 (planting beans on M1 land). In the second year, M2 planted beans, while M1 and M3 planted other crops. In the third year, M3 planted beans, while M1 and M2 planted other crops. The maximum profits for each of these three years are Q1, Q2, and Q3. If it is necessary to plan for the following n years starting from 2023 as the first year, then these ‘n’ years can also be divided into the following three situations:

$$\begin{cases} n = 0 \ (\text{mod } 3) \\ n = 1 \ (\text{mod } 3) \\ n = 2 \ (\text{mod} 3) \end{cases} \tag{5}$$

For the first scenario, simply repeat the three planning methods of T1, T2, and T3. For the second scenario, the known planting results in 2023 (T1) can be directly used as the planting plan for the nth year, and the other n-1 years can be sorted in rotation according to T1, T2, and T3. For the third scenario, consider recording Qmax=max (Q2, Q3), Qmin=min (Q2, Q3). Then record the planting situation (T2 or T3) corresponding to Qmax as TQmax, and use it as the planting situation for the nth year. Use the known planting result (T1) in 2023 as the planting situation for the (n-1) year, and sort the previous n-2 years according to T1, TQmax, and TQmin. For example, considering a time period of 8 [because 8 = 2 (mod3)] years, the analysis process based on the third scenario is shown in Figure 1 below:

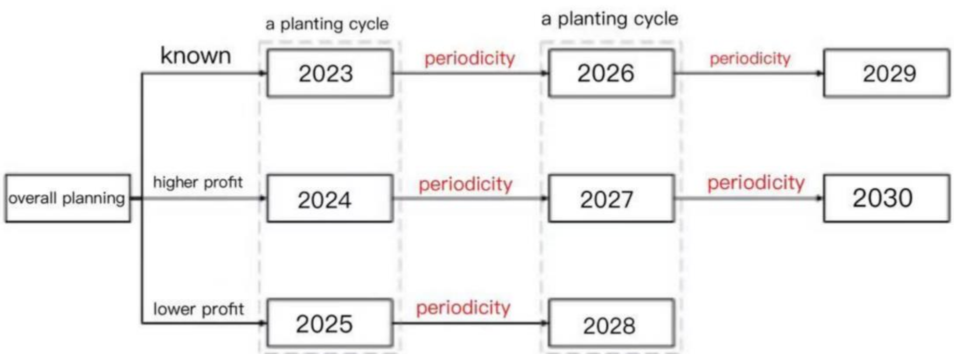

Figure 1. Long term planning scheme in the third scenario

In this way, by giving a certain period, we ensure that the benefits are maximized as much as possible while meeting the requirements of "crops cannot be planted continuously" and "bean crops must be planted once every three years on each piece of land", and enable the model results to be generalized.

2.3. Solution based on single objective programming model

Firstly, when determining the maximum profit, the actual selling price of various types of crops is an important indicator. However, according to research, it is easy to know that the selling prices of different types of crops often fluctuate within a small area rather than remain constant, so the actual selling price is not an accurate value. In this case, randomly selecting a price within the price range or obtaining the actual selling price by taking the average is not reasonable. In fact, the small-scale fluctuations in the sales price of goods are closely related to supply and demand. According to literature review, commodity prices usually decrease with an increase in total supply. Therefore, it is necessary to use a function to fit the selling price. In order to accurately reflect the impact of supply and demand on prices, we have selected two benchmark points as the basis. For the ‘j’th crop, one of the reference points X_{j1}, the coordinate is $(0, Max_j)$;another reference point X_{j2}, the coordinate is (N_j, Min_j). While the N_j refers to the ‘j’th crop Expected sales volume in the market. Max_j and Min_j representing the highest and lowest selling prices of the ‘j’th crop respectively.We define N_j in this way:

$$N_j = \sum_{i=1}^{54} \eta_{ij} S_{ij} \tag{6}$$

The two points $(0, Max_j)$ and (N_j, Min_j) represent the two extreme values of the price range respectively. That is to say, when there is no supply of such crops, the selling price of this crop can reach the theoretical maximum value. When the supply reaches the expected sales volume, the selling price of this crop reaches the theoretical minimum value (the excess will be sold at half price or directly wasted), providing a benchmark for modeling the relationship between supply and actual selling price. Due to the fact that exponential functions can effectively capture the nonlinear relationship between prices and supply, based on the above settings, we adopt exponential functions $\omega = Ae^{-bp}$ as the objective function to link the relationship between the supply and actual selling prices of 41 different crops. The optimization problem to be solved can be explicitly expressed as a single objective function. Taking into account multiple data indicators of crops, solve for the optimal planting plan. This division makes the model more accurate and facilitates effective comparison and optimization between different crop species. In the process of model construction, we used total profit E, total selling price R, total cost C, as well as various crop yields per mu η_{ij} and sales unit price ω_j as decision variables to solve the planting plan that maximizes total profit. The specific calculation formula for the objective function is as follows:

(1) Actual sales unit price ω: the actual sales unit price ω is the actual sales unit price obtained by solving the supply P_j of the bth crop and its fitted supply actual price curve, which satisfies

$$\omega_j = A_j e^{-b_j P_j} \tag{7}$$

where ω_j denotes the actual selling price of the jth crop, P_j denotes the supply of the jth crop, and A_j and b_j represent the corresponding coefficients of the supply actual selling price curve fitted to the jth crop.

Total selling price: the total selling price R is the total income after completing the sale of crops, defined as follows:

$$R = \sum_{i=1}^{41} R_j \tag{8}$$

where R_j denotes the total selling price of the 'j'th crop. The calculation formula is:

$$R_j = \omega_j P_j \tag{9}$$

where ω_j denotes the actual sales unit price of the jth crop, and P_j denotes the supply of the jth crop.

Total cost: the total cost C is the sum of the actual costs of planting all crops, defined as:

$$C = \sum_{i=1}^{54} C_i \tag{10}$$

where C_i denotes the total cost of the ′i'th plot, calculated using the following formula:

$$C_i = \varphi_{ij} S_i \tag{11}$$

where φ_{ij} denotes the yield per mu of the jth crop on the ith plot, and S_i denotes the area of the ith plot

Total profit: the total profit E is the total net profit after completing the sale of crops, defined as follows:

$$E = R - C \tag{12}$$

where R is the total selling price and C is the total cost.

Regarding scenario 1 of the first step assumption, which is that the unsold portion exceeding the expected sales volume leads to complete waste; And situation 2, where the excess sales volume exceeds the expected sales volume and is sold at 50% of the selling price (based on the supply price curve, when the actual production exceeds the expected sales volume, the excess should be sold at 50% of the lowest selling price), multiple single objective programming models are established to separately solve for the maximum total profit of leguminous plant planting schemes and non leguminous plant planting schemes, and then obtain the optimal planting scheme for a three-year cycle. Finally, compare the annual total profit values of the last two years of the cycle, select the plan with the larger annual total profit as the planting plan for 2024, and the plan for the crop with the smaller total profit in 2025, and then carry out long-term promotion.

2.4. Optimization solution under multiple constraint conditions

The appeal method only provides rough preliminary planning and solution from a macro perspective, ignoring a large number of influencing factors. Therefore, the second step should take these factors into consideration and establish a more complex and comprehensive model. Specifically, regarding the dispersion of management costs, it is important to define "dispersion" as excessive dispersion of crop planting can lead to increased management costs. Therefore, dispersion D is an indicator used to quantify the dispersion of crops on different land parcels. It measures the spatial distribution dispersion of a specific crop by evaluating and calculating its distribution on existing farmland. The dispersion reflects the degree of deviation between the planting situation of a certain crop on various plots of land and the completely dense planting situation, and evaluates the dispersion of the distribution based on this. The dispersion degree D of all crops is defined as follows:

$$D = \sum_{j=1}^{41} D_j \tag{13}$$

In which D_j denotes the dispersion of the ‘j’th crop, and the calculation formula is as follows:

$$D_j = \frac{1}{N} \cdot \sum_{i=1}^{N} \left(\frac{f_{ij}}{t_j} - \frac{1}{N} \right)^2 \ (N = 54, \text{representing the total number of land parcels}) \tag{14}$$

where N denotes the total number of land blocks, which is 54 here; f_{ij} is a 0-1 variable representing whether the jth crop is planted on the ‘i’th plot of land, calculated using the following formula:

$$f_{ij} = \begin{cases} 0 & \text{The 'j'th crop was not planted on the 'i'th} \\ 1 & \text{The 'j'th crop was planted on the 'i'th p} \end{cases} \tag{15}$$

t_j denotes the sum of the number of plots of land planted for the ‘j’th crop on different types of land, calculated using the following formula:

$$t_j = \sum_{i=1}^{54} f_{ij} \tag{16}$$

It can be inferred that the more dispersed the distribution of a certain crop on all land plots, the higher its dispersion value, indicating that the crop appears more frequently on different types of land; If the dispersion of the planting plan is too high, it will correspondingly increase management costs, and adjustments need to be made to make the planting distribution more concentrated. Next, consider the area efficiency function and efficiency coefficient of management costs. Considering that planting crops on a large area of arable land with a small area can increase the cost of cultivation and management, we define the area efficiency function and efficiency coefficient to reflect the impact of different areas through specific numerical values. Through investigation, it has been found that for tens of hectares of arable land, if the cultivated area of a certain crop is less than 10 hectares, it will lead to a decrease in efficiency; For small-scale farmland in greenhouses, as long as the area is less than 0.6 hectares (in other words, as long as it is divided and planted), it will lead to a decrease in efficiency. Define the area efficiency function and efficiency coefficient as follows: area efficiency function $f_1(x)$ and $f_2(x)$, which are the efficiency function for large cultivated land and small cultivated land in greenhouses, where x is the planting area of a certain crop. They should satisfy the following properties:

$$f_1(x) \in [0,1], \left(x \in [0,+\infty)\right) \tag{17}$$

$$f_2(x) \in [0,1], \left(x \in [0,+\infty)\right) \tag{18}$$

When approaching infinity, the efficiency function approaches 1, and when the area of large cultivated land reaches 10 hectares or more and the area of small cultivated land reaches 0.6 hectares (i.e., when the efficiency is basically unaffected), the efficiency approaches 100%:

$$\lim_{x\to+\infty} f_1(x) = 1 \text{ and } |f_1(10) - 1| < 0.02 \tag{19}$$

$$\lim_{x\to+\infty} f_2(x) = 1 \text{ and } |f_2(0.6) - 1| < 0.02 \tag{20}$$

In addition, the two functions should also satisfy the following properties:

$$\frac{df(x)}{dx} > 0 \tag{21}$$

$$\frac{d^2f(x)}{dx^2} < 0 \tag{22}$$

The efficiency function value decreases monotonically with the decrease of area, and the rate of decrease accelerates near zero. When the planting area is zero, the efficiency is zero, that is:

$$f_2(0) = f_1(0) = 0 \tag{23}$$

Find two functions that meet the above four conditions and obtain the following expression:

$$f_1(x) = \frac{1 - e^{-0.5x}}{1 + e^{-0.5x}} \tag{24}$$

$$f_2(x) = \frac{1 - e^{-10x}}{1 + e^{-10x}} \tag{25}$$

In fact, we used a saturated tanh function for fitting, but there were differences in the coefficients. Finally, the efficiency coefficient is defined by the efficiency function, and the overall efficiency coefficient θ is the mean of all crop efficiency coefficients, which can comprehensively evaluate the overall efficiency level of all crops. Its definition is as follows:

$$\theta = \frac{\sum_{j=1}^{41} \theta_j}{41} \tag{26}$$

where θ_j denotes the efficiency coefficient of the 'j'th crop, which can quantitatively evaluate the production efficiency of each crop and be used to measure the planting benefits of different crops on various plots of land:

$$\theta_j = \frac{\sum_{i=1}^{34} f_1(S_{ij}) + \sum_{i=35}^{54} f_2(S_{ij})}{54} \tag{27}$$

Where S_{ij} denotes the planting area of the 'j'th crop on the 'i'th piece of land in addition, the second step has already taken into account the annual changes in sales prices, so the exponential function defined in Part 2.3 is no longer used to estimate the selling price of each crop. Instead, the average value is directly used to fit a new function in the subsequent model for estimation. Next, consider the disaster coefficient in planting risk. Considering that natural disasters also have a significant impact on crops, a disaster coefficient ψ is introduced to quantify the related effects of natural disasters on crops. This coefficient is based on three independent variables: disaster occurrence rate, disaster damage degree, and disaster duration, and analyzes the impact of ten natural disasters such as earthquakes, volcanoes, and typhoons on crops. Among them, the degree of disaster damage is quantified on a scale of 1-5 from mild to severe. After that, use the Independent Weight Grey Correlation Analysis method to assign weights to the three independent variables, and ultimately select the two natural disasters with the greatest impact for in-depth analysis. Independence - Grey Relational Analysis takes the allocation of weights based on the independence of independent variables as its core idea. If a certain independent variable is difficult to express linearly with other independent variables, then assign a greater weight to that independent variable. The theoretical basis for the Independent Weight Grey Correlation Analysis is as follows:

(1) Relevance determination:

$$R_j = \frac{\sum_{j=1}^{m}(x_j - \bar{x})(\tilde{x} - \bar{x})}{\sqrt{\sum_{j=1}^{m}(x_j - \bar{x})^2 (\tilde{x} - \bar{x})^2}} (j = 1,2,3 \cdots) \tag{28}$$

(2) Use the reciprocal of correlation to determine the weight vector:

$$R = \left[\frac{1}{R_1}, \dots \frac{1}{R_m}\right] \tag{29}$$

(3) Determination of independent variable weights:

$$W_j = \frac{\frac{1}{R_j}}{\sum_{j=1}^{m}\frac{1}{R_j}} \tag{30}$$

Through this method, it was found that drought and plant viruses are the two most severe factors affecting crops. Therefore, a disaster score table 1 was defined as follows: the lower the impact, the higher the score. At the same time, if a piece of farmland is affected differently by two natural disasters, corresponding scores can also be obtained based on the table.

Table.1. Disaster Score Table

Drought/Plant Viruses	No(10)	Mild(7)	Moderate (5)	Serious influence(3)
No effect	10	7	5	3
Mild impact	7	6	4	2
Moderate impact	5	4	3	1
Serious influence	3	2	1	0

Finally, we first investigate the incidence and duration of various natural disasters in the region, and then use the Delphi method to score the severity of each disaster on a scale of 1-5, with 5 being the most harmful. Finally, the independent weight grey test method was used to provide the weight distribution of three influencing factors, and the comprehensive calculation showed that drought and plant viruses had the most severe impact on crops in the region. Table 2 in the third part of this article also provides specific data on incidence rate, severity level, duration, and the weights of these three factors. As a consequence, we select drought and plant viruses as the two most serious hazards affecting crops. Therefore, this article only discusses these two influencing factors. The incidence rates of these two natural disasters are denoted as P_{H_1} and P_{H_2}, and their specific incidence rates and impact ratings on crops in the four types of land are also detailed in the data analysis in Part 3.

To evaluate the sensitivity of crop price fluctuations to economic impacts in the context of planting risks, we introduce the concept of "range coefficient" χ. The range coefficient is used to quantify the fluctuation range of crop unit prices, helping us determine the stability of different crops in price changes. The specific steps for constructing the range coefficient are as follows:

(1) For the 'i'th crop, we calculate the range coefficient χ_i of its price series.And Des (i) denotes the range of the price sequence, which is the difference between the maximum and minimum values of the price. Its calculation formula is as follows:

$$\mathrm{Des}(i) = \sup\{x_i\} - \inf\{x_i\} \tag{31}$$

Where $\{x_i\}$ is the price sequence of the 'i'th crop.

(2) Calculate the average value of the price sequence $\mathrm{Ave}(i)$: $\mathrm{Ave}(i)$ is obtained by taking the average of the two ends of the range, and its specific calculation formula is as follows:

$$\mathrm{Ave}(i) = \frac{\sup\{x_i\} + \inf\{x_i\}}{2} \tag{32}$$

The range coefficient χ_i denotes the ratio of range to mean, and its specific calculation formula is:

$$\chi_i = \frac{\mathrm{Des}(i)}{\mathrm{Ave}(i)} \tag{33}$$

(3) The overall range coefficient$\chi$is the sum of the range coefficients for all crops, and the formula is as follows:

$$\chi = \sum_{i=1}^{41} \chi_i \tag{34}$$

The obtained χ provides a comprehensive indicator for comparing the impact of crop price fluctuations under different schemes.

A larger χ value indicates greater overall price fluctuations and corresponding higher planting risks; On the contrary, a smaller χ value indicates smaller price fluctuations and lower planting risks. Considering the constraints of the appeal, we use Monte Carlo based methods for solving. Prior to this, due to the fact that the fluctuation amplitude of each variable is within an interval range rather than a constant value, in order to reduce subjective human intervention and "pseudo-random" problems, we chose the Brownian motion model to randomly generate fixed values[10]. In three-dimensional space, the Brownian motion model of particles can be represented as follows:

$$L(t) = \begin{cases} x_0 + \sigma W_x(t) \\ y_0 + \sigma W_y(t) \\ z_0 + \sigma W_z(t) \end{cases} \tag{35}$$

Among them, (x_0, y_0, z_0) is the starting point coordinate, $W_x(t), W_y(t), W_z(t)$ are the Wiener stochastic process of Brownian motion, σ is the diffusion coefficient, which controls the motion scale of Brownian motion. Due to the need for data normalization and expansion to the range of 0-5, $\sigma = 1$ is chosen to simplify the calculation. We take 3 discrete points per second to predict the rate of change for three years (one cycle) and process this data as follows:

$$\alpha_t = 5 \cdot \frac{\widehat{x_t}}{\max\{\widehat{x_t}\} - \min\{\widehat{x_t}\}} \tag{36}$$

where $\widehat{x_t}$ is the horizontal axis of the particle at second t, and $\{\widehat{x_t}\}$ is the horizontal axis data set. Similarly, apply the same treatment to variables β and γ. This method ensures the randomness of the data while limiting the values of α, β and γ to the range of 0-5. Next, set the following parameters: η_{ij} is the yield per acre of the 'j'th crop on the 'i'th plot of land, S_{ij} is the planting area of the 'j'th crop on the 'i'th plot of land, ω_j is the unit selling price (yuan/jin, 1 jin is 0.5 kilograms) of the 'j'th crop, and φ_{ij} is the planting cost per acre of the 'j'th crop on the 'i'th plot of land. The profit calculation formula for the 'j'th crop is as follows:

$$E_{1j} = \sum_{i=1}^{54} S_{ij}\left(\eta_{ij} \cdot \omega_j - \varphi_{ij}\right) \tag{37}$$

$$E_{2j} = \left(N_j \cdot \omega_j\right) - [\sum_{i=1}^{54}\left(S_{ij} \cdot \varphi_{ij}\right) - \left(\sum_{i=1}^{54} \eta_{ij} \cdot S_{ij} - N_j \right) \cdot 0.5\omega_j] \tag{38}$$

Where E_{1j} and E_{2j} represent the total profit of the 'j'th crop without exceeding the expected planting amount and exceeding the expected planting amount, respectively. Introducing the 0-1 variable Y_j to indicate whether the 'j'th crop exceeds the expected planting amount, the calculation formula is:

$$Y_j = \begin{cases} 1, & \sum_{i=1}^{54} \eta_{ij} \cdot S_{ij} \le N_j \\ 0, & \sum_{i=1}^{54} \eta_{ij} \cdot S_{ij} > N_j \end{cases} \tag{39}$$

The total profit E can be calculated as:

$$E = \sum_{j=1}^{41}\left[E_{1j} \cdot Y_j + E_{2j} \cdot \left(1 - Y_j\right)\right] \tag{40}$$

According to the above definition, the annual variation formulas for φ_{ij} (planting cost), η_{ij} (yield per mu), ω_j (sales unit price), and N_j (expected market sales volume) are as follows:

$$\varphi_{ij} = \varphi_{ij}(1 + 5\%) \tag{41}$$

$$\varphi_{ij} = \varphi_{ij}(1 + 5\%) \tag{42}$$

$$\omega_j = \begin{cases} \omega_j & (j \in [1,16]) \\ \omega_j(1 + 5\%) & (j \in [17,37]) \\ \omega_j(1 - |\gamma_t|\%) & (j \in [38,40]) \\ \omega_j(1 - 5\%) & (j = 41) \end{cases} \tag{43}$$

$$N_j = \begin{cases} N_j(1 + 5\% + |\alpha_t|\%) & j \in [6,7] \\ N_j(1 + \alpha_t\%) & j \in [1,5] \cup [8,41] \end{cases} \tag{44}$$

Then, using the Delphi method to weight the three factors in the table, the impact weights of sales profit, management cost, and planting risk were obtained as 0.5, 0.3, and 0.2, respectively. At the same time, for management costs, the weight of the impact of crop planting area and dispersion degree is 0.6 and 0.4, and for planting risks, the proportion of price fluctuations and risk resistance ability is also 0.6 and 0.4. Therefore, the final objective function appears in a simple form:

$$\max[0.5 \cdot (2/\pi)arctan(\mathrm{E}) + 0.3 \cdot (2/\pi)arctan(-\lambda) + 0.2 \cdot (2/\pi)arctan(\mathrm{u})] \tag{45}$$

where E is the total profit, λ is the management cost coefficient, and μ is the sudden planting risk coefficient, calculated as follows:

$$\lambda = 0.6\,\mathrm{D} + 0.4\,\theta \tag{46}$$

$$\mathrm{u} = 0.6\,\psi - 0.4\,\chi \tag{47}$$

The use of *arctan* function is to normalize data. The *arctan* function can place data between 0 and π/2, and then multiply by 2/π to place data between 0-1. Due to the inability to accurately determine the maximum and minimum values of data E, λ, and u, min-max normalization and z-score normalization can not be used. Similarly, if we use the logarithmic function of the e-index for scaling, it is difficult to determine the data range between 0-1. Therefore, we use the *arctan* function for normalization here.[11]

Plan separately for farmland that requires and does not require the planting of beans, and ultimately determine the planting method for a certain year based on maximizing profits. Finally, calculate the situation for one cycle and promote it.

3. Data analysis

Firstly, let's perform a simple unit conversion: 1 'mu' equals 666 square meters, and 1 yuan equals 0.138 US dollars.

The initial data, including the planting situation in 2023, the yield per mu of each crop, the price range, and the average cost per mu, are all sourced from the official website. Based on this data, this article uses Monte Carlo method to randomly sprinkle points to provide several planting situations, and then limiting and optimizing them according to the article, the final results are obtained. We still analyze them separately according to the first and second steps:

In scenario one of the first step: the excess crop is wasted and cannot be sold. At this time, there is no significant difference in the planting distribution of various crops within one cycle compared to 2023. Specifically, taking 2024 as an example, the cultivation of fungi is as follows: 1.8 mu of white spirit mushrooms, accounting for the largest proportion. For grain (non-legume) crops, wheat has a maximum planting area of 235 mu, located in four different plots, accounting for the largest proportion. Next are 178 mu of wheat and 72 mu of corn. Sorghum, barley, and other crops are planted on dozens of mu of land. For grains (legumes), ignoring the differences in nitrogen fixation among different legumes, from a profit perspective alone, the maximum planting area is 121 mu (2 plots) for mung beans and 135 mu (2 plots) for soybeans, followed by 110 mu for black beans and 60 mu for red beans. For vegetables, excluding legumes, white radish, red radish, and Chinese cabbage (because these three vegetables can only be planted in the second season of irrigated land and cannot be planned too flexibly), the remaining vegetables are extensively planted with small green vegetables, eggplants, and tomatoes, covering an area of more than ten mu, while the remaining vegetables are only 0.6 mu or 1.2 mu (only planted in small areas in greenhouses).

Horizontally speaking, the overall planting situation in 2024 and 2023 is similar. Vertically speaking, the planting area of White Spirit Mushroom is the widest among fungi due to its high average profit per mu (130,000-170,000 yuan/mu, ranking second) and relatively high demand. The reason why wheat has the widest planting area among grains is because it has a good average profit per mu (2,000-2,800 yuan/mu), but also has a high market demand. And the larger planting areas of small vegetables, eggplants, and tomatoes are also due to their high demand.

In the second scenario of the first step, the excess crop portion is sold at 50% of the lowest selling price. At this point, we found that "cucumber" and "elm mushroom" were extensively planted, with elm mushroom planting reaching 5.4 mu (far exceeding other fungi). For vegetables, the cucumber planting area reaches an astonishing 75.8 mu, while the majority of vegetable planting areas are only 0.6 mu or 1.2 mu. This is because cucumber and elm mushroom have the highest average profit per mu among vegetables and fungi (70,000 to 93,000 yuan/mu and 250,000 to 320,000 yuan/mu), which directly leads to the fact that even if sold at only 50% of the lowest selling price, the average profit per mu of these two crops is still much higher than the average (the average profit per mu for vegetables is about 25,000 yuan, and the average profit per mu for fungi is 100,000 yuan). This is consistent with the results of intuitive consideration. In other words, planting high-profit crops such as cucumbers and elm mushrooms on a large scale is a good choice when all of them can be sold.

Step 2: After considering various factors comprehensively, extreme situations of crop cultivation (such as the large number of cucumbers and elm fungi mentioned above) no longer occur. The final result will be obtained through continuous optimization after Monte Carlo sprinkling, and will be analyzed according to the factors considered.

The degree of planting dispersion and the size of planting area: After continuous optimization, it was finally found that for each crop of vegetables (excluding Chinese cabbage, white radish, and red radish) and edible fungi, the planting area should not exceed 7 plots for eggplants, while the planting areas for other edible fungi and vegetables should be concentrated in 4-6 plots; The minimum planting area is 0.175 mu, which is chili pepper. For grain crops, the maximum number of planting plots for a certain crop is 19, which is black beans, while the number of planting plots for other grain crops is 5-12; The minimum planting area is 0.722 mu, which is red beans. The result obtained is in line with intuitive thinking. Simply put, because the demand for each crop remains relatively unchanged, it is necessary to divide the large plots of land for crops with lower demand. Similarly, for crops with high demand to be distributed on small plots of land, it inevitably leads to the same crop being planted on different lands. Ideally, if each crop can be planned according to 0.01 to 0.001 mu, an almost perfect solution can be achieved. But this will bring incalculable management costs and troubles, so it is necessary to find a reasonable allocation method. The results obtained through continuous optimization illustrate this point very well.

Continuing the impact of natural disasters such as drought and plant viruses discussed in Part 2: using Delphi method and independent weight grey test method, the common natural disasters are obtained as follows. The weight of each natural disaster is objectively given, and the two most serious natural hazards in this region are "drought" and "crop virus". The table is as follows:

Table.2. The attributes and final weights of natural disasters

types of disasters	incidence rate	hazard level	Duration(month)	final level
earthquake	8%	3	4	
volcano eruption	0.10%	4	12	
typhoon	5%	4	2	
tornado	1%	3	2	
flood	15%	5	4	
drought	35%	5	24	1
mountain landslide	3%	4	3	
tsunami	0.10%	3	12	
hail	15%	3	1	
plant virus	25%	5	3	2
Weight	26%	28%	46%	Total = 100%

The two natural disasters that ultimately had the greatest impact were drought and plant viruses. Then use the Delphi method to determine the impact of each natural disaster on crops in different locations, and introduce the natural disaster index ψ_i (the comprehensive score of the 'i'th piece of land):

$$\psi_i = \begin{cases} [5P_{H_1} + 3P_{H2} + 1(P_{H_1}P_{H2}) + const] & (i \in [1,26]) \\ [3P_{H_1} + 3P_{H2} + 0(P_{H_1}P_{H2}) + const] & (i \in [27,34] \\ [7P_{H_1} + 7P_{H2} + 6(P_{H_1}P_{H2}) + const] & (i \in [35,50] \\ [10P_{H_1} + 7P_{H2} + 7(P_{H_1}P_{H2}) + const] & (i \in [51,54 \end{cases} \quad (48)$$

Each term in the function is the probability of a certain disaster occurring and the score corresponding to this piece of land.Constis a constant, representing the product of the probability of not experiencing these two disasters and the maximum score of 10 points. The formula is as follows:

$$const = 10(1 - P_{H_1} - P_{H_2} - P_{H_1}P_{H_2}) \quad (49)$$

In which $P_{H_1} = 35\%, P_{H_2} = 25\%$. Finally, we calculated the disaster coefficient as follows:

$$\psi = \frac{\sum_{j=1}^{41} \psi_j}{41} \quad (50)$$

where P_{H_1} and P_{H_2} represent the probability of the occurrence of the type of disaster.

By calculation, we conclude that irrigated land has the highest planting risk, followed by other outdoor land. Indoor greenhouses and smart greenhouses have lower risks, while smart greenhouses have lower risks than ordinary greenhouses.

4. Conclusion

In this study, the computational efficiency was significantly improved through reasonable model assumptions and simplification, while the impact on the global optimal solution was minimal. For example, periodically introducing and utilizing Brownian motion models to simulate stochastic processes effectively reduces errors. In addition, the proposal of some models helps to quantify fuzzy evaluation criteria, such as dispersion, efficiency function, price range, and natural disaster coefficient definitions, so that different situations can be quantitatively analyzed and corresponding evaluation criteria can be established. However, there is a certain subjectivity in the processing and investigation of some data in this article. For example, in the weight setting of the second question, the Delphi method is completely used, and the composition of the expert review team has limitations. The dimensionality reduction of data is also significant, for example, in the second question, 80% of natural disasters were screened out and only two types of disasters were retained for analysis. For future research, for example, in the method of weight determination, Monte Carlo method can be used to randomly sprinkle points and generate enough schemes, and then entropy weight method can be used for objective weighting. Compared with subjective weighting, the weight determined by entropy weighting method is more universal and general, which can further reduce errors. In summary, this study not only improves computational efficiency, but also enhances the reliability and applicability of the results.

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