# Research on optimal crop planting strategy based on particle swarm algorithm and Monte Carlo model

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**Abstract.** This paper establishes a crop planting model based on particle swarm algorithm and Monte Carlo simulation to address rural planting problems in the mountainous areas of North China, and obtains the optimal planting plan with the goal of maximizing returns. First, through data preprocessing and analysis, it was found that the 2023 planting plan has crop planting dispersion and yields affected by plots, seasonal and other problems. The planning analysis model is used and the particle swarm algorithm is used to predict the best planting strategy under the constraints of different conditions. Secondly, further increase passive factors and risk factors, and establish a Monte Carlo model to predict fluctuations. Taking into account the other various influencing factors, the Monte Carlo model is used to quantify the influencing factors, and the particle swarm algorithm is used to obtain the best planting strategy. Finally, by establishing a fit model, the correlation between expected sales volume, sales price and planting cost is analyzed, and it is used as a constraint to further optimize the planting plan to maximize profits.

**Keywords:** Particle Swarm Optimization, Monte Carlo Simulation, Planning Model.

## 1. Introduction

Agriculture is the basic industry that supports the national economy, and its development level directly affects the national economic security and social stability[1]. With the growth of population and the decreasing farming resources, increasing crop yields and incomes has become an important goal of agricultural development [2]. The traditional crop planting methods mainly rely on manual judgment and lack scientificity and systematicity. In order to adapt to the needs of modern agricultural development, it has become an inevitable trend to introduce advanced technical means and scientific decision-making methods [3]. At present, domestic and foreign scholars have carried out a lot of research work in crop planting optimization [4]. However, the existing research mainly focuses on the impact of single factors on crop planting [5][6], lacks consideration of the comprehensive impact of multiple factors, and rarely involves the impact of substitution and complementarity among crops [7]. This paper aims to build a crop planting model based on particle swarm algorithm [8], considering a variety of factors, including planting density, seasons, plots, expected sales volume, sales price and planting cost [9], analyzing the impact of substitution and complementarity among crops, and providing theoretical support and technical support for the development of agricultural modernization [10].

## 2. Particle Swarm Algorithm and Monte Carlo Simulation

### 2.1. Data acquisition and preprocessing

This article collects data on planting varieties, prices and returns, which are derived from the open source website: https://www.mcm.edu.cn .

During the process of sorting the data, it was found that the crop planting situation in 2023 was relatively scattered (as shown in Figure 3), which was not conducive to profit maximization, and the yield per mu of crops was greatly affected by the planting fields and the planting season.

The Monte Carlo model can be used to simulate the unit sales price of different crops under different plots (as shown in Figure 1) and the sales price of crops planted in different plots (as shown in Figure 2). The sales profit per mu can be calculated based on the unit sales price.


**Figure 1** The unit price of crops planted in different plots


**Figure 2** Sales price of crops planted in different plots

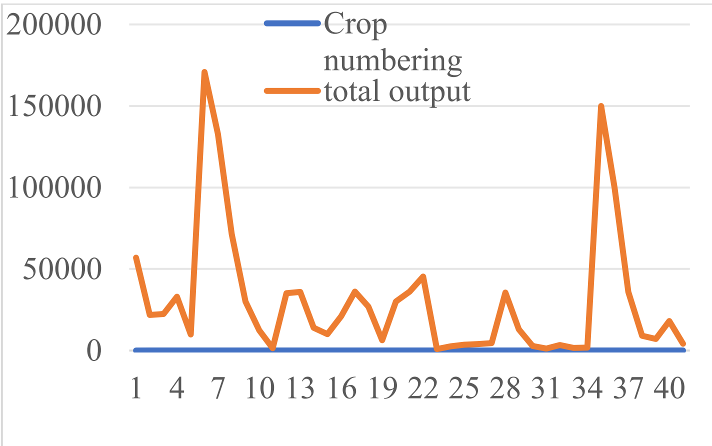


**Figure 3** Total output of different crops in 2023

## 2.2. Data acquisition and problem analysis

### 2.2.1 Analysis of optimal crop planting scheme based on stable market

The research object is the optimal planting plan obtained by various varieties of crops between 2024 and 2030 under different lands and different seasons. The data obtained shows that the crops planted in the place are relatively scattered in 2023 and the planting plan is poor. Now, in order to solve this problem, we optimize the planting plan, analyze the overall profit, establish a nonlinear planning model, and bring in various constraints for solving .

### 2.2.2 Analysis of the best planting schemes that consider market volatility and risks

In order to formulate the optimal planting plan between 2024 and 2030, this article needs to comprehensively consider the expected sales volume, the per mu yield of crops is affected by weather, the crop planting cost is affected by market conditions, sales price and other uncertainties, as well as potential planting risks . For the impact of market volatility and risk factors, we used Monte Carlo simulation to analyze it to obtain the optimal constraints.

### 2.2.3 Analysis of the best planting scheme that comprehensively considers crop substitution and complementarity

This article is divided into the following steps for analysis. The first step is to analyze the correlation between expected sales volume, sales price, and planting cost, and obtain a linear expression to solve the next step as a new constraint. The second step is to comprehensively consider various factors to design it.

## 3. Model establishment and solution

### 3.1. Establishment of nonlinear programming model

Settings of decision variables:

$G_{i,j}^{t}$ represents the type of plant planted on the i-field land in the year $t$, season $j$, and season $i$.

$\mathrm{H}_{\mathrm{i,j}}^{\mathrm{t}}$ represents the type of plant planted on the i-field land in the year $t$, season $j$, and season $i$.

When the sales volume exceeds expectations, it causes unsalable sales in two situations:

(1) When actual production is lower than expected sales:

$$Sum_1 = \sum_{t=2024}^{2030}\sum_{i=1}^{54}\sum_{j=1}^{2}\left(P_{H_{i,j}^t} \times C_{H_{i,j}^t} \times G_{i,j}^t\right) - \sum_{i=1}^{54}\sum_{j=1}^{2}\sum_{t=2024}^{2030} W_{H_{i,j}^t} \times G_{i,j}^t \tag{1}$$

The actual output is the sales volume, and the total sales revenue minus the cost is the total profit.

(2) When actual production is higher than expected sales:

$$Sum_2 = \sum_{t=2024}^{2030}\sum_{i=1}^{54}\sum_{j=1}^{2}\left(P_{H_{i,j}^t} \times Q_{H_{i,j}^t}\right) - \sum_{i=1}^{54}\sum_{j=1}^{2}\sum_{t=2024}^{2030} W_{H_{i,j}^t} \times G_{i,j}^t \tag{2}$$

The excess of expectations causes unsalable sales, and the expected sales benefit is the total profit, and the total profit is reduced by deducting the planting cost.

(3) When the sales exceed the expected portion, it is divided into two situations:

When actual production is lower than expected sales:

Same as $Sum_1$. Similarly, you can get:

$$Sum_1 = \sum_{t=2024}^{2030}\sum_{i=1}^{54}\sum_{j=1}^{2}\left(P_{H_{i,j}^t} \times C_{H_{i,j}^t} \times G_{i,j}^t\right) - \sum_{i=1}^{54}\sum_{j=1}^{2}\sum_{t=2024}^{2030} W_{H_{i,j}^t} \times G_{i,j}^t \tag{3}$$

When the actual output is lower than the expected sales volume, the actual output is the sales volume, and the total sales revenue minus the cost is the total profit.

When actual production is higher than expected sales:

$$Tem = C_{H_{i,j}^t} \times G_{i,j}^t - Q_{H_{i,j}^t} \tag{4}$$

$$Sum_3 = \sum_{t=2024}^{2030}\sum_{i=1}^{54}\sum_{j=1}^{2}\left(P_{H_{i,j}^t} \times Q_{H_{i,j}^t} + 0.5 \times P_{H_{i,j}^t} \times Tem\right) - \sum_{i=1}^{54}\sum_{j=1}^{2}\sum_{t=2024}^{2030} W_{H_{i,j}^t} \times G_{i,j}^t \tag{5}$$

The exceeding expectations will be sold at a price reduction of 50% of the 2023 sales price. That is, the total sales benefit is the expected sales benefit plus 50% of the expected output benefit, so the total profit is the total sales benefit minus the planting cost.

(4) Where constraints:

Each crop cannot be planted continuously on the same plot (including greenhouse):

$$H^t{}_{i,j} \neq H^{t+1}{}_{i,j} \quad \forall i, j, t \tag{6}$$

Plant legumes at least once in three years:

$$\sum_t \sum_{H^t{}_{i,j} \in \text{beans}} G^t{}_{i,j} \geq 1 \qquad \forall \text{i} \tag{7}$$

The planting area of a certain crop on a certain plot (including greenhouses) cannot exceed the maximum area:

$$\sum_{H^t{}_{i,j}} G^t{}_{i,j} \leq \text{Maximum area of block} \quad \forall i, j, t \tag{8}$$

The planting grounds of each crop each season cannot be too dispersed:

$$\left| G^t{}_{i,j} - G^t{}_{i,j'} \right| \leq \partial \qquad \forall j, j' \in \text{Adjacent block} \tag{9}$$

$\partial$ is the allowable planting area difference.

The area of each crop planted on a single plot should not be too small:

$$\forall_{H^t{}_{i,j}} G^t{}_{i,j} \geq \varepsilon \qquad \forall i, j, t \tag{10}$$

$\varepsilon$ is minimum planting area under the premise of ensuring sensitivity.

### 3.1.1 Solving the nonlinear programming model

Objective function:

When the actual output is lower than the expected sales volume, the actual output is the sales volume, and the total sales revenue minus the cost is the total profit.

$$Sum_1 = \sum_{t=2024}^{2030}\sum_{i=1}^{54}\sum_{j=1}^{2}\left(P_{H^t{}_{i,j}} \times C_{H^t{}_{i,j}} \times G^t{}_{i,j}\right) - \sum_{i=1}^{54}\sum_{j=1}^{2}\sum_{t=2024}^{2030} W_{H^t{}_{i,j}} \times G^t{}_{i,j} \tag{11}$$

The excess of expectations causes unsalable sales, and the expected sales benefit is the total profit, and the total profit is reduced by deducting the planting cost.

$$Sum_2 = \sum_{t=2024}^{2030}\sum_{i=1}^{54}\sum_{j=1}^{2}\left(P_{H^t{}_{i,j}} \times Q_{H^t{}_{i,j}}\right) - \sum_{i=1}^{54}\sum_{j=1}^{2}\sum_{t=2024}^{2030} W_{H^t{}_{i,j}} \times G^t{}_{i,j} \tag{12}$$

The exceeding expectations will be sold at a price reduction of 50% of the 2023 sales price. That is, the total sales benefit is the expected sales benefit plus 50% of the expected output benefit, so the total profit is the total sales benefit minus the planting cost.

$$Tem = C_{H_{i,j}^t} \times G_{i,j}^t - Q_{H_{i,j}^t} \tag{13}$$

$$Sum_3 = \sum_{t=2024}^{2030}\sum_{i=1}^{54}\sum_{j=1}^{2}\left(P_{H^t{}_{i,j}} \times Q_{H^t{}_{i,j}} + 0.5 \times P_{H^t{}_{i,j}} \times T\text{em}\right) - \sum_{i=1}^{54}\sum_{j=1}^{2}\sum_{t=2024}^{2030} W_{H^t{}_{i,j}} \times G^t{}_{i,j} \tag{14}$$

$$S.t\begin{cases} {H^t}_{i,j} \neq {H^{t+1}}_{i,j}(\forall i,j,t) \\ \sum_{t} \sum_{{H^t}_{i,j} \in \text{beans}} {G^t}_{i,j} \geq 1(\forall \text{i}) \\ \sum_{{H^t}_{i,j}} {G^t}_{i,j} \leq \text{Maximum area of block}(\forall i,j,t) \\ \left| {G^t}_{i,j} - {G^t}_{i,j'} \right| \leq \partial(\forall j,j' \in \text{Adjacent block}) \\ \forall_{{H^t}_{i,j}} {G^t}_{i,j} \geq \varepsilon(\forall i,j,t,\ \ \varepsilon \text{ is the minimum planted area}) \end{cases} \tag{15}$$

### 3.2. The best planting plan considering market volatility and risks

(1) Using Monte Carlo simulation, the specific values of the given relevant factors were quantified, and the crop yield growth rate per mu from 2024 to 2030 was calculated (as shown in Figure 4), the crop sales price growth rate from 2024 to 2030 (as shown in Figure 5), the crop sales growth rate from 2024 to 2030 (as shown in Figure 6), and the crop planting cost growth rate from 2024 to 2030 (as shown in Figure 7).

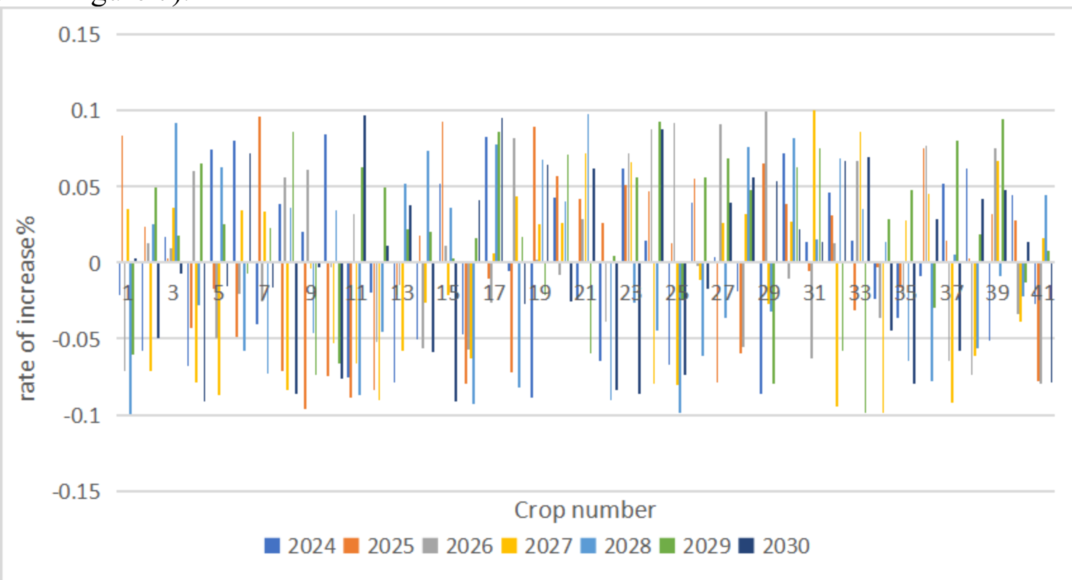


**Figure 4** Crop yield growth rate from 2024 to 2030

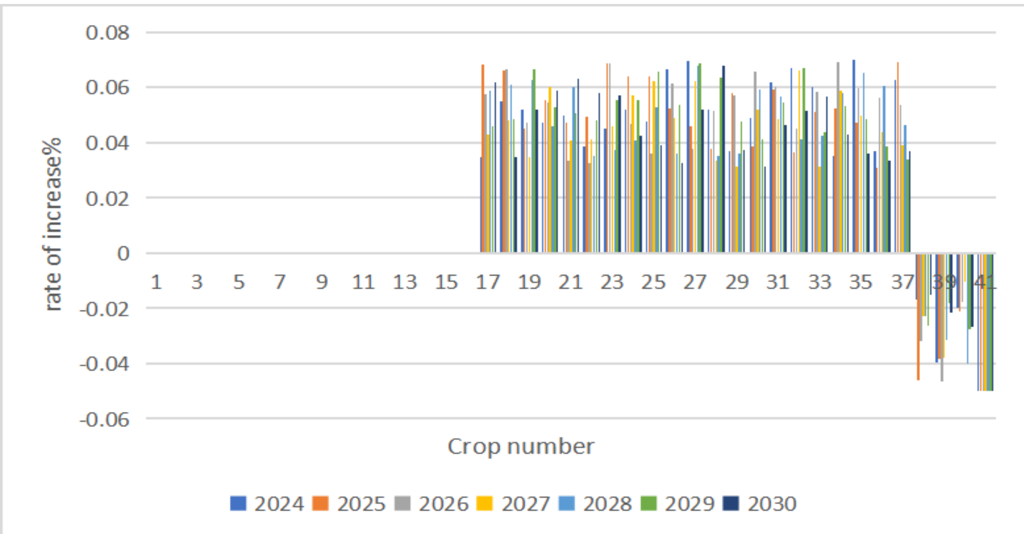

**Figure 5** Crop sales price growth rate from 2024 to 2030

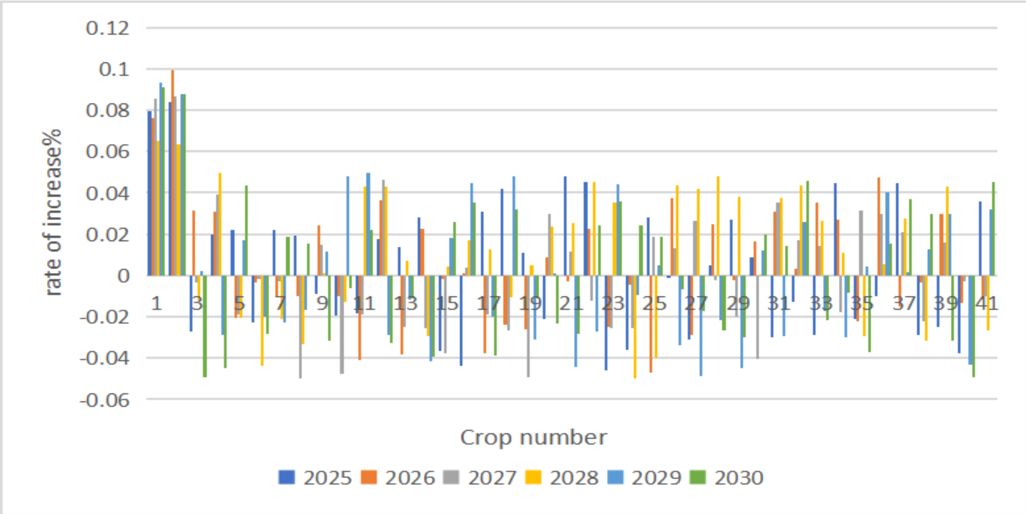


**Figure 6** Increase in crop sales from 2024 to 2030

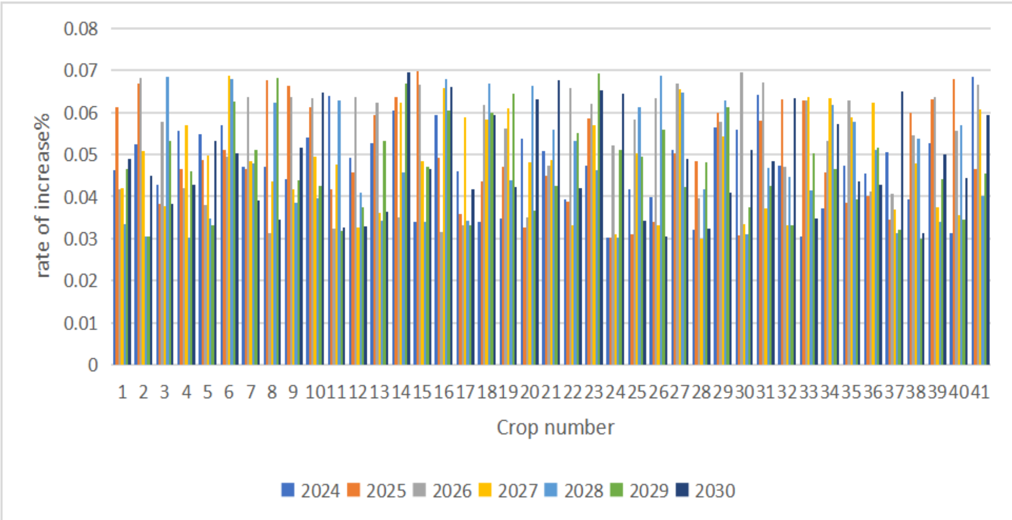


**Figure 7** Crop planting cost growth rate from 2024 to 2030

New constraints can be obtained based on the Monte Carlo simulation results:

$$P_k^t = P_k^{2023} \times (\theta_k)^{t-2023} \quad \forall k, \ t \in [2024, 2030] \tag{16}$$

After analysis, it can be assumed that $\theta_k$ is the rate of change of crop sales price, and the sales price of crop $k$ in year t is multiplied by $(\theta_k)^{t-2023}$ based on the sales price of crop $k$ in 2023.

$$C_k^t = C_k^{2023} \times (\vartheta_k)^{t-2023} \times (1-\phi_k)^{t-2023} \quad \forall k, \ t \in [2024, 2030] \tag{17}$$

$$W_k^t = W_k^{2023} \times (\omega_k)^{t-2023} \quad \forall k, \ t \in [2024, 2030] \tag{18}$$

After analysis $\omega_k$, it can be set as the rate of change of crop planting cost, and the planting cost of crop $k$ in $t$ year is multiplied by $(\omega_k)^{t-2023}$ based on the sales price of crop $k$ in 2023.

$$Q_k^t = Q_k^{2023} \times (\varpi_k)^{t-2023} \quad \forall k, \ t \in [2024, 2030] \tag{19}$$

After analysis, it can be assumed that $\varpi_{\mathrm{k}}$ is the quantification of the expected sales rate of crops, and the expected sales of crop $\mathrm{k}$ in $\mathrm{t}$ year is multiplied by $(\varpi_{\mathrm{k}})^{\mathrm{t}-2023}$ based on the expected sales of crop $\mathrm{k}$ in 2023.

$$\sum_{\mathrm{k}=1}^{41} Q_{\mathrm{k}}^{2023} = \sum_{\mathrm{i}=1}^{54}\sum_{j=1}^{2} Q_{H_{i,j}^{2023}} \tag{20}$$

$$\sum_{\mathrm{k}=1}^{41} C_{\mathrm{k}}^{2023} = \sum_{\mathrm{i}=1}^{54}\sum_{j=1}^{2} C_{H_{i,j}^{2023}} \tag{21}$$

$$\sum_{\mathrm{k}=1}^{41} W_{\mathrm{k}}^{2023} = \sum_{\mathrm{i}=1}^{54}\sum_{j=1}^{2} W_{H_{i,j}^{2023}} \tag{22}$$

$$\sum_{\mathrm{k}=1}^{41} P_{\mathrm{k}}^{2023} = \sum_{\mathrm{i}=1}^{54}\sum_{j=1}^{2} p_{H_{i,j}^{2023}} \tag{23}$$

(2) When the actual output is less than expected output:

$$Sum_4 = \sum_{t=2024}^{2030}\sum_{k=1}^{41}\left(P_k^t \times C_k^t \times G_k^t - W_k^t \times G_k^t\right) \tag{24}$$

The total profit is the actual production sales revenue minus the planting cost.

(3) When the actual output is higher than the expected output:

$$Sum_5 = \sum_{\mathrm{t}=2024}^{2030}\sum_{k=1}^{41}\left(P_k^t \times Q_k^t + \mu \times P_{\mathrm{k}}^t \times \left(C_k^t \times G_k^t - Q_k^t\right) - W_k^t \times G_k^t\right) \tag{25}$$

After adding new constraints, new changes occur in the part beyond expectations. Suppose it is the random risk factor simulated by the Monte Carlo model, and the total profit is the expected sales income plus the expected sales income multiplied by the random risk factor and minus the cost.

The objective function is:

$$Sum_4 = \sum_{t=2024}^{2030}\sum_{k=1}^{41}\left(P_k^t \times C_k^t \times G_k^t - W_k^t \times G_k^t\right) \tag{26}$$

$$Sum_5 = \sum_{\mathrm{t}=2024}^{2030}\sum_{k=1}^{41}\left(P_k^t \times Q_k^t + \mu \times P_{\mathrm{k}}^t \times \left(C_k^t \times G_k^t - Q_k^t\right) - W_k^t \times G_k^t\right) \tag{27}$$

The constraints mentioned in the previous article are included by default in the following constraints.

$$S.t\begin{cases} P_k^t = P_k^{2023}\times(\theta_k)^{t-2023} \\ C_k^t = C_k^{2023}\times(\vartheta_k)^{t-2023}\times(1-\phi_k)^{t-2023} \\ W_k^t = W_k^{2023}\times(\omega_k)^{t-2023} \\ Q_k^t = Q_k^{2023}\times(\varpi_k)^{t-2023} \\ \sum_{k=1}^{41} Q_k^{2023} = \sum_{i=1}^{54}\sum_{j=1}^{2} Q_{H_{i,j}^{2023}} \\ \sum_{k=1}^{41} C_k^{2023} = \sum_{i=1}^{54}\sum_{j=1}^{2} C_{H_{i,j}^{2023}} \\ \sum_{k=1}^{41} W_k^{2023} = \sum_{i=1}^{54}\sum_{j=1}^{2} W_{H_{i,j}^{2023}} \\ \sum_{k=1}^{41} P_k^{2023} = \sum_{i=1}^{54}\sum_{j=1}^{2} p_{H_{i,j}^{2023}} \end{cases} \quad \forall k,\ t\in[2024,2030] \tag{28}$$

### 3.3. Optimal planting plan that comprehensively considers multiple factors

(1) Use the fitting model to find the linear relationship between expected sales volume, sales price and expected cost.

$$\text{Set: } Z = aX + bY + C \tag{29}$$

Using the fitting model, we can find:

$$Z = 1445 - 0.114X + 28.808Y \tag{30}$$

Y: Planting costs X: Sales unit price Z: Expected sales C: Balance factor

(2) Use the obtained linear relationship as a new constraint, and based on 2.2, the optimal planting plan between 2024 and 2030 is obtained.

$$Sum_4 = \sum_{t=2024}^{2030}\sum_{k=1}^{41}\left(P_k^t\times C_k^t\times G_k^t - W_k^t\times G_k^t\right) \tag{31}$$

$$Sum_5 = \sum_{t=2024}^{2030}\sum_{k=1}^{41}\left(P_k^t\times Q_k^t + \mu\times P_k^t\times\left(C_k^t\times G_k^t - Q_k^t\right) - W_k^t\times G_k^t\right) \tag{32}$$

Add new constraints on the previous basis:

$$S.t\begin{cases} y = ax + bz \\ C_{k_2}^t = C_{k_2}^t - T_{k_1,k_2}\times G_{k_1}^t \\ C_{k_2}^t = C_{k_2}^t + F_{k_1,k_2}\times G_{k_1}^t \end{cases} \tag{33}$$

$T_{k_1,k_2}$ set as the degree of substitution of crop $k1$ to crop $k2$

$F_{k_1,k_2}$ is equal to the degree of promotion of crop $k1$ to crop $k2$.

By solving the solution, we can obtain the optimal planting plan between 2024 and 2030.

(3) Comparing the optimal planting plan with the actual data in previous years, it can be obtained that the expected sales volume is inversely proportional to the planting cost.

## 4. Conclusion

This paper constructs a crop planting model based on particle swarm algorithm, aiming to optimize crop planting strategies in rural areas in North China. Through the analysis of the planting plan, the model effectively solves the problems of crop planting dispersion, yields affected by land, seasonal and other factors, and considers the substitutability and complementarity between crops, and ultimately maximizes profits. The research results show that this model is highly operable and adaptable in practical applications, can provide farmers with scientific basis for planting decision-making and provide technical support for agricultural modernization. However, although this model has good application effects in the current study, there is still a certain room for optimization. For example, more environmental factors and external interference factors can be further introduced in the future to improve the robustness and accuracy of the model. At the same time, optimizing the processing efficiency of large-scale data sets and the real-time algorithms is also an important direction for future research. Through continuous improvement and improvement of the model, it is expected to be promoted and applied in a wider region and more complex agricultural environment, and further promote the goal of agricultural development and farmers' income increase.

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