Particle Swarm Optimization for Agricultural Problems

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Abstract. The research objective of this paper is to provide guidance for crop planting planning, thereby assisting farmers in maximizing their profits. In the development of rural economies, efficiently utilizing limited arable land resources poses a significant challenge. To simulate real-world scenarios, the paper first introduces the "dichotomy model" of bargaining between sellers to calculate the actual transaction amount. Next, it establishes constraints based on the requirements of arable land and crops. Finally, using the Particle Swarm Optimization (PSO) algorithm, it predicts the optimal crop planting strategies for the period 2024-2030 under different decision-making scenarios. The first decision-making scenario yields a maximum profit of 3.65 million yuan, while the second scenario results in a maximum profit of 7.77 million yuan. The experimental research concludes that selling surplus products at discounted prices can maximize profits, and it also demonstrates that this model can accurately predict future sales performance.

Keywords: Decision optimization, dichotomy model, particle swarm optimization.

1. Introduction

In the national economic system, agriculture often serves as the foundational industry that determines the level of rural development[1]. High-standard crop cultivation is an indispensable component of agricultural development. However, people often focus solely on innovations in agricultural technology, often neglecting the rational arrangement of crop types, which in turn leads to low crop productivity and significantly reduced economic benefits. In fact, according to Popkin's Rational Peasant Behavior Model, adjusting the agricultural structure, such as adjusting crop varieties and factor allocation, is conducive to maintaining maximum agricultural efficiency and increasing economic returns[2]. Given the relatively limited arable land resources in rural areas, in order to enhance production efficiency, it is necessary to undertake structural optimization and reform of crop types and planting practices. This will further increase economic returns and ensure the sustainable development of the agricultural economy[3].

In this thesis, the aim is to simulate real-world agricultural scenarios by introducing the "dichotomy model" of bargaining between sellers and considering planting constraints among various crops, thereby deriving the optimal planting plan. The thesis is structured as follows:

In the first part, the research background will be introduced, which highlights the current status, challenges, and necessity of agricultural planting optimization. This part will also outline the thesis's research methods, providing an overall framework.

In the second part, two core tools will be focused on: the "dichotomy model" for seller bargaining and the Particle Swarm Optimization (PSO) algorithm. This part will detail the construction and application of the "dichotomy model" and explain the basics and parameters of the PSO algorithm, establishing a theoretical foundation.

In the third part, these models and algorithms will be applied to agricultural planting optimization. This involves defining an objective function, constructing a mathematical model with planting constraints, simulating seller bargaining using the "dichotomy model," and finding the optimal planting plan with the PSO algorithm. Case studies demonstrate their practical effects.

In the fourth part, experimental data will be analyzed to evaluate model performance under various parameter settings, focusing on optimal planting plans, improved planting benefits, and handling complex planting constraints. This part will draw conclusions and discuss potential improvements.

In the fifth part, the thesis will be summarized, assessing the applicability and effectiveness of tools. Explorations on other potential applications will continue, such as agricultural resource allocation and ecological agriculture planning, and propose directions for future research, addressing existing limitations and incorporating insights from other research methods, which may have lacked comprehensive consideration of bargaining dynamics and planting constraints.

Through the above structural arrangement, this thesis aims to systematically demonstrate how to solve agricultural planting optimization problems by introducing the "dichotomy model" of bargaining between sellers and the PSO algorithm, providing scientific evidence and technical support for sustainable agricultural development.

2. Correlation theory

In a free market, sellers aim for higher profits while consumers desire lower prices. If the price of a commodity is negotiable, both parties will bargain until a consensus is reached[4]. Based on this backdrop, in order to make the research results closer to reality and address the potential bargaining issues between buyers and sellers in actual sales, this thesis introduces the "Bisection Method Model" for bargaining by sellers. Assuming each negotiation reduces the current price by half, after n rounds of negotiations, it is found that the final price stabilizes at a certain value, which is then used as the transaction price in the model for the research.

Suppose the cost price for the seller is a yuan, and the initial selling price is b_0 yuan, where $a < b_0$. The process of bargaining between the buyer and seller is shown in Table 1.

Table.1. The derivation process of binary classification model

Bargaining times	Consumer bargaining	Counter offer
The first time	$a_1 = \frac{1}{2} b_0$	$b_1 = a_1 + \frac{1}{2}(b_0 - a_1)$
The second time	$a_2 = b_1 - \frac{1}{2}(b_1 - a_1)$	$b_2 = a_2 + \frac{1}{2}(b_1 - a_2)$
The third time	$a_3 = b_2 - \frac{1}{2}(b_2 - a_2)$	$b_3 = a_3 + \frac{1}{2}(b_2 - a_3)$
……	……	……
The n_{th} time	$a_n = b_{n-1} - \frac{1}{2}(b_{n-1} - a_{n-1})$	$b_n = a_n + \frac{1}{2}(b_{n-1} - a_n)$
……	……	……

Finally, through mathematical induction, it is concluded that the final transaction price will stabilize at one-third of the initial selling price. (Hereinafter, it will be referred to as the "Dichotomy Model" in the paper.)

The Particle Swarm Optimization (PSO) algorithm is based on the idea of simulating the foraging behavior of bird flocks[5]. Each bird knows its individual best position and shares the best position of the flock. Through collaboration within the flock, they jointly seek the optimal solution to the target. By utilizing shared and known information, multiple individuals continuously update their positions until the optimal solution is found. Therefore, it is also known as the "Bird Flock Algorithm".

This algorithm establishes different particles, each representing a potential solution. To ensure the model's efficiency, the number of particles in this model is set to 30. Within the model, these 30 particles will determine their direction of movement and speed based on their own information and shared information, conducting new searches while moving towards the optimal solution until the global optimal solution is found[6]. In addition to setting the number of particles, the following parameters also need to be configured for this model:

Inertia weight (w): The inertia weight determines the extent to which the current velocity influences the velocity of the next step. Clearly, a larger value of w means that the velocity is more influenced by inertia, resulting in a broader search range and enabling the exploration of more unknown areas, thereby enhancing the algorithm's global search capability. Conversely, a smaller w reduces the influence of inertia on the velocity, consequently diminishing its impact on global search[7]. To facilitate the establishment of this model, the inertia weight is set to 0.5. That is, if the velocity of the current step is 1, the initial velocity of the next step will be 0.5.

Learning factor (c): The learning factor, also known as the acceleration factor, acts as an acceleration that, along with the inertia weight, influences the velocity. To facilitate the establishment of this model, the learning factors in the model are all set to 1.5.

Iteration count: The iteration count determines the number of times particles search for the optimal solution. To make the model more efficient, avoid wasting computational resources, and ensure the accuracy of the model results, the iteration count in the model is set to 200.

Particle Swarm Optimization (PSO) is a dynamic process that starts by randomly generating initial positions, continuously updates to new positions, and moves from the initial positions to the optimal solution. The formula for calculating the particle's position can be expressed as: previous position + previous position's velocity × 1 (movement time).

$$x_i^n = x_i^{n-1} + v_i^{n-1} \tag{1}$$

Since displacement is a vector, it can be abstracted as the displacement of a coordinate on a two-dimensional plane, with the direction of displacement determined by the vector sum of the direction towards the individual's best position and the direction towards the group's best position. The velocity is jointly determined by the inertia of the previous step's velocity and the current level of cognition, which is represented in the model by individual and social learning factors.

$$v_i^n = w \times v_i^{n-1} + c_1 \times r_1 \times (selfbest_i^n - x_i^n) + c_2 \times r_2 \times \left(allbest_i^n - x_i^d\right) \tag{2}$$

Here, $selfbest_i^n$ represents the individual's known best position, $allbest_i^n$ represents the group's known best position, and each particle gradually approaches the optimal solution based on its velocity and direction.

3. Experiment

Through preliminary data collection, the researchers obtained the crop planting distribution and crop sales of a village in North China in 2023.By introducing the "Bisection Method Model" and Particle Swarm Optimization (PSO), this study aims to calculate the optimal crop planting plan for the years 2024 to 2030. The core objective of the crop planting plan and strategy is to rationally allocate planting areas for different crops through data analysis and prediction, in order to maximize the utilization of agricultural resources and achieve maximum profit[8]. Therefore, the objective function of this optimization model is to maximize the total profit of the crops. However, due to the existence of two different strategies for handling surplus production - Option 1: unsold surplus leading to waste, and Option 2: selling surplus at a 50% discount - these will establish two objective functions and seek the maximum profit for each respectively.

Option 1: Unsold goods resulting in waste.

$$Z_1 = \sum_{i,j} \left(price_i \times \min\left(C_{ij}, W_i\right) - cost_i\right) \tag{3}$$

Option 2: Sell the excess at half price.

$$Z_2 = \sum_{i,j} \left(price_i \times \min\left(C_{ij}, W_i\right) + 0.5 \times price_i \times \max\left(0, C_{ij} - W_i\right) - cost_i\right) \tag{4}$$

Where price_i represents the transaction price of the ith crop, W_i represents the sales volume of the ith crop, and $\cos t_i$ represents the total cost of the ith crop (calculated as the sum of the area of each plot multiplied by its respective unit cost).

Based on the collected data, it is evident that the total sales profit is primarily determined by the actual crop yield, the actual selling price of the crops, and the cultivation costs. Hence, the two objective functions can be solved using the same set of constraints. The actual yield of crops is influenced and constrained by factors such as the cultivated area, yield per unit area, and expected sales volume. The cultivated area for crops is limited by the available farmland, while the type of crops to be planted is influenced by crop-specific characteristics and constraints related to continuous cropping. Additionally, the distribution and crop rotation requirements for each type of crop must be considered. Based on the interrelationships among these different factors, a crop planting plan model can be established. The relevant constraints are as follows:

The cultivated area is limited, so in actual planting, the sum of the cultivated areas for each season cannot exceed the total area of the land parcel P_j.

$$\sum_i M_{i,j,q,t} \le P_j, \forall i, q \in \{1,2\}, t \in \{2024, \dots, 2030\} \tag{5}$$

Continuous cropping refers to the practice of planting the same crop consecutively in the same field. This practice significantly impacts soil microbial communities, leading to a stagnant soil environment that lacks rejuvenation and results in alterations in microbial populations, potentially favoring the emergence of pathogenic microorganisms such as malignant pathogens[9]. These pathogens exhibit strong adaptability and can rapidly proliferate in suitable soil conditions, making plants susceptible to root infections. Such infections pose a threat to crop health and can lead to reduced yields. Therefore, it is stipulated that the same crop should not be planted consecutively in the same field.

$$M_{i,j,q,t} \cdot M_{i,j,q,t+1} = 0, \forall i, j, q \in \{1,2\}, t \in \{2024, \dots, 2029\} \tag{6}$$

Legume crops secrete special proteins to attract nitrogen-fixing bacteria called rhizobia, which use the roots of legume crops as their workplace to convert nitrogen in the air into ammonia and ammonia compounds through a chemical reaction. Efficiency and yield: Legume crops combine with rhizobia to form small nitrogen fertilizer factories, providing nitrogen fertilizer for plants. Research shows that growing legume crops can delay leaf aging in other economic crops, enhance soil enzyme activity, improve soil nutrients, and benefit production efficiency[10]. Therefore, it is stipulated that all soil blocks (greenhouses) must plant legume crops at least once every three years.

$$\sum_{t}^{t+2} \sum_{i \in \{T_i \in \{T_2, T_3\}\}} M_{i,j,q,t} \ge P_j, \forall j, q \in \{1,2\}, t \in \{2024, \dots, 2028\} \tag{7}$$

In order to facilitate crop management, crops should not be too dispersed, and the area for crops within the same plot should not be too small. Therefore, the planting area for crops is set as an integer multiple of 0.1 (mu, a unit of area in China), and efforts should be made to ensure that the planting area for crops in each plot is greater than 0.3 mu.

$$M_{i,j,q,t} \ge 0.1N + 0.3, \forall i, j, q \in \{1,2\}, t \in \{2024, \dots, 2030\} \tag{8}$$

Different rules apply to the crops that can be planted in various types of land. For example, flat dry land, terraced fields, and hillsides are suitable for planting one crop season per year, while irrigated land can support either one or two crop seasons annually. Ordinary greenhouses are suitable for planting one season of vegetables and one season of edible fungi each year, while smart greenhouses are suitable for planting two seasons of vegetables each year. Additionally, different rules apply to the planting of different crops. For instance, Chinese cabbage, white radish, and red radish can only be planted in the second season on irrigated land.

$$M_{i,j,q,t} \leq N_{i,j,q} \cdot P_j, \forall i,j,q \in \{1,2\}, t \in \{2024, \ldots, 2030\} \tag{9}$$

The sales prices of agricultural products will be determined through the "Dichotomy Model", with pricing set at two-thirds of the initial price set by the merchants.

Through data preprocessing, the actual prices and crop yields are calculated and sorted to establish a sales profit model for crops. After the model is built, in order to effectively solve the optimization problem, the Particle Swarm Optimization (PSO) algorithm is introduced to find the optimal solution. The overall approach is shown in the diagram below. By initializing a particle swarm of planting plans and adjusting the positions of the particles according to the objective function during iterations, the optimal planting plan is ultimately found. The simplified flowchart is shown in Figure 1.

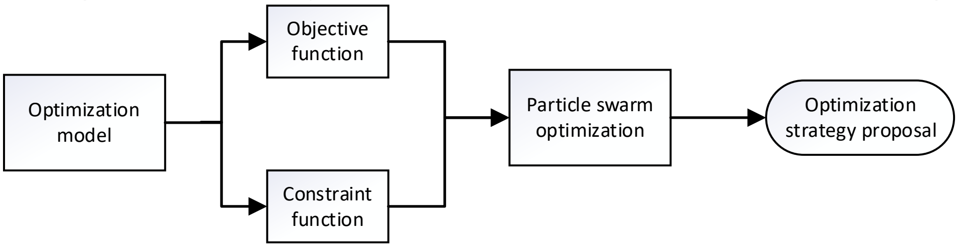

Figure 1: Simplified flowchart

After conducting the aforementioned experiments, it has been found that the treatment method in Plan B is significantly superior to that in Plan A, and the application of this model can also be used to predict the optimal planting strategy for the future.

4. Results

By utilizing the "Dichotomy Model" for specific pricing and the Particle Swarm Optimization (PSO) algorithm to find the optimal solution, and then exporting the resulting planting plan, this study has arrived at the following conclusions, as shown in Table 2.

Table.2. Experimental result

ways	Profit（in yuan）	compare
Unmarketable of disposal of excess production leads to waste	3649671.97	less
Dispose of excess production at a 50% discount	7765951.87	more

From the experimental results, this study can observe that the profit obtained from treating surplus production as unsalable goods is 3.65 million yuan, while the profit from selling surplus production at a 50% discount is 7.77 million yuan. The profits from price reduction and discounted sales are significantly higher than those from treating the surplus as unsalable. Based on the analysis of the experimental process mentioned above, it can conclude that for surplus production, people should choose to reduce prices rather than treat it as unsalable. Additionally, the application of this model can successfully determine the optimal planting strategy for the future.

5. Conclusions

In this paper, it introduces the "Dichotomy Model" and Particle Swarm Optimization (PSO) to address the problem of how farmers can efficiently allocate land and choose crops for cultivation. This thesis derives the optimal planting strategy for a village in northern China from 2024 to 2030, demonstrating the feasibility of the model proposed in this paper in real-life scenarios. The integration of mathematical modeling into agricultural economic research represents an interdisciplinary exploration that not only simplifies and visualizes complex agricultural economic issues for deeper insights and analysis but also reveals the essential characteristics and operational laws of the agricultural economy based on mathematical principles, thereby enhancing the efficiency of solving economic problems. In the future, the study will aim to apply this model to practical agricultural production to address the overall layout of the production process. By using recorded raw data, it will validate the goals and tasks of agricultural production, clarify its patterns, digitally design various production factors, and precisely operate and manage them. This will optimize the allocation of resources involved in agricultural production processes, thereby effectively improving production efficiency and contributing to agricultural development. Meanwhile, there are some issues with the model mentioned. When faced with more complex scenarios, more intricate constraints need to be established, which increases the difficulty of modeling. Additionally, the model's wide-area adaptability requires further verification. The direction of future research could be to improve the accuracy of prediction by introducing more models.

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