Optimizing Agricultural Planting Strategies with Linear Programming and MOPSO

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Abstract. The deep implementation of rural revitalization strategy has put forward higher requirements for our agricultural economy and production. However, in reality, the unreasonable allocation of resources and the impact of natural disasters pose challenges to agricultural output. In this paper, a new agricultural planting optimization model combining linear programming and multi-objective particle swarm optimization algorithm is proposed, and the resource allocation and production conditions in the northern mountainous areas are systematically studied from 2024 to 2030. By integrating economic benefits and ecological constraints, the model realizes the maximization of agricultural benefits and the sustainability of resource utilization. Linear programming effectively optimizes planting area and resource allocation, while MOPSO improves the adaptability and robustness of the model through global search. The model introduces dynamic constraints, such as crop rotation and land use restrictions, and innovatively incorporates the soil restoration benefits of legume crops into the optimization framework. Case studies under different market scenarios (slow sales and low sales) show that the model can provide efficient planting strategies, and its practicability and effectiveness are verified. The research results provide theoretical support and practical guidance for precision agriculture and rural revitalization, and suggest that dynamic variables and data-driven technologies should be combined in the future to further enhance the optimization potential and application value of the model.

Keywords: Linear Programming, MOPSO, Planting Optimization, Resource Allocation, Precision agriculture.

1. Introduction

In recent years, with the deepening of the rural revitalization strategy, China's agricultural economy and rural face have undergone profound changes. However, the distribution of agricultural resources is complicated, the types of cultivated land are diverse, and the climate conditions are limited, so how to scientifically and reasonably allocate planting resources to maximize economic and ecological benefits has become the key issue of agricultural development. In the existing studies, Alotaibi and Nadeem (2021) pointed out that linear programming has significant advantages in the optimization of resource allocation and planting pattern, but the current studies mostly focus on the optimization of a single objective, and do not fully consider the multi-objective balance under dynamic conditions [1]. To this end, Li et al. (2020) proposed multi-objective particle swarm optimization (MOPSO) algorithm, which combined economic, ecological and social benefits to demonstrate its potential in complex agricultural resource allocation problems [2]. However, Najafabadi et al. (2019) believe that despite the excellent performance of smart agriculture technology in improving crop yield, existing studies lack an effective framework for collaborative optimization of smart agriculture facilities and traditional cultivated land [3]. In addition, Laso et al. (2018) proposed a strategy combining life cycle assessment with linear programming to assess the ecological benefits of agricultural waste recycling, but long-term ecological benefits such as soil restoration effects of legumes have not been included in existing optimization models [4]. In this paper, a new optimization model combining linear programming and multi-objective particle swarm optimization algorithm is proposed, which for the first time incorporates dynamic constraints and soil restoration effects into the optimization design and explores the cooperative planting strategy of smart greenhouses and traditional cultivated land.

The main contributions of this paper include: 1) proposed a multi-objective optimization model under dynamic constraints to realize the comprehensive optimization of agricultural resources; 2) To creatively incorporate the ecological benefits of legumes into long-term constraints; 3) Build a framework for collaborative optimization of smart agricultural facilities and traditional cultivated land.

The structure of this paper is as follows: the first part is the introduction, introducing the research background, the current situation and the contribution points; The second part is related theory, expatiating the linear programming and multi-objective particle swarm optimization. The third part is the experiment design and analysis, describing the experiment idea and process in detail. The fourth part is the experimental conclusion, summarizing the research results; The fifth part is the conclusion, expounding the research significance and future prospect.

2. Related Theories

Linear programming is a mathematical method for optimizing a linear objective function, whose goal is to find the optimal solution of the objective function under a set of linear constraints. Linear programming is widely used in resource allocation, cost control and production planning. Its basic forms include objective function, decision variable and constraint condition. Simplex method or interior point method is usually used to solve linear programming, which has the characteristics of high computational efficiency and intuitive results and is suitable for dealing with large-scale problems. However, due to its assumed linear relationship, linear programming is difficult to deal with complex nonlinear problems and dynamic constraints [6].

Multi-objective particle swarm optimization is an optimization algorithm based on swarm intelligence, which is used to solve the optimization problems of multiple conflicting objectives. By simulating the movement of particles in the search space, MOPSO uses the group cooperative search behavior to find the Pareto optimal solution in the global scope. Its core mechanism includes goal balancing, Pareto frontier construction and particle position updating. MOPSO is particularly suitable for problems where multiple objectives (such as economic versus ecological benefits) need to be balanced, enabling optimization under complex multi-constraint conditions [7].

3. Experments

In this study, the planting conditions of a village in the northern mountains were taken as an example, and a detailed experimental scheme was designed. The experiment covers a total of seven annual cycles from 2024 to 2030, covering 54 plots or smart greenhouses and 41 common crop species. The experimental design combined linear programming and multi-objective particle swarm optimization algorithm to simulate the allocation of agricultural resources under dynamic constraints, focusing on the analysis of crop yield maximization under two different market scenarios (slow sales and reduced sales) [8].

Total revenue W is defined as the net income from the sale of crops minus the cost of planting. In order to more comprehensively analyze the agricultural income under different market scenarios, this study designed the objective function from two perspectives to explore the effects of slow sales and price reduction treatment on the total income.

The first scenario optimizes revenue in the slow-selling case. In this case, the lack of market demand leads to the unmarketable part of the crop, and the research focuses on maximizing the benefits of the actual sales part:

$$\text{Maximize}\, W_1 = \sum_{\alpha=2024}^{2030} \sum_{\chi=1}^{2} \sum_{\lambda=1}^{41} \left(k_\lambda \cdot \min(y_{\lambda,\alpha,\chi}, t_\lambda) - c_\lambda \cdot \sum_{\beta} x_{\alpha,\beta,\chi,\lambda} \right) \tag{1}$$

In the second scenario, a portion of the crop exceeding demand is sold at a reduced price. In this scenario, two parts of the revenue from normal sales and reduced sales are considered:

$$\text{Maximize } W_2 = \sum_{\alpha=2024}^{2030}\sum_{\chi=1}^{2}\sum_{\lambda=1}^{41}\left(k_\lambda \cdot \min(y_{\lambda,\alpha,\chi}, t_\lambda) + k_\lambda^{'} \cdot \max(y_{\lambda,\alpha,\chi} - t_\lambda, 0) - c_\lambda \cdot \sum_\beta x_{\alpha,\beta,\chi,\lambda}\right) \quad (2)$$

Since the area occupied by crop planting in each plot containing greenhouses each year cannot exceed the total area of the crop planting area, for each plot or greenhouse Pβ, the sum of the annual crop area x α, β, χ, λ, Need to be less than or equal to the total plot area Aβ.

$$\sum_{\lambda=1}^{41}\sum_{\beta=1}^{54}\sum_{\chi=1}^{2}\sum_{\alpha=2024}^{2030} \le A_\beta, \forall\beta, \chi \in \{1,2\}, \alpha \in \{2024,......,2030\} \quad (3)$$

The two greenhouses can plant different crops in different seasons. In ordinary greenhouses, only one season of vegetables and one season of edible fungi can be planted every year. Therefore, the following two constraints can be listed:

$$\sum_{\lambda\in\{\lambda|S_\lambda=S_3\}} x_{\alpha,\beta,1,\lambda} + \sum_{\lambda\in\{\lambda|S_\lambda=S_5\}} x_{\alpha,\beta,2,\lambda} \le A_\beta, \forall\beta, \mathrm{T}_\beta = T_5, t \in \{2024,......., 2030\} \quad (4)$$

$$\sum_{\lambda\in\{\lambda|S_\lambda=S_3\}} x_{\alpha,\beta,1,\lambda} + \le A_\beta, \forall\beta, \mathrm{T}_\beta = T_6, \chi \in \{1,2\}, \quad t \in \{2024,......., 2030\} \quad (5)$$

If the same crop (repeated crop) is planted for two consecutive years, the decrease of the second year will be caused. Therefore, for each plot Pβ, the same crop β cannot be planted continuously in the adjacent two years or two seasons.

$$x_{\alpha,\beta,\chi,\lambda} \cdot x_{\alpha+1,\beta,\chi,\lambda} = 0, \forall\lambda, \beta, \chi \in \{1,2\}, \alpha \in \{2024,......, 2029\} \quad (6)$$

Beans rhizobia is beneficial to the soil, so that the soil is beneficial to planting crops, so it is stipulated that within three years, each plot or greenhouse should grow beans at least once, so the constraints can be drawn in the following formula [9]:

$$\sum_{\alpha^{'}=\alpha}^{\alpha+2}\sum_{\lambda\in\{\lambda|S_\lambda\in\{S_2,S_4\}\}} x_{\alpha^{'},\beta,\chi,\lambda} \ge A_\beta, \forall\beta, \chi \in \{1,2\}, \alpha \in \{2024, 2025, 2026, 2027, 2028\} \quad (7)$$

Each season, the planting of the same crop should not be too dispersed, so the minimum planting area is set to 0.1 mu:

$$x_{\alpha,\beta,\chi,\lambda} \ge 0.1 \cdot b_{\alpha,\beta,\chi,\lambda}, \forall\lambda, \beta, \chi \in \{1,2\}, \alpha \in \{2024,......, 2030\} \quad (8)$$

Where $b_{\alpha,\beta,\chi,\lambda}$ =1 when $x_{\alpha,\beta,\chi,\lambda}$ > 0, otherwise $b_{\alpha,\beta,\chi,\lambda}$ =0.

Due to the soil and seasonal factors of dry land, terraces and hillsides, they can only grow one season of crops each year:

$$\sum_{\chi=1}^{2}\sum_{\lambda} x_{\alpha,\beta,\chi,\lambda} \le A_\beta, \forall\beta, \mathrm{T}_\beta \in \{T_1, T_2, T_3\}, \forall\alpha \quad (9)$$

The irrigated land can grow one or two crops a year:

$$\sum_{\lambda}\sum_{\chi=1}^{2} x_{\alpha,\beta,\chi,\lambda} \le 2A_\beta, \forall\beta, \; T_\beta = T_4, \forall\alpha \quad (10)$$

Because the insulation of the greenhouse is better than the outdoor land, the greenhouse can be planted for two crops every year:

$$\sum_{\lambda}\sum_{\chi=1}^{2}x_{\alpha,\beta,\chi,\lambda}\le 2A_{\beta},\forall\beta,T_{\beta}\in\{T_5,T_6\},\forall\alpha \tag{11}$$

Dry land, terraced fields and hillside land are suitable for planting grain crops in a single season every year (except rice) [10]:

$$\sum_{\chi=1}^{2}x_{\alpha,\beta,\chi,\lambda}\le A_{\beta},\forall\beta,\ T_{\beta}\in\{T_1,T_2,T_3\},\forall\lambda \text{ 且 } S_{\lambda}\in\{S_1,S_2\}\setminus\{C_{16}\},\forall\alpha \tag{12}$$

The irrigated land can be grown in a single season or two seasons per year:

$$\sum_{\lambda\in\{\lambda|S\in\{S_3,S_4\}\}}x_{\alpha,\beta,2,\lambda}\le A_{\beta}\cdot b_{\beta,\alpha},\forall\beta,\ T_{\beta}=T_4,\forall\alpha \tag{13}$$

When two seasons are grown on an irrigated site, a variety of vegetables can be grown in the first quarter (except Chinese cabbage, white radish and carrot); in the second season, only one of Chinese cabbage, white radish and carrot can be grown (easy management):

$$\sum_{\lambda\in\{C_{35},C_{36},C_{37}\}}x_{\alpha,\beta,1,\lambda}=0,\forall\beta,\ T_{\beta}=T_4,\forall\alpha \tag{14}$$

$$\sum_{\lambda\in\{C_{20},\ldots\ldots C_{34}\}}x_{\alpha,\beta,2,\lambda}=0,\forall\beta,\ T_{\beta}=T_4,\forall\alpha \tag{15}$$

According to seasonal requirements, Chinese cabbage, white radish and carrot can only be grown in the second season of irrigated land:

$$\sum_{\beta\notin\{\beta|T_{\beta}=T_4\}}x_{\alpha,\beta,2,\lambda}=0,\forall\lambda\in\{C_{35},C_{36},C_{37}\},\forall\alpha \tag{16}$$

Ordinary greenhouses grow two seasons of crops every year. In the first season, a variety of vegetables can be planted (except Chinese cabbage, white dream bu and carrot). In the second season, only edible fungi can be grown:

$$\sum_{\lambda\in\{C_{35},C_{36},C_{37}\}}x_{\alpha,\beta,1,\lambda}=0,\forall\beta,\ T_{\beta}=T_5,\forall\alpha \tag{17}$$

$$\sum_{\lambda\in\{\lambda|S_{\lambda}\in\{S_1,S_2,S_3,S_4\}\}}x_{\alpha,\beta,2,\lambda}=0,\forall\beta,\ T_{\beta}=T_5,\forall\alpha \tag{18}$$

Because edible fungi are adapted to grow in a low and suitable temperature and humidity environment, they can only be planted in ordinary greenhouses in autumn and winter:

$$x_{\alpha,\beta,2,\lambda}=0,\forall\beta,\ T_{\beta}=T_5,\forall\lambda\in\{\lambda\,|\,S_{\lambda}=S_5\},\forall\alpha \tag{19}$$

The smart greenhouse can grow two seasons of vegetables every year (except Chinese cabbage, white radish and red Mengbu):

$$\sum_{\lambda\in\{C_{35},C_{36},C_{37}\}}x_{\alpha,\beta,\chi,\lambda}=0,\forall\beta,\ T_{\beta}=T_6,\forall\chi\in\{1,2\},\forall\alpha \tag{20}$$

In conclusion, a complete linear planning model is finally formed by constructing the above objective functions, decision variables and constraints. The core task of this model is to maximize or minimize the objective function by rationally allocating resources under the established linear constraints and then optimize the agricultural benefits.

4. Results

Through experimental design and model construction, linear programming and multi-objective particle swarm optimization were used to systematically analyze different planting strategies and resource allocation schemes. In the process of solving the model, linear programming optimizes the key variables such as planting area and concentration degree by simplex method to ensure that the initial feasible solution can be found under the condition of limited resources. At the same time, multi-objective particle swarm optimization further explores the strategy balance under different constraints and uses the global particle search ability to identify the global optimal solution.

In the actual solution, this paper respectively optimized two market scenarios (slow sales and reduced sales). The calculation using Pycharm platform shows that the optimal planting strategy and the maximum total return under the two scenarios have been successfully solved. The following are some of the optimal planting scenarios for 2024-2030 under different scenarios. The results are shown in Table 1.

Table 1: Table of planting scheme optimization results

	Plot name	soybean	Beans black	beans red	beans green	Climbing beans	wheat
first quarter	A1	0	0	0	0	0	0
	B1	0	2.4	0	0	0	3.7
	C1	0	0.1	0	0	0	0
	D1	2	0.1	0	0	0	0
	E1	0.7	0	0	0	0	0
Second quarter	F1	0	0.4	0	0	0	0
	D1	0.2	0	0.1	0	1.4	0
	E1	1.3	0	2.9	0	0	0
	F1	0	10.4	0	0	0	5.8
	Plot name	soybean	Beans black	beans red	beans green	Climbing beans	wheat
first quarter	A1	0	0	0	0	0	0
	B1	0	0	1.2	0	9.3	0
	C1	0	0	0	0.1	0	0
	D1	0	0	0	0	0.1	0
	E1	3	4.2	0	0	0	0
	F1	0	0	0	0	0	0
second quarter	D1	0	3.5	0	0	7.8	0
	E1	0	0	0	0	0	0
	F1	0	0	0	0	7.8	0

The results of model solving show that during 2024-2030, the planting strategies under different market scenarios show the optimal characteristics of resource allocation. Table 1 shows the partial planting conditions of six major crops in the first eight plots, from which it can be seen that the planting distribution of different plots and greenhouses in different seasons not only meets the constraints of planting area and crop type but also realizes the maximization of economic benefits. In the slow-selling scenario, the model is more inclined to optimize the planting area allocation of high-demand crops to reduce resource waste. In the cut-price scenario, the model maximizes the total revenue by expanding the planting area suitable for cut-price treatment.

5. Conclusions

Based on linear programming and multi-objective particle swarm optimization algorithm, this paper proposes a new optimization model of agricultural planting strategy and systematically studies the resource allocation and production conditions in the northern mountainous areas from 2024 to 2030. The results show that linear programming can effectively optimize planting area and resource allocation, and multi-objective particle swarm optimization can further improve the adaptability and robustness of the model through global search. This paper innovatively incorporated the soil restoration effect of legume crops into the constraint conditions, combined with the collaborative optimization of smart agriculture and traditional cultivated land, and took into account the balance of economic and ecological benefits. This study provides a theoretical basis for precision agriculture and rural revitalization. In the future, more complex dynamic variables and data-driven technologies can be combined to further enhance the application potential and practical effects of the model.

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