

Agricultural Planting Optimization Strategy Based on Genetic Algorithm and Monte Carlo Algorithm

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Abstract. Under the rural revitalization strategy and agricultural modernization, this study addresses the challenges of limited and diverse cultivated land resources in rural areas, aiming to scientifically allocate crop and land resources, optimize planting plans, and promote sustainable rural economic growth. Despite ongoing improvements, current planting plans often overlook critical factors such as crop diversity, land types, and climate impacts. This research explores how to allocate crop and land resources effectively under constraints like crop rotation, avoiding repeated planting, and land area limitations, to maximize income over the next seven years. Land is categorized into two groups: dry flat land, mountainous land, and sloping land in one group, and irrigated land, ordinary greenhouses, and smart greenhouses in another. Decision variables are set as crop planting areas, weighted by quarterly profit per acre, while constraints include planting legumes at least once every three years, total planting area limits, and avoiding the same crop for two consecutive years. A 0-1 integer programming model and value matrix are introduced, and to tackle overproduction and waste, a Monte Carlo algorithm and genetic algorithm are implemented in Python to maximize total revenue, deriving the optimal planting plan and projected annual sales. In the first scenario, the total profit for the next seven years is approximately three million five hundred thousand dollars.

Keywords: Genetic Algorithm, 0-1 Programming, Monte Carlo Algorithm.

1. Introduction

As agricultural production develops towards intensification and intelligence, the rational use of cultivated land resources to develop the organic planting industry is of great significance to rural development and economic sustainable development. However, in a certain mountainous rural area in North China, the types of cultivated land are diverse and restricted by factors such as climate, which faces many challenges in planting planning. In existing studies, Song et al. (2021) studied the adjustment of cultivated land utilization layout based on crop planting suitability, and achieved the optimization of spatial structure and cultivated land utilization methods of different grain crops, combining cultivation with land protection. However, this study was only conducted on rice, soybeans, and corn, and has certain limitations [1]. Sajid et al. (2022) A two-stage decision support system considering weather uncertainty and resource constraints was proposed to optimize planting decisions, but the study did not consider the impact of land type on planted crops [2]. Liu et al. (2023) established a multi-objective spatial crop planting structure optimization model with the goals of maximizing regional economic water efficiency (EWP), minimizing blue water dependence (BWFr_{ate}) and minimizing grey water footprint (GWF_{grey}), but the study was only conducted on plains and low hills, which has great limitations in practice [3]. Adamo et al. (2024) proposed a constraint programming model and proved the feasibility of determining the optimal crop planting layout, but did not consider the impact of land type and temperature in different seasons on crop planting [4]. Dai et al. (2021) optimized the crop planting structure in south-central China based on water footprint theory [5]. Yang et al. (2024) explored how to optimize the crop planting structure in Sichuan Province by focusing on water resource utilization efficiency [6]. Wang et al. (2021) investigated the optimal planting structure under water footprint and varying spatiotemporal agroclimatic conditions [7]. Zhang et al. (2022) examined the impact of land costs on crop planting choices [8]. Chen et al. (2023) studied the planting area and structure of major food crops in the Yellow River Basin [9]. Hu et al. (2025) conducted research on the optimization of crop layout in

Heilongjiang Province [10]. For different terrains and climates, this paper proposes an optimization model that includes Monte Carlo algorithm, 0-1 programming and genetic algorithm. First, the Monte Carlo algorithm and 0-1 programming model are used to seek the initial feasible solution, and then the genetic algorithm is used to find the optimal planting plan.

The contributions of this paper mainly include: 1) Proposing a planting optimization scheme that fully considers the actual production of multiple crops. 2) Constructing a planting optimization framework for the coexistence of smart greenhouses and traditional farmland. 3) Creatively incorporating the convenience of farming operations and field management into constraints.

This paper is organized as follows: Section I introduces the research background, current status, and the main contributions of this paper. Section II explains the relevant theories, focusing on the Monte Carlo algorithm, 0-1 programming, and genetic algorithm. Section III describes the ideas and detailed process of the experiment in detail. Section IV summarizes the experimental results. Section V explains the research conclusions and puts forward future prospects.

2. Related Theories

2.1. 0-1 Integer Programming

Integer programming is a form of linear programming in which variables take integer values. It is usually expressed as minimizing the objective function Z and satisfying the condition $Ax = b$ and the variables take integer values. 0-1 integer programming is a special form of integer programming. The decision variable x can only take 0 or 1. It is suitable for solving problems with logical relationships, sequential relationships and mutually exclusive conditions. The 0-1 integer programming model includes an objective function and constraints. The objective function can be the maximum or minimum of a certain expression, and the constraints limit the range of variables.

The general integer programming model is as follows:

$$\text{maximize } z = \sum_{i=1}^n c_i x_i \quad (1)$$

$$\text{S. T } \sum_{i=1}^n a_i x_i \leq b, x_i \in \{0,1\}, i = 1,2, \dots, n \quad (2)$$

Where c_i is the coefficient of the objective function, a_i is the coefficient of the constraint, b_i and is the upper limit of the constraint.

2.2. Monte Carlo simulation

Monte Carlo simulation is a numerical statistical method based on random sampling. It solves problems with probabilistic properties by repeated random sampling. This method is suitable for dealing with complex systems or problems. Its core idea is to use randomness to simulate system behavior or calculate complex problems. The main task of Monte Carlo simulation is to clarify the randomness and uncertainty in the problem, including determining random variables, selecting probability distributions, defining the relationship between variables, and generating random samples.

2.3. Genetic Algorithm

Genetic algorithm is a computational model that simulates the principles of natural selection and genetics. It searches for the optimal solution by simulating the natural selection and genetic mechanisms in Darwin's theory of biological evolution. The algorithm takes all individuals in the population as the object and uses randomization technology to guide the efficient search of the encoded parameter space. Among them, selection, crossover and mutation constitute the genetic operations of the genetic algorithm; parameter encoding, initial population setting, fitness function design, genetic operation design, and control parameter setting constitute the core content of the genetic algorithm.

3. Experiments

Common planting sites include flat dry land, mountainous land, irrigated land, greenhouses, etc., and common crops include rice, wheat, soybeans, etc. Therefore, according to the planting requirements of different planting sites and the sales strategies of various crops, it is necessary to formulate reasonable sales strategies to maximize the planting profits. For the unsale of the excess part, resulting in waste and the excess part, this article will 2023 Annual sales price 50% The two situations of selling at a reduced price. This paper divides the planting land into two categories, flat dry land, mountainous land and hillside land are classified as the first category, and irrigated land, ordinary greenhouses and smart greenhouses are classified as the second category for analysis. The decision variable is set x_{ijkl} as the planting area of the plant, c_{ijkl} which is the profit per acre of a certain plant in a certain quarter. Taking into account the land planting strategy, the conditions such as not planting legumes at least once every three years, the total area of crops, the total output of each crop is less than the expected sales, and the same crop is not planted for two years are introduced into the 0-1 planning model to establish the corresponding 0-1 matrix and continuous matrix, and bring in the corresponding objective function. The Monte Carlo algorithm is used to find the initial solution and the genetic algorithm is used for optimization to solve the maximum total benefit and the optimal planting plan. After algorithm solution analysis, this paper obtains the maximum planting profit and planting strategy between 2024 and 2030.

For the first type of flat dry land, mountainous land and hillside land, the types of crops planted there are different from those planted in other areas, that is, the planting plans of flat dry land, mountainous land and hillside land will not affect the planting plans of other areas. In this paper, it is set as the planting area of crops, i is the plot, j is the crop type, t is the planting year, k is the quarter, where 0 is 1 quarter, 1 is 2 quarters, -1 is a single quarter, $i=1,2,\dots,26$, $j=1,2,\dots,10$, $t=1,2,\dots,7$. To solve the maximum profit of the crop planting strategy, the following objective function can be determined:

$$E = \max \sum_{n,i,j=1}^{n,i,j} S_j \cdot P_j \cdot e_j; i = 1,2 \dots 26; j = 1,2,\dots,10 \quad (3)$$

Among them, E is the maximum total profit of planting crops, S_j is the area of crop planting, P_j is the crop yield per mu, e_j and is the profit per mu corresponding to a certain type of land. In order to determine the maximum profit, this paper determines the following constraints for the planting strategy:

Plant legumes at least once every three years:

$$t_i - t_j \leq 2 \quad (4)$$

In which t_i, t_j different crops were planted.

The total area of crops grown on each plot of land is less than or equal to the available area of the land:

$$S \leq S_{all} \quad (5)$$

Where S_{all} represents the available land area.

Total production of each crop is less than expected sales:

$$S_j \cdot P_j < B \quad (6)$$

Where B is the expected sales.

The same type of crops cannot be planted for two years:

$$t_j \neq (t + 1)_j \quad (7)$$

For the second type of land, decision variables are introduced similarly to the first type of land. Additionally, a continuous matrix X is defined, where each element in the matrix represents the area of the j_{th} crop planted on the i_{th} type of land. Furthermore, this paper introduces a 0-1 matrix to

indicate whether a crop is planted or not, where 1 denotes that the j_{th} crop is planted on the i_{th} land parcel, and 0 denotes that the j_{th} crop is not planted on the i_{th} land parcel.

$$Y_{i,j} = \begin{cases} 1, & i \in \{1,2,\dots,28\}; j \in \{1,2,\dots,52\} \\ 0, & \end{cases} \quad (8)$$

To solve the maximum profit of planting the second plot of land, the following objective function can be determined:

$$E = \max \sum_{n,i,j=1}^{n,i,j} X_{ij} \cdot Y_{ij} \cdot e_{ij} \quad (9)$$

In order to solve the objective function, this paper needs to consider the corresponding constraints. In addition to the constraints related to the first type of land, the second type of land also needs to introduce its special constraints. Since crops cannot be completely unplanted or negative, the objective equation should satisfy the all-zero constraint and the non-negative constraint:

$$\sum_i^n \sum_j^m x_{i,j,t} = 0 \quad (10)$$

$$x_{ijt} \geq 0 \quad (11)$$

In which $i = 1,9,25; j = 4,6,8,\dots,38,45,47,49,51; n = 8,24,28; m = 2,44,52$. For the plant yield that exceeds the expected sales volume, this paper improves the original objective function as follows:

$$E = \sum(X_{ij} * Y_{ij} * e_{ij}) + (\sum X_{ij} - B)E' \quad (12)$$

Among them, X_{ij} represents the output of each crop that does not exceed the expected sales volume; Y_{ij} represents a 0-1 matrix, represents the expected sales volume; E' represents the profit that exceeds the expected part. Since the types of crops planted in flat dry land, mountainous land and hillside land are different from those planted in other areas, that is, the planting plans of flat dry land, mountainous land and hillside land will not affect the planting plans of other areas, flat dry land, mountainous land and hillside land are classified as the first category for analysis, and the genetic algorithm is used to solve the optimal solution; the iterative process diagram is given in Figure 1.

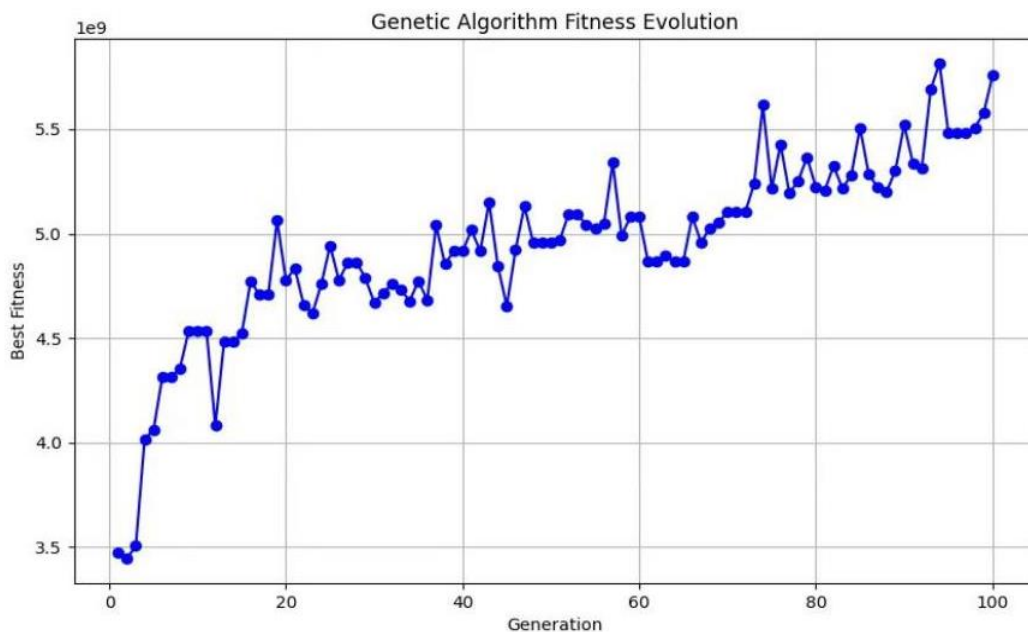


Figure 1. Genetic algorithm iteration diagram

It can be found that in the iterative process, irrigated land, ordinary greenhouses and smart greenhouses are classified as the second category for analysis, and the improved Monte Carlo algorithm is used to obtain the optimal planting plan.

4. Results

Combined with the objective function and constraint equation, this paper classifies flat dry land, mountainous land and hillside land into the first category for analysis, and uses the genetic algorithm to solve the optimal solution; then classifies irrigated land, ordinary greenhouses and smart greenhouses into the first category for analysis, and uses the improved Monte Carlo algorithm to obtain the optimal planting plan. After parameter adjustment, this paper determines the parameters of the genetic algorithm as shown in Table 1:

Table 1. Genetic algorithm parameters

Main parameter name	Value
Population size (NP)	1000
Crossover probability (Pc)	0.8
Probability of mutation (Pm)	0.05
Evolutionary Algebra (G)	100

In the solution, this article presents the planting plan for the case of unsalable crops. Using PyCharm calculation, the results show that the optimal planting strategy and maximum total benefit in this case have been successfully solved. The following are some optimal planting scenarios for 2024-2030 under the condition of unsalable crops. The results are shown in Table 2.

Table 2. Planting strategy optimization table

	Land Type	Grains (beans)	food	Vegetables (beans)	vegetable	Edible Fungi
First Quarter	A	297	68	0	0	0
	B	402	217	0	0	0
	C	40	68	0	0	0

(Continued of the previous table)

	Land Type	Grains (beans)	food	Vegetables (beans)	vegetable	Edible Fungi
First Quarter	D	0	42	29	38	0
	E	0	0	1.2	8.4	0
	F	0	0	0	2.4	0
Second quarter	D	0	0	0	36	0
	E	0	0	0	0	9.6
	F	0	0	0.6	1.8	0

Taking into account the unsaleable and wasted portion of the crops, the annual sales of flat dry land, mountainous land and hillside land from 2024 to 2030 under the optimal planting plan are obtained through genetic algorithm as shown in Table 3.

Table 3. Sales volume of flat dry land, mountainous land and hillside land in 7 years

years	Sales
2024	1603000
2025	1920000
2026	1921000
2027	1786000
2028	2189000
2029	2342000
2030	3595000

Taking into account the unsaleable and wasted portion of the crops, the Monte Carlo algorithm is combined with the genetic algorithm to obtain the annual sales of irrigated land, ordinary greenhouses and smart greenhouses from 2024 to 2030 under the optimal planting plan as shown in Table 4.

Table 4. Sales volume of irrigated land, ordinary greenhouses and smart greenhouses in the past 7 years

years	Sales
2024	1678000
2025	2967000
2026	3261000
2027	3694000
2028	3931000

(Continued of the previous table)

years	Sales
2029	4157000
2030	5296000

The above experimental results show that the model proposed in this paper can maximize the overall economic benefits while meeting the constraints of planting area, land type and scientific planting requirements. In the unsalable scenario, the model is more inclined to optimize the planting area configuration of high-demand crops and reduce resource waste.

5. Conclusion

In this paper, we propose a genetic algorithm based on Monte Carlo optimization, which provides an effective solution for crop planting strategies in 2024-2030. The algorithm combines genetic algorithms in matrix analysis and intelligent computing, which not only improves the efficiency and accuracy of the algorithm, but also provides a more effective mathematical framework and methodology for the algorithm. It enhances the interpretability and reliability of the algorithm. On the other hand, the Monte Carlo algorithm has the ability to calculate multiple scenarios of multiple unknowns at the same time, and the error is easy to determine. However, there is still room for

improvement in this model, because the results of the genetic algorithm are affected by the parameter settings, and the results are not always optimal, but close to the optimal solution.

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