Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 15, No. 3, 2025

Crop Optimization Model Based on Robust Genetic Algorithm

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Abstract: In the context of the current rural economic transformation, the optimization of crop planting structure has emerged as a critical task, particularly in light of limited resources, market fluctuations, and environmental challenges. This paper addresses the practical issues of constrained rural cultivated land resources and multiple restrictions on crop cultivation in the mountainous regions of North China by constructing a hybrid model that integrates robust optimization and interval planning. The model accounts for the interval fluctuations of future expected sales, yield per unit area, planting costs, and selling prices, and employs a genetic algorithm to simulate the natural evolution process, thereby seeking an approximate optimal solution. By proposing an optimal crop planting plan for the period from 2024 to 2030, this study not only provides academic support but also offers practical guidance for navigating a complex and ever-changing agricultural environment. The findings aim to enhance the resilience and sustainability of rural economies, ensuring that they can adapt to both current and future challenges in agricultural production and resource management.

Keywords: Crops, Planting Strategies, Robust Optimization, Interval Optimization, Genetic Algorithms.

1. Introduction

Under the background of current rural economic transformation, optimizing crop planting structure has become a key task to improve agricultural production efficiency and promote sustainable rural development. With increasingly limited resources, fluctuating market demand and intensifying environmental challenges, how to rationally utilize cultivated land resources and optimize crop cultivation under complex constraints has become a practical problem to be solved urgently. In recent years, in response to this problem, many scholars and research institutions have proposed different optimization models and solutions, trying to find the approximate optimal crop planting strategy under the conditions of uncertainty and multiple constraints [1-2].

In agricultural planting, the problem of uncertainty is particularly prominent [3-4]. The fluctuation of expected crop sales, yield, planting cost and market price often makes farmers face greater risks when making planting decisions. Especially in North China, the optimization of planting structure has become more complicated due to climate change, land use change and unstable market supply and demand. In this context, the combination of robust optimization and interval planning becomes an effective solution. This method not only considers a variety of uncertain factors, but also can find feasible optimization strategies in the case of limited resources, which greatly improves the flexibility and sustainability of agricultural production [5].

The objective of this study is to construct a hybrid model based on robust optimization and interval planning to deal with the practical problems of rural cultivated land resource constraints and multiple crop planting constraints in mountainous areas of North China. Specifically, we design an optimization model that takes into account future expected sales, yield per unit area, planting cost, and selling price fluctuations, and use genetic algorithms to simulate natural evolutionary processes and seek approximate optimal solutions. With this approach, we are able to optimize crop structure under multiple uncertain conditions, improving the resilience and economic efficiency of agricultural production.

Compared with traditional crop planting planning methods, the innovation point of this study is the introduction of a hybrid model combining robust optimization and interval planning, which can not only effectively deal with uncertainties in planting, but also realize the optimization of crop planting under multiple constraints [6]. In addition, genetic algorithm is also used to simulate the natural evolution process, which further improves the adaptability and optimization effect of the model. In the face of complex and changing agricultural environments, this approach can provide more precise and flexible solutions for agricultural production, thereby enhancing the resilience and sustainability of rural economies.

2. Data Simulation and Index Analysis

In order to adapt to the complex and diverse planting environment in Northeast China, this study obtained simulation data from 2024CUMCM, covering key indicators such as cultivated land type, plot area, planted crops and their planting conditions, production cost and selling price. After statistical analysis of these data, it is divided into the following main sections:

(1) Cultivated land type and area: 6 different types of cultivated land were simulated, with a total of 67 plots, ranging in area from 0. 6 mu to 86 mu, including six types of cultivated land, such as flat dry land, terraced land, hillside land, irrigated land, ordinary greenhouses and smart greenhouses. The total area of arable land is 1253 mu.

(2) Crop types and types: A total of 41 crops were simulated and classified into different types of grain, grain(beans), vegetables, vegetables(beans), edible fungi, etc.

(3) Planting season: simulate the planting season of different crops, some crops can only be planted in a single season, while some crops can be planted in two seasons. For example, flat drylands, terraces and hillsides are suitable for growing food crops(excluding rice)in a single season each year, while ordinary greenhouses and smart greenhouses can grow vegetable crops in two seasons.

(4) Economic indicators: there are significant differences in the per mu yield, planting cost and selling price of different crops. For the same crop, the economic index of different cultivated land types also showed some differences.

3. Model Introduction

3.1. Simulation rule-making

In order to optimize planting structure and improve land use efficiency, many constraints should be considered in crop planting planning. The main planting constraints are as follows：

(1) Total planted area limit: the total planted area of all crops cannot exceed the total planted area of the land. Where represents the total planted area of landT_j.

$$\sum_k \sum_i X_{ijk}^t \cdot \alpha_{ij} \le T_j(t = 2n + 1, i \le 16, 1 \le j \le 7, n \in N) \quad (1)$$

$$\sum_k \sum_i X_{ijk}^t \cdot \alpha_{ij} \le T_j(t = n, 17 \le i \le 41, 7 \le j \le 12, n \in N) \quad (2)$$

(2) Bean restrictions: To protect the quality of the land, plant bean crops at least once in three years. Where m_{jk} represents the area of the k number of the j land type.

$$\sum_t^{t+5} (\sum_{i=1}^{5} \alpha ij \cdot X_{ijk}^t) \ge m_{jk} \, (1 \le j \le 6) \quad (3)$$

$$\sum_t^{t+5} (\sum_{i=17}^{19} \alpha ij \cdot X_{ijk}^t) \ge m_{jk} \, (7 \le j \le 12) \quad (4)$$

(3) Avoid recropping: The same crop cannot be continuously planted on the same land to prevent excessive depletion of soil fertility and the accumulation of pests and diseases.

$$X_{ijk}^t \ne X_{ijk}^{t+2} (1 \le i \le 16) \quad (5)$$

$$X_{ijk}^t \ne X_{ijk}^{t+1} (17 \le i \le 41) \quad (6)$$

(4) Rice planting restrictions: Rice can only be grown for one season to meet the requirements of its growth cycle and climatic conditions.

$$X_{ijk}^{t+1} = 0(i = 16, 7 \le j \le 8, t = n, n \in N) \quad (7)$$

(5) Planting can not be scattered: crop planting should be centralized and avoid scattered distribution to improve management and harvest efficiency.

$$\sum_k y_{ijk} \le \frac{\sum_k X_{ijk}^t}{minj + 1} \quad (8)$$

(6) The planting area should not be too small: ensure that in the plot of land type i, number j, the crop area is more than 25%of the plot

$$\sum_i X_{ijk} \ge m_{jk} \cdot 0.75 \quad (9)$$

3.2. Robust optimization

Robust Optimization is an important method to deal with uncertain optimization problems. Different from traditional optimization methods, robust optimization considers the fluctuation of uncertain parameters, aiming to find the optimal solution and improve the stability and reliability of the solution. The goal is to optimize decisions that still perform well in the worst case [7].

Suppose we have a standard linear programming optimization problem where we want to solve the optimal solution x under the influence of an uncertain parameter u. The format of the standard optimization problem is:

$$\begin{aligned} &min_x c^T x \\ &\text{s.t. } Ax \le b, \\ &x \ge 0, \end{aligned} \quad (10)$$

Considering the index fluctuation in the real situation, the data conditions are further constrained to simulate the changes that can occur in the future expected sales volume, per mu yield, planting cost and selling price.

(1) Future sales of wheat and corn are expected to grow between 5% and 10% a year.

$$S_{ij}^t \in [1.05\alpha_{ij} S_{ij}^t, 1.1\alpha_{ij} S_{ij}^{t-2}](i = 6,7) \quad (11)$$

Where S_{ij}^t represents the normal sales of the i crop on the j land type in the t quarter, and α_{ij} represents the variable 0-1, indicating whether the i crop can be planted on the j land type.

(2) Other crop sales are expected to change ±5% relative to 2023

$$S_{ij}^t \in [0.95\alpha_{ij} S_{ij}^t, 1.05\alpha_{ij} S_{ij}^{t-2}](i \ne 6,7) \quad (12)$$

Where S_{ij}^t represents the normal sales of the i crop in the j land type in the$t$ quarter.

(3) The yield of crops per mu varies by ±10% per year under the influence of climate

$$l_{ij}^t \in [1.05\alpha_{ij} l_{ij}^t, 1.1\alpha_{ij} l_{ij}^{t-2}](1 \le i \le 41) \quad (13)$$

l_{ij}^t represents the yield per mu of the i crop in the j land type in the t quarter.

(4) Crop costs are rising by about 5% a year

$$C_{ij}^t = 1.05\alpha_{ij} C_{ij}^{t-2}(1 \le i \le 41) \quad (14)$$

C_{ij}^t represents the cost of planting the i crop on the j

land type in quarter t .

(5) The selling prices of grain are basically stable, and the selling prices of vegetables and plants increase by about 5% on average every year

$$R_{ij}^{t} = \alpha_{ij} R_{ij}^{t-2} (1 \le i \le 16) \quad (15)$$

$$R_{ij}^{t} = 1.05\alpha_{ij} R_{ij}^{t-2} (16 \le i \le 37) \quad (16)$$

R_{ij}^{t} represents the sale price of the i crop in the j land type in the t quarter.

(6) The sales price of edible fungi has decreased steadily, and the price has been reduced by 1% to 5% every year

$$R_{ij}^{t} \in [0.95\alpha_{ij} R_{ij}^{t}, 1.01\alpha_{ij} R_{ij}^{t-2}] (37 \le i \le 40) \quad (17)$$

(7) The price of morels is falling by 5% a year

$$R_{ij}^{t} = 0.95\alpha_{ij} R_{ij}^{t-2} (i = 41) \quad (18)$$

Combine the constraint conditions with the formula of the robust algorithm, and determine the objective function formula as follows:

$$Z_{max} = \sum_{i} \sum_{j} (R_{ij} \alpha_{ij} S_{ij} - \sum_{t}^{i+1} \sum_{k} C_{ij} \alpha_{ij} X_{ijk}^{t}) \quad (19)$$

3.3. Genetic Algorithm

The robust optimization technique aims to find an optimal solution that can maintain good performance in all possible scenarios under the condition of parameter uncertainty or external environment disturbance. In this model, the planting operation arrangement is optimized by considering the total profit in the worst case, so that the model can achieve the optimal solution in all possible scenarios.

Genetic algorithm, as an optimization search method based on the principles of natural selection and genetics, performs well in robust optimization due to its powerful global search capability [8]. It seeks the optimal solution by simulating the biological evolution process, and the specific steps are as follows:

(1) Initialization: An initial population is randomly generated, and each individual in the population represents a candidate solution to the problem.

(2) Evaluation: Calculate the fitness of each individual in the population, fitness is usually related to the objective function, to measure the ability of an individual to solve problems.

(3) Selection: Selection is made according to the fitness of individuals, and the better individuals are more likely to be selected for reproduction, simulating the principle of natural selection.

(4) Crossover: Randomly select a pair of individuals as parents, and perform crossover operations with a certain probability to generate new offspring individuals, so as to improve the diversity of solutions combined with parental characteristics.

(5) Variation: Random variation is carried out on newly generated offspring individuals to introduce new gene variants, increase population diversity, and avoid local optimality.

(6) Replacement: According to a set strategy, individuals in the original population are replaced with newly generated offspring to form a new population, which usually involves retaining the optimal individuals or random replacement.

(7) Termination: The algorithm terminates when the preset maximum number of iterations, fitness meets a predetermined threshold or population convergence and other conditions are reached; Otherwise, return to Step 2 to continue the iteration.

The flow chart of genetic algorithm is shown in the figure 1:

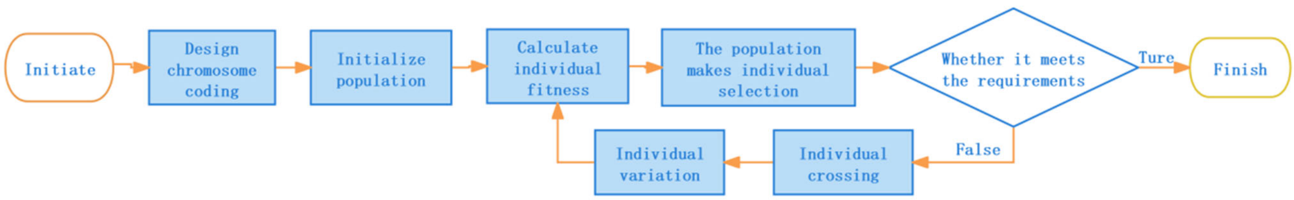

Figure 1. Genetic algorithm flow chart

3.4. Planting planning income model

In a robustly-optimized genetic algorithm, fitness evaluation ensures robustness by evaluating individuals under various uncertainty scenarios. Cross operations create child solutions by combining parts of two parent solutions, while mutation introduces changes by randomly changing parts of the solution. The selection of the next generation is usually based on a combination of the current population and offspring to ensure diversity and retain elite solutions. The termination criteria of the algorithm can be maximum algebra, convergence of the solution, or satisfactory fitness level.

The pseudo-code is as follows:

(1) Initialize population P with a set of random solutions

(2) Assess the worst-case fitness of each individual in the population

(3) When the termination conditions are not met, repeat the following steps:

a. Select parent individuals in the population based on fitness

b. Cross-operate the selected parents to generate child individuals

c. Mutate the offspring with a certain probability

d. Assess the worst-case fitness of each progeny individual

e. Select individuals from the current population and offspring to form the next generation

(4) End the loop

Output the best solution found

Through the iteration of genetic algorithm, btained the optimal crop planting plan of different years, and calculated the maximum profit of the corresponding years. Through these results, we can clearly see that the profit level of the optimization model in each year has a high stability, showing good adaptability and reliability (Figure 2).

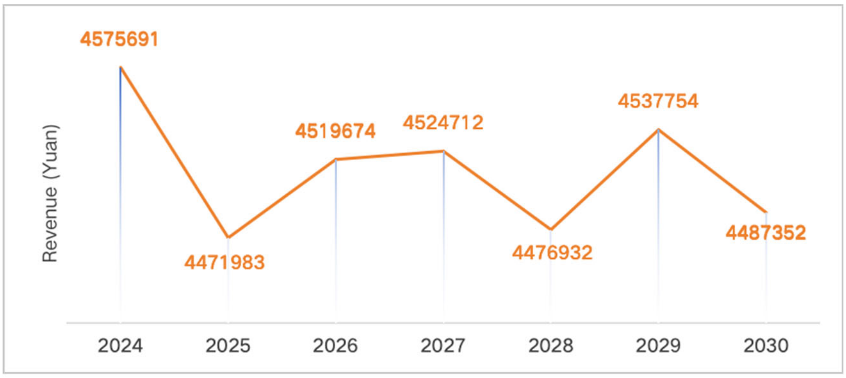

Figure 2. Forecast revenue chart

4. Conclusion

In this paper, a multi-condition optimization problem solving method combining genetic algorithm and robust optimization is proposed to provide an optimal scheme for rural crop planting planning in Northeast China from 2024 to 2030. The optimization model takes into account land type, crop characteristics, market demand, price fluctuations and other factors, and constructs a flexible system including matrix and linear programming models, which can effectively deal with planting constraints of different crops on different lands. In particular, the introduction of interval planning and robust optimization methods enables the model to cope with the uncertainty of future economic indicators and provide more robust optimization results.

However, the application of this model also faces certain limitations. The model can not fully capture the influence of market dynamics and emergencies on planting conditions, and there may be errors.

Future studies can further improve and expand the model, especially to establish a unified agricultural database to provide accurate and complete data support, so as to reduce the impact of data bias on results. Further integrate external factors such as market dynamics and emergencies, and adopt more flexible forecasting and optimization methods to improve adaptability and accuracy in complex environments.

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