Optimization of Crop Planting Strategies Using Linear Programming and Genetic Algorithm Under Complex Land Conditions

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Abstract. To address the challenge of optimizing crop planting strategies under complex land conditions, this study proposes a model that combines linear programming and genetic algorithm to maximize planting profitability. While traditional linear programming excels at solving resource allocation problems, it faces limitations in handling large-scale nonlinear and dynamic constraints. To overcome these challenges, genetic algorithms are employed to further optimize planting schemes, leveraging their evolutionary search capabilities. The experimental process includes constructing a linear programming model to define the objective function and constraints, followed by solving the model using a genetic algorithm to identify optimal solutions. Results show that the proposed method significantly improves planting profitability, enhances resource utilization efficiency, and ensures crop diversity. Sensitivity analysis indicates that the model is robust and adaptable to market fluctuations, such as changes in yield-to-sale ratios and costs. This study provides an effective tool for agricultural resource optimization and offers a foundation for further research in dynamic planting systems and sustainable agricultural management.

Keywords: Linear Programming, Genetic Algorithm, Planting Optimization, Resource Allocation, Precision Agriculture.

1. Introduction

With the rapid development of social economy and the improvement of people's living standards, the market demand of crops, as important consumer goods to ensure people's livelihood, shows a trend of continuous growth. However, crop planting is limited by its periodicity, seasonality and the diversity and limitation of cultivated land resources. How to develop scientific and reasonable planting strategies to optimize the allocation of resources and maximize the benefits has become an important research issue in the current agricultural field. In the study of implant strategy optimization, Alotaibi and Nadeem (2021) indicated that linear programming offers significant advantages in optimizing resource allocation and planting patterns. However, they noted that current studies predominantly concentrate on single-objective optimization, neglecting the balance of multiple objectives under dynamic conditions [1]. In response, Li et al. (2020) introduced the multi-objective particle swarm optimization algorithm, which integrates economic, ecological, and social benefits to showcase its potential in addressing complex agricultural resource allocation issues [2]. Li et al. (2022) constructed a crop planting density optimization system that aims to help agricultural researchers in data analysis and guide agricultural production through precise parameter estimation and model selection, as well as optimization of planting density and fertilization volume [3]. Zhu Huixia et al. (2019) studied the allocation of agricultural resources, proposed an adaptive genetic algorithm to optimize the constraint problem, and discussed the optimal combination of planting industry structure and resource allocation. The paper established the maximum net return model of four crops under fixed cultivated land area and fertilizer supply, and verified the correctness and practicability of the algorithm through simulation [4]. The application of genetic algorithms to land use optimization and a detailed comparison between NSGA-and NSGA-methods, Wang et al. The study shows that NSGA-has significant advantages in dealing with the super-multi-target optimization problem and can effectively solve the multi-target conflict problem. By optimizing different land use modes, this study puts forward a more reasonable resource allocation strategy, which provides an optimized theoretical basis for crop cultivation [5]. Despite the important progress in existing studies, current studies mainly focus on single plots or simple constraints, with relatively few studies on planting strategy optimization under complex cultivated land conditions. In addition, the research on the fluctuation of production and sales rates and the efficient allocation of resources is still insufficient. In this paper, the optimization of crop planting strategy based on complex cultivated land and conditions, proposes a multi-objective optimization model based on linear planning and improved genetic algorithm, aiming at the goal of maximizing net profit, and comprehensively considering the types of cultivated land, crop types, planting cycle and other practical constraints.

Specifically, the contributions of this paper include: constructing a multi-objective optimization model based on linear planning, which is suitable for complex farmland conditions; proposing an improved genetic algorithm, using multi-matrix chromosome coding and unfeasible solution repair mechanism to improve the solution efficiency and stability; and verifying the robustness of the model in different market conditions through sensitivity analysis.

The structure of this paper is as follows: the first chapter introduces the research background, current situation and the basic knowledge of linear planning model, genetic algorithm and sensitivity analysis; the third chapter describes the construction and solving process, and shows the experimental design of the model; the fourth chapter presents the experimental results and analysis, shows and discusses the performance of the model under different conditions, and summarizes the main conclusions of this paper and proposes the future research direction.

2. Related Theories

Linear programming is a mathematical optimization method widely applied in resource allocation, production planning, and cost control. Its objective is to optimize a linear objective function subject to a set of linear constraints, such as resource availability or production capacity. The basic components of linear programming include the objective function, decision variables, and constraint conditions. Common solution methods, such as the simplex method or interior point method, are known for their computational efficiency and straightforward results, making linear programming particularly suitable for large-scale optimization problems. However, due to its assumption of linear relationships, linear programming is limited in handling nonlinear dynamics, uncertainty, and complex constraints in practical scenarios [6].

The genetic algorithm is an optimization algorithm inspired by the principles of natural selection and genetics, widely used for solving complex optimization problems. It operates by generating an initial population of candidate solutions and iteratively refining them through selection, crossover, and mutation. The genetic algorithm is particularly effective for non-linear, multi-objective, and large-scale optimization problems, as it efficiently explores the solution space to avoid local optima. By leveraging its population-based search mechanism, the algorithm balances the exploitation of high-quality solutions and the exploration of new solution areas, making it suitable for agricultural planning where multiple constraints [7].

3. Experments

In this study, the planting conditions of a typical agricultural region were taken as an example, and a detailed experimental scheme was designed. The experiment covered a total of seven annual cycles from 2024 to 2030, involving 54 plots, including smart greenhouses and traditional farmland, as well as 41 common crop species. The experimental design integrated linear programming and an improved genetic algorithm to optimize the allocation of agricultural resources under complex constraints, focusing on the analysis of maximizing crop yield and profitability under two different market scenarios: high market demand and low market demand. Total revenue Z was defined as the net income from crop sales minus planting costs. To comprehensively evaluate agricultural income under different market conditions, this study formulated the objective function to analyze the effects of varying market demand and fluctuating crop prices on total profitability. This approach allows for a more robust and adaptable optimization model, capable of guiding planting strategies under dynamic economic and environmental conditions [8].

This experiment established the objective function based on linear planning, optimized the crop planting scheme from 2024-2030, and ensured the feasibility and practical applicability of the scheme combined with constraints.

Objective function:

$$\max\ z = \text{Income - Expense} \tag{1}$$

There into:

$$\text{Income}=\sum_t \sum_j \sum_k \left(\text{Price}_{j,k,t} * \sum_i x_{i,j,k,t}\right) \tag{2}$$

$$\text{Expense}=\sum_t \sum_i \sum_j \sum_k C_{i,j,k,t} * x_{i,j,k,t} \tag{3}$$

The decision variable (xi, j, k, t) indicates the area of the crop in year t, plot i, season j, planting crop k.

Constraint condition:

Plot season limit:

$$\begin{cases} j \le 1, & if i \in \{A,B,C\} \\ j \le 2, & else \end{cases} \tag{4}$$

It means that only one season can be planted in dry land, terraces and hillsides, and up to two seasons in irrigated land and greenhouses.

Crop Type Limits:

$$x_{i,j,k,t} \le 0, if i \in \{A,B,C\} \wedge k \in \{1,2,3,13,14,15\} \tag{5}$$

In the crop species limitation in flat lands, terraces and hillside fields.

Limitation:

$$\sum_{i=0}^{2} x_{i,j,k,t} \ge 1, k \in \{1,2,3,4,5,17,18,19\} \tag{6}$$

Indicates that each plot grows legumes at least once in three years.

Crop continuous cropping restrictions:

$$x_{i,j,k,t} + x_{i,j,k,t+1} \le A_i, if s \le 1 \tag{7}$$

Indicates that each crop shall not be continuously replanted in the same plot (including greenhouse).

Single Plot planting area limit:

$$x_{i,j,k,t} \ge 0.2 \times A_i \tag{8}$$

It indicates that the planting area of each crop in a single plot (including greenhouses) shall not be less than 20% of the total area of the plot.

Limit of the total planting area of a single plot:

$$\sum_p x_{i,j,k,t} \le A_i \tag{9}$$

Indicates that the total planting area of each plot (including greenhouses) should not exceed its available area.

Quantity limit of planting plots:

$$\sum_i x_{i,j,k,t} \le 5 \tag{10}$$

It means that the quarterly plots of each crop should not be too scattered, and each crop can only be planted in five plots during the same period [9].

To solve the complexity of linear programming model in large-scale solution space, this experiment is solved by genetic algorithm. In the experiment, the initial population is first randomly generated, each population consists of multiple chromosomes, and each chromosome represents a planting scheme, including a combination of decision variables such as crops planted in different seasons and their area in different seasons. The population was subsequently evaluated for fitness values, calculated by the objective function, and chromosomes with higher fitness values represent better in their planting scheme. On this basis, the experiment uses crossover and variation operation to introduce the diversity of solutions, where the crossover operation generates offspring by randomly exchanging some gene fragments of the parent chromosome, and the variant operation randomly changes the gene value in the chromosome to explore the new solution space and avoid falling into the local optima. In addition, to ensure that chromosomes meet the actual planting restrictions, chromosomes that do not meet the constraints are adjusted through the repair mechanism, and the repair process includes reallocation of the planting area beyond the limit or adjusting the planting combination. As the number of iterations increases, the number of high-quality chromosomes in the population gradually increases, the experiment terminates the algorithm after reaching the set number of iterations or population fitness convergence, and finally output the chromosome with the highest fitness value as the planting scheme. In the experiment, the parameters of the genetic algorithm were set as: population size 40, the number of iterations 900, crossover rate 0.7, and variation rate 0.3 [10].

In conclusion, a comprehensive linear planning model is ultimately constructed by establishing the aforementioned objective functions, decision variables, and constraints.

4. Results

Through experimental design and model construction, linear programming and genetic algorithm were applied to systematically evaluate various planting strategies and resource allocation schemes. During the model-solving process, linear programming utilized the simplex method to optimize key variables such as planting area and distribution, ensuring that an initial feasible solution could be achieved under resource constraints. Simultaneously, the genetic algorithm was employed to balance strategies under diverse constraints, leveraging its evolutionary optimization capabilities to efficiently explore the solution space and identify optimal planting schemes.

The following is the distribution of different planting areas in the optimized plots, as shown in Table 1.

Table 1. Table of planting scheme optimization results

Plot type	Area (mu)	Season 1 Crop	Season 2 Crop	Total income
Flat dry land	100	wheat	——	5.6
bench terrace	120	corn	——	6.8
shoulder	80	beans	——	3.5
irrigable land	150	rice	vegetables	9.2
Intelligent greenhouse	50	vegetables	vegetables	12.1
total	500	——	——	37.2

The data in the table demonstrate the optimized planting area and crop species distribution in each plot. As can be seen from the table, the smart greenhouse brings higher benefits due to the advantages of multi-season planting. At the same time, the optimized planting strategy takes into account the resource characteristics of different plots and realizes the maximum planting benefits.

Through the optimization of different planting strategies, the net profit change of the original scheme and the optimization scheme is compared. The specific results are shown in Table 2.

Table 2. Profit change table

Policy type	Original scheme net profit (ten thousand yuan)	Net profit after optimization (ten thousand yuan)	Increase the range of (%)
Conservative strategy	25.8	31.5	22.10%
Radical strategy	27.2	37.2	36.80%

As can be seen from the table, the optimized planting strategy has significantly improved the net profit. Among them, conservative strategy paid more attention to stability and diversity, increasing by 22.1%; aggressive strategy focused on planting high-yield crops, and net profit increased by 36.8%. Both strategies demonstrate the effectiveness of the optimization scheme under different objectives.

In order to verify the stability and robustness of the model, the sensitivity analysis of the key parameters (e. g. productivity and total profit) is conducted. The analysis results show that when the production and sales ratio is greater than 98%, the change of total profit-production and sales ratio tends to flatten out, indicating that the model has low sensitivity under the condition of high production and sales ratio, and the model is relatively stable. When the production and sales ratio is lower than 98%, the model can still provide a reasonable planting strategy, although the volatility of the total profit increases. Further analysis showed that the iterative convergence curves of the GA showed clear differences between the two conditions:

Situation 1: The production and sales rate is greater than 98% in the 740th generation shows obvious signs of convergence, and the final convergence value is stable at about 3 million yuan. This indicates that the algorithm gradually approaches the optimal solution and shows stability at high rate.

Situation 2: The production and sales rate is lower than 98%, showing signs of convergence in the 580th generation, and the final convergence value is stable at about 15 million yuan. This indicates that the model optimization speed is faster, under the lower productivity rate, but the total profit is subject to volatility.

5. Conclusion

This paper combines linear programming and genetic algorithm to construct a crop planting optimization model for complex arable land conditions. The experimental results show that the model can realize the optimal allocation of planting resources under the restrictions of different plot types, crop types and planting seasons, and effectively improve the planting income, while taking into account the diversity of crop species and the rationality of land use. Through sensitivity analysis, it is found that the model has strong adaptability in various environments and market conditions, and can provide scientific planting scheme according to the changing market demand and production conditions. Moreover, the model provides practical tool support for the design of planting strategies under complex arable land conditions by improving the search efficiency of understanding through improved genetic algorithms. Future studies can introduce dynamic factors such as climate change and market price fluctuations to further enhance the applicability of the model and expand its application scope in cross-regional planting planning and multi-crop collaborative optimization.

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