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A Study on Optimal Crop Planting Scheme Based on 0-1 Programming and Genetic Algorithm

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Abstract: *Confronted with multiple pressures including population growth and shrinking arable land, optimizing agricultural planting structures through modern management science and mathematical models to rationally allocate limited land resources is crucial for increasing farmers 'income. Based on rural realities, developing organic farming industries by fully utilizing limited arable land resources and adapting to local conditions holds significant practical importance for sustainable rural economic development. To address this, this study proposes a mathematical model combining 0-1 programming and genetic algorithms. This model integrates the compatibility between 0-1 programming and single-crop farming in farmland block division while leveraging genetic algorithms' advantages in multimodal optimization, thereby enhancing farmers' agricultural profits. In the first phase, there is a variation in the values, with the highest reaching ¥9,511,904.00 and the lowest being ¥7,099,057.75. These figures reflect the highest expected profit levels under different circumstances or conditions in the first phase. Moving into the second phase, after taking into account the fluctuations in influencing factors, compared to the first phase, the data in the second phase shows more significant fluctuations. The highest value of ¥9,140,610 is lower than that in the first phase, and the lowest value of ¥5,492,305 is also notably lower than the lowest in the first phase, indicating that the fluctuations in influencing factors in the second phase have had a substantial impact on the profit projections.*

Keywords: *0-1 Planning Model, Genetic Algorithm, Entropy Weighting Method, Fluctuation Factor*

1. Introduction

At present, China's agricultural sector is grappling with a myriad of challenges. The relentless population growth, coupled with the shrinking arable land area at an alarming pace and the intensifying resource constraints, has created a complex and pressing situation. Among these challenges, the growing tension between ensuring national food security and promoting the sustainable growth of farmers' incomes has emerged as a highly prominent and urgent issue that demands immediate attention. To meet the demand of food, fodder, fuel and fibre for the ever-increasing population of the world, achieving higher land and water productivity of a parcel of land is a major challenge[1].

Achieving high crop yields requires a strict execution of works, the composition of which is determined by numerous factors. Such factors include, for example, the geographical location of the land plot, its size, climatic conditions, characteristics of the growing plants, composition of the topsoil, etc.[2]. Rainfall is one of the most important climatic variables that determine the spatial and temporal patterns of climate variability of a region, which provides useful information for the planning of agricultural production[3]. More than one objective needs to be fulfilled simultaneously to incorporate economic and social requirements in an acceptable and optimal cropping pattern[4]. Given the limited availability of land resources, maximizing crop yields within the existing land boundaries has become an enduring and formidable challenge for Chinese agriculture.

Crop planting structure optimization is a significant way to increase agricultural economic benefits and improve agricultural water management[5]. As the world's largest agricultural nation, China holds a crucial position in global food production. The strategic application of modern management science and mathematical models to optimize crop structures and allocate agricultural resources effectively is not only a scientific approach but also a strategic necessity.

This study selects a rural village in North China as the sample area. This region is characterized by consistently low temperatures throughout the year, which has a significant impact on crop growth cycles and planting seasons. Moreover, the cultivated land in this area exhibits a diverse range of types,

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including paddy fields, dry land, and orchards, spread across extensive farmland.

The methodology of this study adopts a two - stage approach. In the first stage, the focus is on optimizing farmers' annual crop profits while strictly meeting the basic food supply demands. This involves a detailed analysis of the cost - benefit ratio of different crops, considering factors such as planting costs, market prices, and expected yields. In the second stage, the research addresses the uncertainties in annual sales volume, yield per mu, planting costs, and market prices. By incorporating risk assessment and sensitivity analysis, an optimized crop cultivation model is established. This model aims to identify the most effective planting strategy that can balance profit maximization with risk minimization, providing valuable guidance for farmers in making informed decisions.

2. Data source and Preprocessing

The data for this study was sourced from https://www.mcm.edu.cn/. After obtaining the dataset, this paper first categorized the plots across different regions. Considering that some adjacent plots had small planting areas and scattered crops made daily management difficult for farmers, this study decided to reorganize the plots into single-crop cultivation units. Following the elimination of high-cost, low-profit, and non-essential crops from the database, this study classified the remaining crops by planting location and optimized the crop database through list restructuring. The database provides 2023's crop planting data as a reference, which serves as the initial dataset for developing optimal planting plans for 2024-2025.

This study first focuses on determining optimal solutions with fixed influencing factors by transforming the optimization problem into one of maximizing net profits. A 0-1 programming model for maximizing net profits was constructed, and the genetic algorithm was employed to derive both the maximum net profit and its corresponding optimal planting plan. Subsequently, uncertainties in crop sales volume, yield per mu, planting costs, and selling prices were incorporated through volatility factors. After optimizing the initial 0-1 programming model, the study calculated the optimal crop planting plans for farmland in the region during 2024-2030 through a second optimization process.

3. Establishment and Solution of Crop Planting Optimization Model

First of all, the maximum net income is determined by the ideal sales, planting costs and actual wastage losses of unsold products. The maximum net income can be obtained by deducting the planting costs and actual wastage losses of unsold products from the ideal sales. The relationship between the four factors can be expressed as:

$$\mathrm{W} = \mathrm{W1} - \mathrm{W2} - \mathrm{W3} \tag{1}$$

W means net income, W1 means ideal sales, W2 means planting cost, and W3 means actual waste of unsold goods.

Secondly, the ideal sales are related to the yield and selling price of each crop, and the yield is related to the planting area, so the ideal sales can be expressed as:

$$W_1(t) = \sum_{i,j,t} x_{i,j,t} \times s_{i,j,t} \times \alpha_{i,j,t} \times \beta_{i,j,t} \tag{2}$$

Here, xi, j, t denotes whether crop type i was planted in plot j during year t, with values of 0 or 1. $S_{i,j,t}$ represents the area of plot j planted with crop type i in year t. $\alpha_{i,j,t}$ indicates the yield per mu (Chinese acre) of crop type i in plot j during year t. $\beta_{i,j,t}$ shows the selling price of crop type i in plot j for year t.

Next, the planting cost is related to the total area of each crop planting plot and the planting cost per mu, so it can be expressed as:

$$W_2(t) = \sum_{i,j,t} x_{i,j,t} \times s_{i,j,t} \times c_{i,j,t} \tag{3}$$

Where $c_{i,j,t}$ represents the planting cost of the i-th crop on the j-th block of the year t.

Finally, because there will always be some deviation between the actual sales and the expected sales, the actual unsold agricultural products can be sold at half price to recover part of the loss. Therefore, the actual unsold waste loss is related to the total area of each crop planting plot, yield per mu, expected sales

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volume and sales price, which can be expressed as:

$$W_3(t) = \sum_{i,j,t} (x_{i,j,t} \times s_{i,j,t} \times \alpha_{i,j,t} - y_{i,t}) \times \beta_{i,j,t} \tag{4}$$

Among them, $y_{i,t}$ represents the estimated sales volume of the i-th crop in the tth year.

To sum up, this paper established the 0-1 programming model, where i, j and t are the crop number, plot number and year number, which satisfy $1 \le i \le 40, 1 \le j \le 54$, t=1,2,...,7, which correspond to the years 2024-2030 respectively.

Next, this study uses genetic algorithm to solve the optimal solution of the above problem, namely maxW.

Given the constraints of monoculture per plot (with no consecutive double cropping in greenhouses) and the requirement to plant at least one legume every three years for soil improvement, this study established the initial population for the genetic algorithm. Through annual iterations using this algorithm, this paper calculated the maximum net returns for the years 2024 to 2030. The parameters $x_{i,j,t}$ represent the cultivation status of crop i in plot j during year t. The combined results provide the optimal planting plan for each year. There are the predicted maximum net returns for each year shown in Table 1.

Table 1 Maimum net income for each year under the conditions

Year	2024	2025	2026	2027	2028	2029	2030
maxW	9,308,932	8,300,936	7,099,058	9,511,904	8,137,317	7,593,765	7,539,687

The data in the table shows that in the initial years following the implementation of the preset model, farmers experienced significant growth in net income. However, due to constraints in planting conditions, income saw a slight decline before stabilizing. Despite this, the net income over these seven years still showed substantial growth compared to 2023 levels. This demonstrates that the model has proven effective in boosting farmers' income.

There is a line graph of crop planting by year shown in Figure 1.

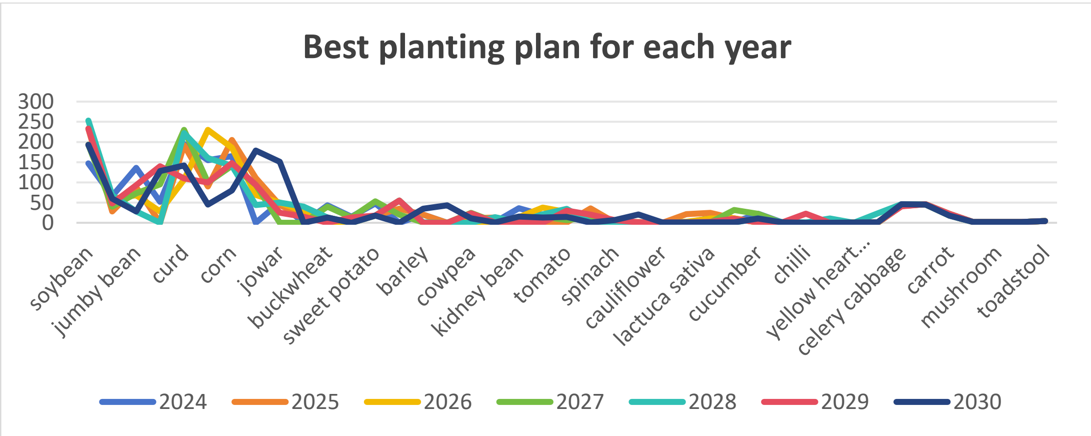

Figure 1 Crop planting in each year under the first step conditions

The data in the figure reveals that soybeans, red beans, cowpeas, and corn are widely cultivated per mu (approximately 0.067 hectares), which aligns with the region's geographical environment and dietary patterns. The North China region exhibits a complex natural environment characterized by "coexisting fertile plains and fragile ecosystems, intertwined monsoon climate and water scarcity," leading to the cultivation of crops that are easy to grow, high-yielding, and durable. Therefore, considering only these constraints is insufficient. This study further incorporates additional environmental factors affecting crop cultivation, conducts secondary optimization of the model, and develops planting strategies that better suit the local conditions of North China.

4. Crop Planting Optimization Model Considering Uncertain Factors Crop planting optimization model considering uncertain factors

Through analyzing online data, it has been observed that North China has experienced significant climate changes in recent years, marked by frequent extreme weather events and declining soil fertility.

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These unpredictable factors significantly impact crop growth, necessitating the incorporation of variables such as climate fluctuations and soil quality into optimization models to enhance the adaptability and reliability of cultivation strategies.

Analysis of the variables revealed that wheat and corn production saw average annual sales growth of 5% to 10%, while other crops experienced ±5% fluctuations. Crop yields per mu (approximately 0.067 hectares) could vary by ±10%, with planting costs rising by 4% to 6% annually. Vegetable prices increased by 4% to 6% yearly, whereas edible mushroom prices decreased by 1% to 5%, and morel prices dropped by 5%.

To simulate and predict planning challenges involving unpredictable future fluctuations, this study employs computer-generated fluctuation factors within the numerical variation range of variables. These generated fluctuation factors are used to calculate fixed values for various influencing factors across different years. Subsequently, newly created parameters—including planting costs, yield per mu (Chinese acre), sales prices, and other metrics—are input into a 0-1 programming model. Through genetic algorithm optimization, the maximum net benefit is calculated, ultimately yielding more accurate crop cultivation plans that align with the geographical characteristics of North China.

After introducing the volatility factor and iterative calculation by genetic algorithm, there are the predicted annual profits from 2024 to 2030 represented by M and the values shown in Table 2.

Table 2 Maimum net income for each year under the conditions

Year	2024	2025	2026	2027	2028	2029	2030
Profit M	7,768,402	9,140,610	6,311,117	8,782,842	8,782,254	8,491,225	5,492,305
maxW	9,308,932	8,300,936	7,099,058	9,511,904	8,137,317	7,593,765	7,539,687

Through comparative analysis of pre-and post-introduction data, the study revealed that geographical conditions and local market uncertainties significantly impact farmers' annual crop profits, resulting in greater income volatility than pre-introduction levels. However, farmers' 2023 income of 6,964,063.50 yuan still shows improvement. These findings confirm that the mathematical model combining 0-1 programming with genetic algorithms proves effective in boosting farmers' income. Future strategies to enhance income growth should focus on mitigating these uncertainties.

There are the specific planting plan for 2024-2030 shown in Figure 2.

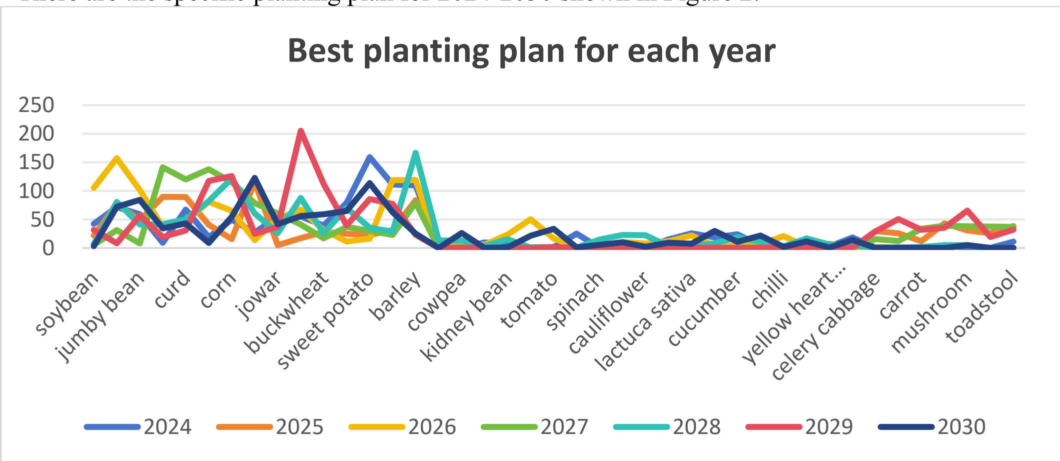

Figure 2 Crop planting in each year under the second step conditions

The data reveals that while the variety of crops planted each year remains relatively stable, significant fluctuations occur in planting quantities. This phenomenon is closely tied to changing production factors such as crop yield per mu (approximately 0.067 hectares), cultivation costs, and market demand. The findings suggest that farmers should conduct thorough assessments of soil quality and market conditions before planning their annual crop rotations. Such strategic planning can significantly enhance their profitability in agricultural production.

5. Conclusions

This study develops a crop cultivation optimization model combining 0-1 linear programming with genetic algorithms. To maximize net returns, the model operates in two distinct phases: one considering

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environmental and market factors, and the other excluding local characteristics. The two-phase approach serves dual purposes: first, it provides preliminary viable optimization solutions for diverse regions; second, it enhances precision by incorporating fluctuation parameters based on regional geographical features, agricultural markets, and dietary cultures, enabling more accurate optimization. Subsequent research can simply adjust these fluctuation parameters to obtain region-specific solutions. The computational results demonstrate the model's practical viability. However, limitations exist. For instance, the study only analyzed farmland in North China with limited experimental data. Future research could validate the model's applicability across different regions or optimize it through iterative refinement.

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