Research on Optimal Crop Planting Strategy based on NSGA-II Algorithm

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Abstract

The purpose of this paper is to explore the optimal planting scheme of crops to reduce planting risks and realize sustainable development of rural economy. Firstly, the actual crop yields of a rural village in the mountainous region of North China are collected and calculated to replace the expected future sales of various crops; with the maximum annual profit and the most portable management of crops as the objective function, eight constraints are set up from the perspectives of reasonableness, economy, and seasonality, and a multi-objective planning model is established. The non-dominated sorting technique of genetic algorithm NSGA-II is utilized to solve the optimal crop planting scheme for the next 7 years, and the optimal value is determined in the Pareto frontier solution. Finally, the scatter heat map is plotted to reflect the optimal planting scheme in the case of production exceeding part (production>sales) stagnation as planting one crop per year in single-season plots and alternating two crops per year in double-season plots.

Keywords

Multi-objective Planning Model; NSGA-II Algorithm; Optimal Planting Scheme.

1. Introduction

With the development of modern economic level, China's population growth, urbanization and industrialization process accelerated, the pressure of arable land increased dramatically, which led to the population, the contradiction between the arable land is increasingly acute [1], to strengthen the land remediation and arable land utilization, make full use of limited arable land resources, according to the local conditions, and the development of organic planting industry, is to promote the sustainable development of the agricultural economy is an important basis. Therefore, selecting suitable crops and optimizing planting strategies are crucial for agricultural development.

2. Background

The mountainous areas of northern China are characterized by low temperatures all year round, and most of the arable land can only be planted with one crop season per year. Taking a village in the region as an example, the survey found that the current status of arable land is shown in the table 1:

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Table 1. Requirements for each type of arable land

Type of Farming	Specificities	Special Needs
Semi-arid Land	Suitable for one season of food crops per year	● The same plot can be combined with different crops each season. ● Each crop should not be planted in the same plot with successive heavy crops or yields will be reduced; ● All land in each plot will be planted with a legume crop at least once in three years starting in 2023. ● Each crop should not be spread too thinly and planted on too small an area per season.
Stepped Fields		
Hillside		
Waterlogged Land	Suitable for growing one season of rice or two seasons of vegetables per year	
Ordinary Greenhouse	Suitable for growing one season of vegetables and one season of edible mushrooms per year	
Intelligent Greenhouse	Suitable for growing two seasons of vegetables per year	

3. Notation

Table 2. Notation

Notation	Mean
i	Crop type
j	Number of arable land plots
t	year
p_{ijt}	Acres of crop i planted in plot j in year t
m_{ijt}	Total production of crop i planted in plot j in year t
l_{ijt}	Sales of crop i planted in plot j in year t
n_{ijt}	Unit price of crop i planted in plot j in year t
r_{ij}	Cost of crop i planted in plot j in year t
x_{ijt}	Total selling price of crop i planted in plot j in year t
y_{ijt}	Total cost of crop i planted in plot j in year t

4. Data Sources and Processing

4.1 Data Sources

In order to develop the optimal planting program for the next seven years in the countryside, it is first necessary to collect relevant information such as the growth of crops in the region, and for this purpose, the study was carried out by consulting a large amount of information and combining the data collected by the National Bureau of Statistics, the Ministry of Agriculture and Rural Development and some agricultural research institutions (the Chinese Academy of Agricultural Sciences and the China Agricultural University) in a comprehensive manner.

4.2 Data Pre-processing

(1) Outlier test

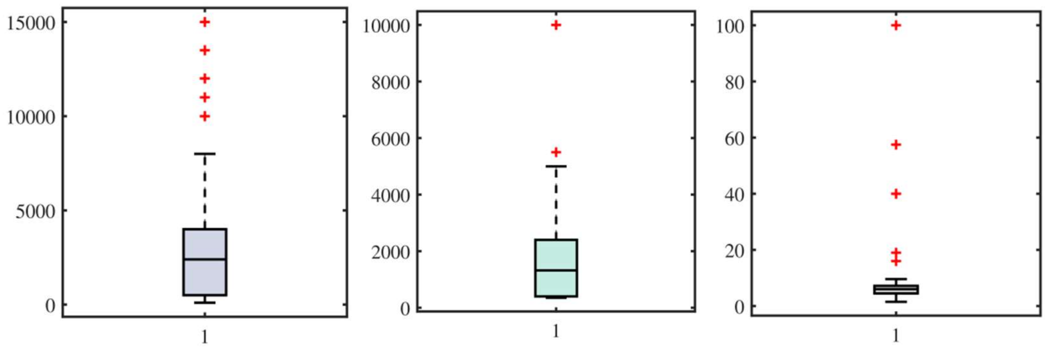

Figure 1. Schematic diagram of outlier test

As shown in the figure, from left to right are the outlier detection results for the three indicators of “mu yield”, “planting cost” and “selling price”. Most of the data are normal, only a small number of possible abnormal values are discharged, for large deviations in the data, the algorithm will be considered anomalous values, screened out, after checking the specific values and the corresponding crop name, access to information found to be a rare species, close to the real situation, the data are retained.

(2) Quantitative data processing

For the purpose of analysis, the names of the plots in the area were quantified and processed, as flat dry land, terraced land, hillside land, and ordinary greenhouses can only grow single-season crops, and each plot was numbered only once. Water-consumed land and smart greenhouses can grow double-season crops, and they will be numbered according to the planting season, i.e., numbered twice. The final quantitative results are shown in Table 3:

Table 3. Quantitative rule

Quantification of parcel names	j	Quantification of parcel names	j
A1	1	D2(a)	29
A2	2	D2(b)	30
...	...	...	...
B8	14	E8	50
B9	15	E9	51
...	...	...	...
D1(a)	27	F4(a)	65
D1(b)	28	F4(b)	66

(3) Calculation of crop production in 2023

Assuming that the sales of crops are equal to their production, the values of production of each crop in 2023 were obtained from the data collected:

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Table 4. Crop production and sales in 2023

Crop number	Yield/pound	Crop number	Yield/pound
1	57000	21	36210
2	21850	22	45360
3	22400	23	900
...	...	...	...
14	14000	35	150000
15	10000	36	100000
...	...	...	...
19	6240	40	18000
20	30000	41	4200

5. Multi-objective Planning Model

5.1 Model Building

Multi-objective optimization can comprehensively consider multiple objectives and constraints, and obtain a more comprehensive and effective optimization scheme by analyzing the mutual influence and trade-off relationship between different objectives [2]. Therefore, a multi-objective optimization model is constructed based on planting area-season-profit and other perspectives, and two objective functions and constraints are set up as follows:

(1) objective function 1: in order to make the countryside crop planting program to reach the optimum, that is, the countryside should be made each year to maximize sales profits, according to “profit = total sales - cost” to set up the first objective function, set the total profit and to ensure that the total profit of g maximum:

$$g=\sum_{i=1}\sum_{j=1}\sum_{t=1}x_{ijt}-\sum_{i=1}\sum_{j=1}\sum_{t=1}y_{ijt} \tag{1}$$

The cost of planting crops is related to the type of crop, the area planted and the year, and for this reason, it is possible to calculate the cost on the basis of the factors that influence it:

$$y_{ijt}=p_{ijt}\times r_{ij} \tag{2}$$

When production > sales, the excess is stagnant and results in wastage, the total sales are:

$$x_{ijt}=\min\{m_{ijt},l_{ijt}\}\times n_{ijt} \tag{3}$$

(2) objective function two: in order to ensure that each planting of each plot of crop species as little as possible, we set up a second objective function, first of all, set up a certain crop in a plot of planting for s_{ijt}; that is, for a certain crop for the existence of species and not planted in two cases, in order to facilitate the research and analysis, the use of the “Zero-One Planning” is as follows:

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$$s_{ijt} = \begin{cases} 1 \\ 0 \end{cases} \tag{4}$$

Where 1 means that the i crop is planted in the j plot in the t year and 0 means that it is not planted. In order to satisfy the condition that the plots are planted with as few crop species as possible, s_{ijt} needs to be minimized, i.e., the second objective function is:

$$\min\{\sum_{i=1}\sum_{j=1}\sum_{t=1} s_{ijt}\} \tag{5}$$

(3) Constraints

[Constraint 1] The planting area is limited and defined, and individual crops cannot be planted in a plot that exceeds the original total area p_j of the plot:

$$0 \le p_{ijt} \le p_j \tag{6}$$

[Constraint 2] To avoid yield reductions, each crop cannot be grown in successive heavy crops on the same plot:

$$s_{ijt} + s_{ij(t+1)} \le 1 \qquad t \in (1,6) \tag{7}$$

[Constraint 3] In order to utilize the growth-promoting effect of legume crop rhizobial soils on other crops, all land in each plot is satisfied by planting a legume crop at least once in three years:

$$s_{ijt} + s_{ij(t+1)} + s_{ij(t+2)} \ge 1 \qquad t \in (1,5) \qquad i \in (1,5) \cup (17,19) \tag{8}$$

[Constraint 4] Flat drylands, terraces and hillsides are suitable for only one season of food crops per year, i.e. it is not possible to grow double cropping, including rice:

$$s_{ijt} = 0 \qquad t \in (1,7) \qquad i \in (16,41) \qquad j \in (1,26) \tag{9}$$

[Constraint 5] Waterlogged land is suitable for growing only one season of rice or two seasons of vegetables per year, i.e., it is not suitable for growing single-season crops:

$$s_{ijt} = 0 \qquad t \in (1,7) \qquad i \in (1,15) \qquad j \in (27,42) \tag{10}$$

[Constraint 6] If two seasons of vegetables (except cabbage, white radish, and carrot) are grown in a given small watering plot; only one of the three choices described above can be grown in the second season:

$$\sum_{i=35}^{37} s_{ijt} = 1 \qquad t \in (1,7) \qquad i \in (17,34) \qquad j \in (27,42) \tag{11}$$

[Constraint 7] Based on seasonal requirements, cabbage, white radish and red radish can only be planted in the second season of the watered field, i.e:

$$s_{ijt} = 0 \qquad t \in (1,7) \qquad i \in (35,37) \qquad j \in (1,26) \cup (43,66) \tag{12}$$

[Constraint 8] Edible mushrooms can only be grown in ordinary greenhouses in the fall and winter because they need to grow in a low and suitable temperature and humidity environment. Because of the need to grow a variety of vegetables in the first season of the ordinary greenhouses, edible fungi can only be grown in the second season. Thus for:

$$s_{ijt} = 0 \qquad t \in (1,7) \qquad i \in (38,41) \qquad j \in (1,34) \cup (59,66) \tag{13}$$

The objective function and constraints of the multi-objective optimization model are summarized as follows:

$$s.t. = \begin{cases} g = \sum_{i=1}\sum_{j=1}\sum_{t=1} x_{ijt} - \sum_{i=1}\sum_{j=1}\sum_{t=1} y_{ijt} \\ \min\{\sum_{i=1}\sum_{j=1}\sum_{t=1} s_{ijt}\} \\ 0 \le p_{ijt} \le p_j \\ s_{ijt} + s_{ij(t+1)} \le 1 & t = 1,\cdots,6 \\ s_{ijt} + s_{ij(t+1)} + s_{ij(t+2)} \ge 1 & t = 1,\cdots,5 \;\; i = 1,\cdots,5,17,\ldots,19 \\ s_{ijt} = 0 & t = 1,\cdots,7 \;\; i = 16,\cdots,41 \;\; j = 1,2,\cdots,26 \\ s_{ijt} = 0 & t = 1,\cdots,7 \;\; i = 1,2,\cdots,15 \;\; j = 27,\cdots,42 \\ s_{i_1jt}\sum_{i=35}^{37} s_{ijt} = 1 & t = 1,\cdots,7 \;\; i_1 = 17,\cdots,34 \;\; j = 27,\cdots,42 \\ s_{ijt} = 0 & t = 1,\cdots,7 \;\; i = 35,\ldots,37 \;\; j = 1,2,\cdots,26,43,\cdots,66 \\ s_{ijt} = 0 & t = 1,\cdots,7 \;\; i = 38,\cdots 41 \;\; j = 1,2,\cdots,34,59,\cdots,66 \end{cases} \tag{14}$$

5.2 NSGA-II Algorithm Solution

The multi-objective genetic algorithm NSGA-II is used and improved to solve the problem. Compared with the traditional multi-objective genetic algorithm, NSGA-II introduces the non-dominated sorting technique, which can grade individuals according to their non-domination, retain multiple non-dominated solutions, and find more high-quality solutions [3]; meanwhile, it introduces the Knudsen distribution distance, which ensures a more even distribution of individuals in the frontier, and improves the diversity of solutions [4].

The algorithm is a stochastic search algorithm that draws on natural selection and natural genetic mechanisms in biology, and is derived from genetic algorithms (GA), which introduces non-dominated ordering, proposes crowding and crowding comparison operators, and introduces an elite strategy [5]. However, the core of the algorithm still maintains the selection, crossover, and mutation

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of the genetic algorithm, which makes the objective function change from the original unique optimal solution to the Pareto solution set, and thus provides more possibilities for practical applications.

Description of algorithmic improvements:

●Hybrid coding: a hybrid coding of BG coding and RI coding is used to accommodate the case where the decision variables in this question are both 01 and continuous variables.

●Prior knowledge: incorporate prior knowledge and specify some initial values to accelerate model convergence.

●Global archive: global archive is introduced to retain the global optimal solution and avoid the loss of good populations.

5.3 Analysis of Results

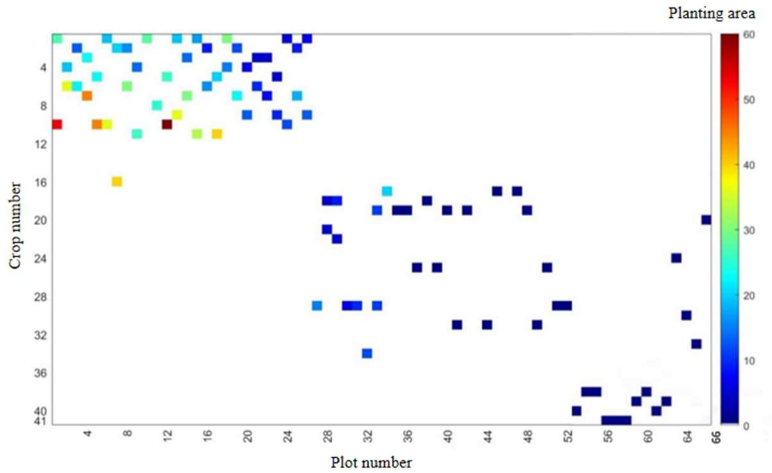

Figure 2. Heat maps in case of excess stagnation

According to the establishment of the eight qualifying function (constraints), the solution to its solution, so that the objective function and the net profit of the crops planted in that year is the largest, that is, the optimal planting program. As can be seen from the above figure, when production > sales, the excess part of the stagnant sales, resulting in waste, for crops that can only be planted in a single season in the planting of planting plots can only be planted in a crop, in the arrangement of planting, the upper left corner of the regional crop planting concentrated intensively, but there is still a large area of vacant space, combined with the image and the annex crop blocks can be seen, food, especially in the planting of the planting of the planting of the legume plant rate will do their best to meet the planting rate of At the same time reduce the occurrence of continuous and small area planting, so that the profit is maximized.

6. Conclusion

A multi-objective optimization model with the NSGA-II algorithm resulted in an optimal cropping scheme for planting one crop per year in single-season plots and two crops per year alternately in double-season plots with maximum satisfaction of legume cultivation and reduction of continuous versus small acreage planting. This scheme maximizes the annual profit while being easy to manage and meets various constraints (e.g., avoiding continuous heavy cropping, ensuring that the legume crop is planted at least once in three years, etc.). This planting strategy not only improves crop yields and quality, but also increases farmers' incomes, maximizes profits, and effectively promotes sustainable agricultural development.

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