Academic Journal of Agriculture & Life Sciences
ISSN 2616-5910 Vol. 5, Issue 1: 145-149, DOI: 10.25236/AJALS.2024.050119

Research on high-yield crop planting strategies in mountainous areas of North China based on a mixed integer linear programming model

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Abstract: *Crops in North China are the main source of economic development in North China. The low perennial temperature in North China has adverse effects on crop yield. How to fully use effective cultivated land resources to develop an organic planting industry according to local conditions, reduce planting risks brought by various uncertain factors, and maximize profits have become the focus of villagers' attention. To solve this problem, based on the theory of linear programming and mixed integer programming, a differential evolution algorithm was used to build a model of crop profit maximization and risk minimization. By establishing the profit maximization and risk minimization model, the optimal planting plan can be worked out for villagers to learn from and help villagers in North China to improve production efficiency, which has certain reference values and also has important practical significance for the sustainable development of the rural economy.*

Keywords: *Mountainous area of North China, Optimal planting scheme, Mixed Integer Linear Programming*

1. Introduction

In North China, the traditional farming model is facing many challenges. Due to the special geographical location, the region has a low temperature all year round, resulting in most cultivated land can only grow crops for one season per year. In addition, the limited nature and diversity of cultivated land resources, including flat and dry land, terraced land, hill land, and irrigated land, have put higher requirements on crop planting strategies. In this context, how to effectively use the limited cultivated land resources, develop the organic planting industry, improve production efficiency, and reduce planting risks has become the key to the economic development of the region.

Optimal allocation of land use is an important way to realize sustainable land use and promote the rapid development of the regional economy and gradual harmony of the environment. Scientific optimal allocation of land use can give full play to the potential of land use, improve the effect of land aggregation, and maintain the balance of the land ecosystem. Therefore, it is particularly important to carry out research on the optimal allocation of land use space by placing the quantity of different land use types in a reasonable geographical space [1]. Chen Dongxu focused on the opportunities faced by agricultural economic development under the background of rural revitalization and the corresponding coping strategies to promote rural revitalization [2]. Ma Maosheng introduced the influencing factors of agricultural planting, analyzed the negative effects of these factors, and put forward strategies to optimize the planting structure, hoping to increase agricultural output and achieve sustainable agricultural development [3]. Wu Junjie put forward effective strategies to strengthen the application of linear programming models in the optimization of agricultural planting structures [4]. Jose Miguel; and Billones Robert Kerwin established a linear programming model to determine the favorable season for harvesting crops [5]. Hemant Poonia used linear programming to allocate land crops and maximize profits [6].

Considering the singleness of Linear Programming and the limitation of some variables to integers, the Mixed Integer Linear Programming (MILP) model was constructed to solve the problem. This model can well deal with problems involving discrete decision variables, and get the result of each problem by introducing uncertainty analysis and the influence of correlation. In this paper, the original data of the 2024 Higher Education Cup question C is used as the data source(https://cumcm.cnki.net/ cumcm// Login/LoginIndex)

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2. The basic fundamentals of Mixed Integer Linear Programming

2.1 Model selection and crop classification

Considering that some variables are limited to integers, this paper adopts the method of mixed integer linear programming to design the optimal strategy. At the same time, considering the situation that there are more types of crops, this paper divides the crops in the original data set into four categories. The Crop classification is shown in Table 1.

Table 1: Crop classification

Group Them	Specific crops
Group one	Soybean, black soya bean, ormosia, gram, burging croton, wheat, corn, tomato, orghum, millet, uckwheat
Group two	Pumpkin, Sweet potato, Naked oats, barley, paddy, cowpea, luxuriant growth, Potato, spinach, Eggplant
Group three	Lactuca sativa, cucumber, lettuce, hili pepper, swamp cabbage, Yellow heart dish, celery, celery cabbage, white radish, carrot
Group four	Spinach, green pepper, lettuce, cabbage, lactuca sativa, Yellow mushroom of elm, mushroom, piewrotus nebrodensis, toadstool

2.2 Add constraints and build objective functions

2.2.1 Add constraints

(1) Total area constraint: The total area of each plot is equal to the sum of the various crops allocated to the plot

$$\forall i \in I, \sum_{j \in J} x_{i,j} \leq A_i \tag{1}$$

where A_i is the total area of block i.

(2) Minimum acreage constraint: The acreage of each crop on a single plot must not fall below a certain minimum

$$\forall i \in I, \forall j \in J, x_{i,j} \geq m_i \tag{2}$$

where m_i is the minimum planted area of plot i.

(3) Legume crop planting constraints: Each plot must be planted with legume crops at least once within three years

$$\forall i \in I, \sum_{j \in \text{legume crops}} x_{i,j} \geq 1 \tag{3}$$

(4) Non-continuous repeat planting constraint: The same crop cannot be planted continuously in the same plot

$$\forall i \in I, \forall j \in J, x_{i,j} \leq \left(1 - x_{i,j\ last\ year}\right) \cdot A_i \tag{4}$$

where j is the crop that was planted on plot i the previous year.

(5) The irrigated field after rice planting cannot be planted for a second crop: If rice is planted on the irrigated field, the field cannot be planted for another crop that year

$$\forall i \in I_{\text{irrigated field}}, x_{i,rice} \cdot \sum_{j \in J \setminus rice} x_{i,j} = 0 \tag{5}$$

(6) Plot type constraint: each crop, can only be grown on those plots that are suitable for its growth.

$$\forall i \in I, \forall j \in J, x_{i,j} \leq A_i \cdot \delta_{i,j} \tag{6}$$

where $\delta_{i,j}$ is a 0-1 variable, if crop j can be grown on plot i, $\delta_{i,j}$ = 1, otherwise $\delta_{i,j}$ = 0.

2.2.2 Build objective functions:

Our goal is to maximize net revenue and minimize slow-selling losses. Therefore, we set the objective function as:

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$$Z = max \sum_{t=2024}^{2030} \sum_{i \in I} \sum_{j \in J} \begin{pmatrix} \left(Y_j(t) \cdot P_j(t) - C_j(t)\right) \cdot x_{i,j}(t) \\ -max\left(0, Y_j(t) \cdot x_{i,j}(t) - S_j(t)\right) \cdot P_j(t) \end{pmatrix} \tag{7}$$

where $x_{i,j}$ represent the area where crop j was planted on plot i in year t, $P_j(t)$ is the selling price of crop j in year t, $C_j(t)$ is the cost of planting crop j in year t, $Y_j(t)$ is crop yield in year t, and $S_j(t)$ is Expected sales of crop j in year t.

Based on this, the yield greater than sales is divided into two cases, including unsalable waste and selling at a reduced price.

2.3 Consider uncertainties and construct objective functions

2.3.1 Uncertainty factors:

(1) The expected sales volume of crops, including wheat and corn sales, are growing 5 to 10 percent a year and the expected sales of other crops fluctuate by plus or minus five percent from year to year.

(2) Yield per mu of crops, including climate and other factors lead to yield fluctuations of ± 10% per mu.

(3) Planting costs, including planting costs increase by an average of 5% each year.

(4) Selling prices, including the prices of grain crops, were stable and the prices of vegetable crops have increased by about 5 percent every year.

2.3.2 Construct objective functions (a model that takes into account uncertainty)

Our goal is to maximize the return and minimize the risk, taking into account the sales volume of crops in the next few years, planting cost, yield per mu, uncertainty of selling price, and planting risk. Then the objective function can be expressed as:

$$\begin{gathered} max \sum_{t=2024}^{2030} \sum_{i \in I} \sum_{j \in J} \left(\left(Y_j(t) \cdot P_j(t) - C_j(t)\right) \cdot x_{i,j}(t) - R_j(t) \cdot x_{i,j}(t)\right) \\ -100 \sum_{t=2024}^{2030} \sum_{i \in I} \sum_{j \in J} R_j(t) \cdot x_{i,j}(t) \end{gathered} \tag{8}$$

where $x_{i,j}(t)$ is represented the area where crop j was planted on plot i in year t, $R_j(t)$is the risk score of crop j in year t, used to measure risk.

3. Results

3.1 Optimal planting strategy when adding constraints

Case 1: More than part is unsalable, resulting in waste.

Case 2: The excess is sold at 50% off the sale price.

We use the mixed integer linear programming model to solve the problem of total production greater than sales. The annual total profits are shown in Figure 1 and Figure 2.

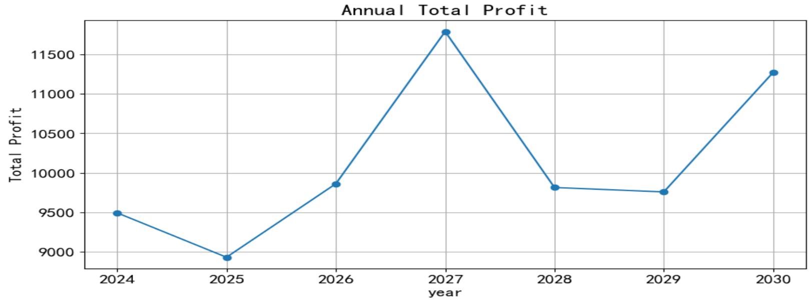

Figure 1: Case 1 Annual total profit

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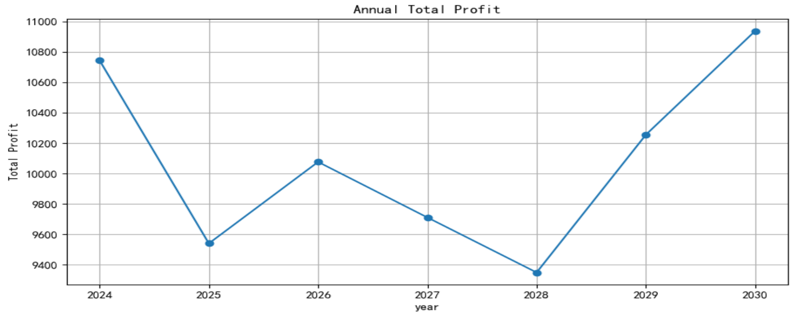

Figure 2: Case 2 Annual total profit

From the line chart, we can see that the annual return rate in case 2 is higher in most cases than in case 1, which makes sense: even if the sales volume is exceeded, some revenue can be obtained by selling at a reduced price, rather than completely wasting it. Therefore, when the total output is greater than the sales volume, we can give priority to the practice of selling at a discount. Although the cost may not be recovered, compared with the other method, we can still obtain a certain income, and we will do our best to help producers reduce their losses.

3.2 Optimal planting scheme under uncertain environment

From the planting area of the four groups of crops grouped in the next seven years, we can see that wheat in the first group has the best growth rate, but the fluctuation range is large, and it still has an advantage over other crops in this group. Obvious changes can be seen, so it is not conducive to analyzing the change trend of crops in this group, and then making predictions; In the second group, the growth of pumpkin, sweet potato, naked oats, and barley is very different from that of other crops in the group. In the third group, the planting area of Chinese cabbage tended to be stable; in the fourth group, the growth of spinach and roselle increased significantly compared with the beginning, and cabbage plummeted during the growth process. It can be inferred that cabbage was greatly influenced by the outside world, so we did not consider cabbage. The plot of planting area for the next seven years is shown in Figure 3. To sum up, we choose the dominant crop among the four groups of crops for planting. The fluctuation trend of other crops in Group 2, Group 3, and Group 4 tends to be stable, and there are still differences compared with the selected local crops. Therefore, we used the selected crops as the reference standard. The selection table of dominant species is shown in Table 2.

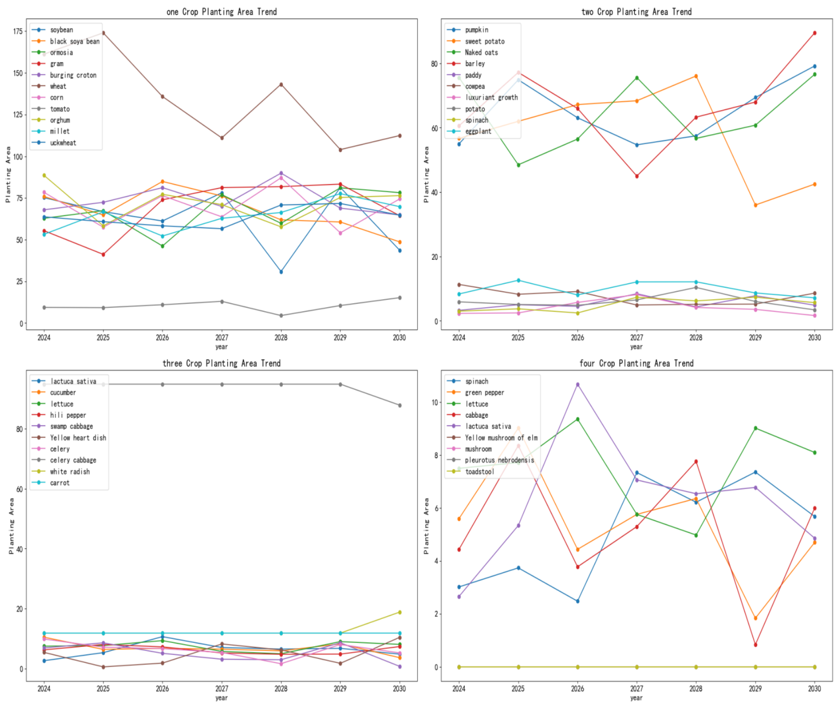

Figure 3: Annual planting area changes of four different crops

ISSN 2616-5910 Vol. 5, Issue 1: 145-149, DOI: 10.25236/AJALS.2024.050119

Table 2: The dominant species selected from the four groups of crops

Group	Dominant species
Group one	wheat
Group two	Pumpkin, Sweet potato, Naked oats,barley
Group three	white radish
Group four	Spinach, lactuca sativa

4. Conclusion

This paper solves the problem of profit maximization of crop cultivation in mountainous areas of North China, taking into account multiple key factors such as sales volume, yield per mu, planting cost, and selling price, and introduces uncertainty analysis to make the model closer to the complexity of actual agricultural production. The risk assessment mechanism is introduced, and the crop sales in the next few years are considered.

Trends in volume, planting costs, and selling prices enhance the robustness and adaptability of the model. At the same time, it includes the total area of land, the minimum planting area, the planting requirements of legume crops, the non-continuous cropping, and the irrigated land after rice planting cannot grow the second season crop. The objective function can be flexibly adjusted according to different situations (such as slow sales and discount sales) to adapt to different market needs and sales strategies. It is also possible to easily simulate the situation of different years by adjusting the parameters, to get a long-term planting strategy. Some assumptions in the model (such as the changing trend of sales volume, price fluctuations, etc.) are based on historical data and empirical estimates and may be biased from the actual situation. Although the model can provide long-term planting strategies, it is weak in immediate response to short-term emergencies (such as natural disasters, sudden changes in market prices, etc.). Dynamic adjustment of the model to adapt to new situations may require re-input of data and re-solving, increasing the difficulty of real-time decision-making.

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