Planting Optimization in the Northern China Based on 0-1 Programming

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Abstract. In order to comprehensively promote the development of agricultural modernization and ensure the sustainability of Rural Revitalization land in North China, this paper will propose a general mathematical model according to the realistic natural constraints of rural areas in mountainous areas of North China, in order to improve the total agricultural income. Through the establishment of 0-1 integer programming model and nonlinear model, the rural crop planting strategy in China from 2024 to 2030 was optimized. Finally, the overall profit of the model shows an upward trend, which is similar to the development trend of China's agricultural product market. The model can flexibly adapt to the changes of market and natural conditions, and has good scalability, which can provide help for the construction of agricultural power.

Keywords: Monte Carlo Algorithms, Planting Optimization Strategy, 0-1 Programming.

1. Introduction

Globally, the shortage of cultivated land resources has become a serious reality. With the continuous growth of population and the increasing demand for food, the area of cultivated land is decreasing due to urbanization, industrialization and the degradation of the natural environment [1]. This has triggered a series of global problems, such as rising food prices, increasing hunger and instability in the international community. This crisis is particularly acute in densely populated developing countries - limited arable land must support huge food demand, and the contradiction between ecological protection and agricultural production has become increasingly prominent. As the most populous country in the world, China has a particularly prominent scarcity of cultivated land resources [2]. Although China has a vast territory, the per capita area of cultivated land is far below the world average. Especially in some areas with severe natural conditions, food production is facing greater challenges [3]. The situation in the mountainous areas of North China is even more special [4]. This area covers the Taihang Mountains, Yans Mountains and other mountains, and most of the cultivated land is distributed in the valleys or hillsides between mountains. The area is small and scattered, so it is difficult to form large-scale mechanized farming, and the production efficiency is far lower than that of the plains [5]. The soil fertility in mountainous areas is limited, and the irrigation conditions are not perfect, which further limits the yield of grain.

We mainly discuss a village in the mountainous area of North China. The temperature in this area is low all year round, and most of the cultivated land can only grow one crop a year. The village has 1201 mu of open-air farmland, which is scattered into 34 plots of different sizes, including flat dry land, terrace, hillside and irrigated land. The flat dry land, terrace and hillside are suitable for planting one season of grain crops every year; Irrigated land is suitable for planting one season of rice or two crops of vegetables every year. There are also 16 ordinary greenhouses and 4 smart greenhouses in the village, each with a cultivated area of 0.6 mu. Ordinary greenhouse is suitable for planting one season of vegetables and one season of edible fungi every year, while smart greenhouse is suitable for planting two seasons of vegetables every year. Different crops can be planted in the same plot (including greenhouse) every season. According to the growth law of local crops, each crop cannot be continuously planted in the same plot, otherwise the yield will be reduced; Since the soil containing rhizobacteria of legumes is conducive to the growth of other crops, the local government requires that all land in each plot (including greenhouses) be planted with legumes at least once in three years from 2023.

In response to the call of national rural revitalization, we will put forward the following questions and establish a mathematical model to reasonably allocate the limited cultivated land resources in the village.

RQ1: Considering that the unsalable part is wasted, what is the optimal planting scheme for crops in the village from 2024 to 2030 ?

We first relied on the statistical data of 2023, considered the inherent characteristics of various land types (including flat dry land, terrace, hillside and irrigated land), and comprehensively evaluated the relationship between the planting costs of different crops and the expected benefits. Then, according to the multiple influencing factors in the problem stem, we introduced the key constraints such as non continuous cropping and bean crop rotation cycle, and established a 0-1 integer programming model. By minimizing the yield of unsold crops, we ensure that all the crops produced can accurately meet the market demand, avoid resource idleness and waste, and maximize economic benefits.

RQ2: Considering the uncertainty of expected sales volume, yield per mu, planting cost and sales price of various crops and potential planting risks, how should the village scientifically plan the crop planting structure from 2024 to 2030?

In order to deal with the decision complexity caused by uncertainty in agricultural production, it is necessary to transform static planning into dynamic adaptation mechanism [6]. RQ2 introduces uncertainty, which is a stochastic programming problem based on RQ1. In combination with government policies, market fluctuations and other influencing factors, we take the sales volume, yield per mu, planting cost and sales price of each agricultural product as indicators, and use Monte Carlo simulation method to calculate the average of 200 data for each of the four indicators of various agricultural products each year in the next seven years, so as to represent the long-term trend of the indicators and determine the specific data of the annual growth value of each indicator of various crops. Then sensitivity analysis was carried out to obtain the influence degree of each index on the results. Based on comprehensive consideration, the optimal planting scheme was proposed.

RQ3: Considering the substitutability and complementarity among crops, as well as the dynamic correlation of sales volume, price and cost, how to formulate a planting plan for a village from 2024 to 2030?

In agricultural production, there are not only mutual restrictions on resource utilization, but also the possibility of mutually beneficial symbiosis between different crops [7]. At the same time, factors such as market demand changes, planting technology updates and policy support will form a linkage effect. In this regard, we first classify crops according to nutrition, and then try to establish a nonlinear relationship model between price and cost [8]. After the objective function is successfully improved, the demand cross price elasticity is used to quantify the substitution and complementarity between products. Then, the relationship between price and sales volume is fitted and constraints are added. Finally, through the 0-1 planning optimization decision, the scheme profit is compared and the optimal scheme is selected [9]. In the future, it is essential to consider more three-dimensional optimization problems that account for the complex interactions among various agricultural factors, including environmental impacts and resource allocation efficiency [10, 11].

Our main contributions are as follows: (1) Accurately match the output and market demand through intelligent planning to reduce unsalable waste. (2) Simulate various possible situations in the future, formulate flexible adjustment schemes, and help villages cope with uncertain changes. (3) Design a planting plan considering the interaction between crops and the market linkage effect to enhance the long-term stability of agricultural production.

2. Methodology

In this section, the objective function is set as the total profit, the growth rate simulation value is obtained by Monte Carlo method, and the objective function is introduced to construct the nonlinear model between price and cost. The crops are classified by K-means clustering algorithm, and the complex relationship between crops is quantified by the elasticity of demand cross price among crops.

2.1. Objective Function

2.1.1. Profit Maximization Objective Function (RQ1)

The equation of the profit maximization is:

$$\sum_{j=1}^{16}\sum_{i=1}^{52}\sum_{t=1}^{7} x_{jit}\cdot S_i\cdot\left(P_{jit}\cdot Y_{jit}-C_{jit}\right)+\sum_{j=17}^{41}\sum_{i=53}^{108}\sum_{t=1}^{14} x_{jit}\cdot S_i\cdot\left(P_{jit}\cdot Y_{jit}-C_{jit}\right)-\sum_{j=1}^{41} P'_{jit}\,Q'_j$$

$$st\{Q'_j=\sum_{i=1}^{40} x_{jit}\cdot Y_{jit}\cdot S_i+\sum_{i=41}^{108} x_{jit}\cdot Y_{jit}\cdot S_i-T_{j(t-1)} \quad (1)$$

$$if\ Q'\geq 0,\ p'_{jit}=p_{jit}$$

$$else\ p'_{jit}=0$$

Where x_{jit} represents whether the j crop is planted on the i custom plot in the t year, S_i represents the area of the i custom plot, P_{jit} represents the sales price of the j crop on the i custom in the t year,Y_{jit} represents the per mu yield of the j crop on the i custom plot in the t year, C_{jit} represents the cost of the j crop on the i custom in the t year.

2.1.2. Profit Maximization Objective Function Considering Cost (RQ2)

Based on RQ1, we considered the growth rate of each variable and the government's policy of purchasing unsalable agricultural products at the lowest purchase price (about 95% of the market sales price), so we adjusted the objective function:

$$\sum_{j=1}^{16}\sum_{i=1}^{52}\sum_{t=1}^{7} x_{jit}\cdot S_i\cdot\left(P''_{jit}\cdot Y'_{jit}-C'_{jit}\right)+\sum_{j=17}^{41}\sum_{i=53}^{108}\sum_{t=1}^{14} x_{jit}\cdot S_i\cdot\left(P''_{jit}\cdot Y'_{jit}-C'_{jit}\right)-\sum_{j=1}^{41} P'_j\,Q'_j$$

$$st\{Q'=\sum_{i=1}^{40} x_{jit}\cdot Y'_{jit}\cdot S_i+\sum_{i=41}^{108} x_{jit}\cdot Y'_{jit}\cdot S_i-T'_{j(t-1)}$$

$$if\ Q'\geq 0,\ P''_i=(1-95\%)P_i \quad (2)$$

$$else\ P''_i=0$$

$$\begin{cases} T'_{j(t-1)}=T_{j(t-1)}\cdot(1+r_{jik}),k=1\\ Y'_{jit}=Y_{jit}\cdot(1+r_{jtk}),k=2\\ C'_{jit}=C_{jit}\cdot(1+r_{jtk}),k=3\\ P''_{jit}=P_{jit}\cdot(1+r_{jtk}),k=4 \end{cases}$$

Where r_{tjk} represents the growth rate of the j crop on the i custom in the t year.

2.1.3. Objective Function for RQ3

Through Pearson correlation coefficient analysis, we found the correlation between variables. The nonlinear model between price and cost is obtained by fitting the nonlinear relationship between variables:

$$P''_{jit}=-5044.715+936.973\cdot l\,n\left(C'_{jti}\right) \quad (3)$$

Considering the cross-price elasticity of demand for alternative and complementary crops, the objective function is finally modified as follows:

$$\sum_{j=1}^{16}\sum_{i=1}^{52}\sum_{t=1}^{7} x_{jit}\cdot S_i\cdot\left(P(C'_{iti})\cdot Y'_{jit}-C'_{jit}\right)+\sum_{j=17}^{41}\sum_{i=53}^{108}\sum_{t=1}^{14} x_{jit}\cdot S_i\cdot\left(P''_{jit}\cdot Y'_{jit}-C'_{jit}\right)-\sum_{j=1}^{41}P'_j\,Q'_j$$
$$if\cdot Q'\geq 0, P''_j=(1-95\%)P_j$$
$$else\cdot P''_j=0 \tag{4}$$
$$E_{j_1j_2}=\begin{cases}0.8174, Crop\cdot j_1\cdot and\cdot crop\cdot j_2\cdot are\cdot alternatives\\ -0.7688, Crop\cdot j_1\cdot and\cdot crop\cdot j_2\cdot are\cdot complementary\\ 0, Crop\cdot j_1\cdot and\cdot crop\cdot j_2\cdot are\cdot not\cdot alternatives\cdot or\cdot alternatives\end{cases}$$

2.2. Constraints

2.2.1. Constraints for RQ1

According to the data in the paper, the change range of each crop yield in the next year compared with the preset sales volume (i.e. the yield of the previous year) shall not exceed 5%.

$$Y=\sum_{i=1}^{108}S_i\,Y_{jit}X_{jit} \tag{5}$$

$$\left|\frac{\sum_{i=1}^{108}S_iY_{jit}X_{jit}-\sum_{i=1}^{108}S_iY_{jit(t-1)}X_{jit(t-1)}}{\sum_{i=1}^{108}S_iY_{jit(t-1)}X_{jit(t-1)}}\right|\leq 5\% \tag{6}$$

According to the law of crop production, each crop cannot be continuously planted in the same plot.

$$X_{jit}+X_{ji(t-1)}\leq 1 \tag{7}$$

In order to promote the yield of each crop, it is required to plant beans at least once in three years on each small plot [12].

$$X_{jk(t+1)}+X_{jit}+X_{ji(t-1)}\geq 1, i\in(1{,}108), j\in(1{,}5)\cup(17{,}19) \tag{8}$$

2.2.2. Constraints for RQ2

Considering the lag and conservatism of ordinary farmers' production decisions, it is assumed that farmers in the village will reserve 30% of the funds to deal with sudden disasters.

$$\sum_{j=1}^{16}\sum_{i=1}^{52}\sum_{t=1}^{7}x_{jit}\cdot S_i\cdot C'_{jit}+\sum_{j=17}^{41}\sum_{i=53}^{108}\sum_{i=1}^{14}x_{jit}\cdot S_i\cdot C'_{jit}\leq B_t\cdot 70\% \tag{9}$$

According to the literature, the yield reduction rate caused by continuous cropping is about 15% [13]. The first question about the constraints of continuous cropping reduction is added as follows:

$$y_{jit}=\begin{cases}y_{ji(t-1)} & , x_{jit}+x_{ji(t-1)}\leq 1\\ y_{ji(t-1)}(1-15\%) & , x_{jit}+x_{ji(t-1)}>1\end{cases} \tag{10}$$

3. Result analysis and discussion

3.1. Results for RQ1

According to the above 0-1 planning model, it can be inferred that the profit value will increase year by year with the increase of years. However, as shown in figure 1, due to the differences between the consideration of the farming strategy in RQ1 and the reality, the fluctuation of profit in the past 8 years tends to be stable, so it cannot fully reflect the real profit changes.

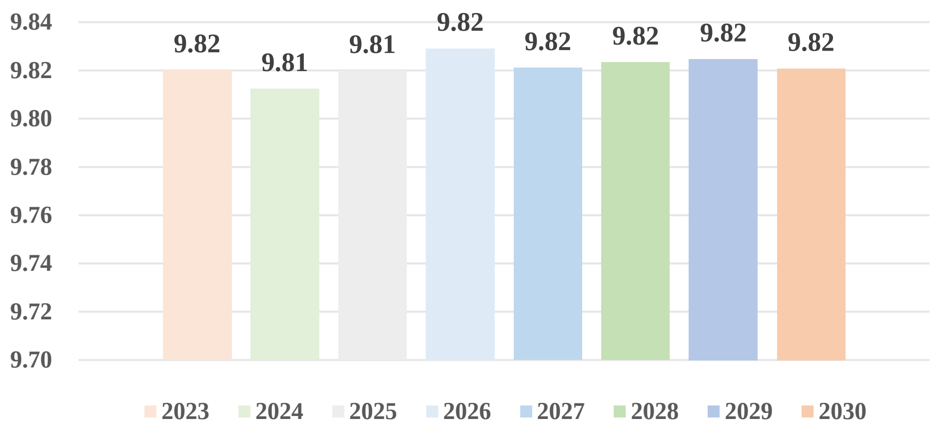

Figure 1. Total sales profit from 2023 to 2030 under RQ1

3.2. Results for RQ2

Based on RQ1, RQ2 added and predicted the data of variables such as yield per mu, planting cost, sales price and sales volume, and considered the national acquisition policy. As shown in figure 2, the total yield of each crop in 2027 under the planting strategy based on model 2. Cereal crops (corn, sweet potato, and wheat) have the largest yield, which is in line with the characteristics of large and stable market demand and provides a reliable guarantee for farmers' income increase.

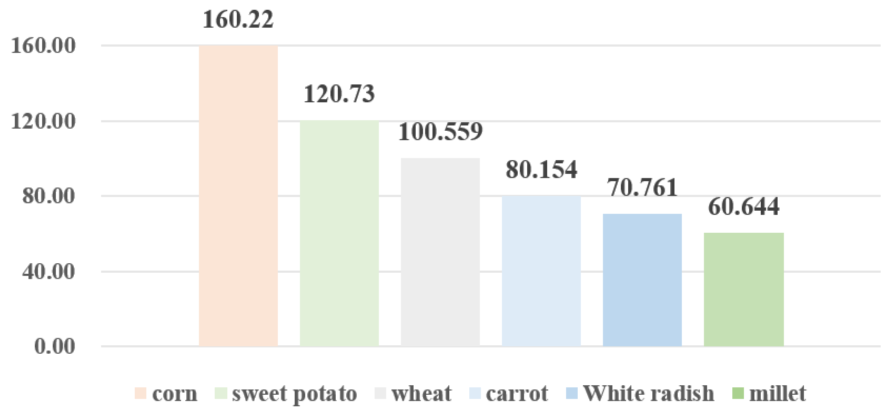

Figure 2. Total output of some crops under RQ2 constraint in 2027

3.3. Results for RQ3

Compared with RQ2, the model established in RQ3 provides a more flexible farming strategy. According to the model, as shown in figure 3, the overall profit shows an upward trend, which is similar to the development trend of China's agricultural product market and more in line with the actual situation.

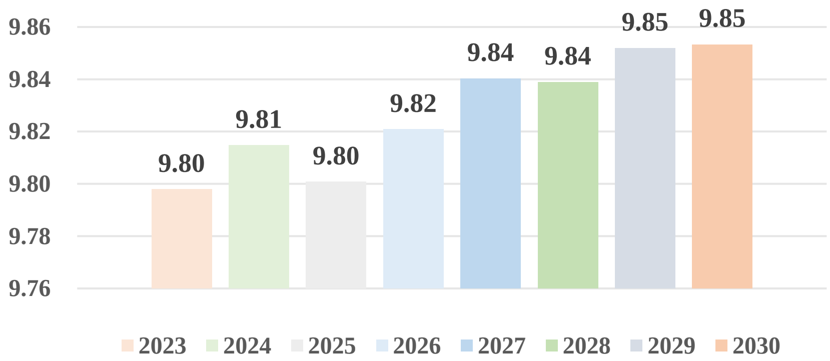

Figure 3. Total sales profit from 2023 to 2030 under RQ3

4. Conclusion

In this paper, a novel framework was proposed to optimize the crop planting strategy in the mountainous rural areas of North China, and clarify the crops planted per unit area in each time period, so as to improve the total agricultural income. This problem is solved by establishing a 0-1 integer programming model, using Monte Carlo simulation algorithm to deal with the uncertainty and randomness of variables, and using a nonlinear model to fit the relationship between variables.

Experiments show that the complex relationship between the quantitative variables (sales price, planting cost and sales volume) and crops in question 3 is more flexible to adapt to the market and is the best of the three schemes. This is obviously applicable to the planting planning in North China and its surrounding areas. In reality, it can also be used to clarify how to allocate limited funds and resources, such as which villages need to build new infrastructure, in order to realize the diversified development of rural economy. However, this method is based on the optimization results of fixed data sets. When using integer 0-1 programming, the number of variables is too large, and the adaptability to emergencies (such as natural disasters, sudden changes in market demand) is poor, so the model needs to be adjusted frequently. Future work should focus on simplifying the constraints of the optimization model to enhance the interpretability and applicability of this framework.

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