Crop Planting Optimization Decision-Making Based on Goal

Yifen Zhou #, Yunqi Li #, Yutong Xiao *, #

School of basic medical sciences, Tianjin Medical University, Tianjin, China, 300041

* Corresponding Author Email: xyt34809@gmail.com

#These authors contributed equally.

Abstract. To scientifically plan the high-standard farmland construction plan, fully promote the implementation of the high-standard farmland construction task and formulate a scientific and reasonable planting strategy for a village in a mountainous area of North China. This article comprehensively consider the expected sales volume, yield per mu, planting cost and selling price, and planting risk, and combined with the allocation of land resources and the crop planting situation of six villages to obtain the optimal planting plan for rural crops from 2024 to 2030. At the same time, we obtain the substitutability and complementarity between crops according to the planting conditions of crops and adjust the planting strategy. This article also introduced climate risk factors to assess the impact of climate on crop cultivation in northern China. The solution proposed in this article is not only better applicable to the polymorphic planting planning in North China based on predecessors but also innovatively introduces a planting plan that is selected according to crop relevance. This program can not only reduce the range of crop types and the pressure on field management; It also helps create rural specialties, turn crops into rural characteristic resources, and realize product advantages. This has a positive reference for constructing rural areas with Chinese characteristics.

Keywords: Multidimensional Linear Programming, Multivariate Mixed Integer Programming, Monte Carlo Algorithm, Spearman's Rank Correlation Coefficient Model.

1. Introduction

The price fluctuation in agricultural markets is an obstacle to the well-being of small-scale farmers in developing countries. Most farmers rationally predict near-future prices as a basis for making planting decisions, and some farmers only react shortsightedly to the most recent crop prices. The latter behavior may lead to overproduction or underproduction, hindering the village's progress toward moderate prosperity. Ming Hu, Yan Liu, and Wenbin Wang [1] elaborated on the importance of cultivating strategic farmers and pointed out the plan for unified strategic planning of land at the village level. Minoli S, Jägermeyr J, Asseng S, et al. [2] showed that adjusting growing periods to climate changes could significantly enhance global crop yields while mitigating negative climate impacts. Zhang, X and Lin, W [3] examines the role of high-standard farmland in enhancing agricultural productivity and food security in China, stressing its importance in meeting future food demands while addressing environmental challenges. Saiara Samira Sajid and Guiping Hu [4] innovatively designed a planning model that manages crop planting, harvesting, and storage, ensuring an optimal planting schedule is designed. Subdivide the Annual Planting Planning Strategy into Planting Planning Per Time Window. J Bailey-Serres, J., Parker, J.E., Ainsworth, E.A. et al. [5] forecast national production losses for maize, rice, wheat, and soybeans around the world. China's main food crops are rice, wheat, and corn. In other words, the problem of land fertility is imminent. Yu T, Mahe L, Li Y, et al. [6] proposed the development of crop rotation techniques according to local conditions and the rational evaluation and policy adjustment of crop rotation practices. This provides the basis for developing a rotation strategy. Richard B, Qi A, Fitt B D L. [7] emphasized the importance of Integrated Crop Management in delivering climate-smart farming systems, balancing low- and high-input production to enhance disease control and sustainability. Wang Z, Yin Y, Wang Y, et al. [8] demonstrated that integrating crop redistribution with improved management can meet China’s food demand while reducing environmental impacts.

Therefore, developing an effective crop rotation strategy should prioritize the improvement of soil fertility as a key component of a sound strategic plan.

Most studies do not consider the impact of cover crops on land resources when allocating land planting resources. Yuvaraj M, Pandiyan M, Gayathri P. [9] experimentally demonstrated that legumes make positive contributions to soil natural carbon storage, soil tilting, soil fertility, and general soil existence. Zheng Juan, Li Fei, Cao Rui, et al. [10] have shown that soil fertility can be greatly improved when fertilized under the condition of planting legume crops. Therefore, we have innovatively developed a strategy of rotating legume crops once every three years to maximize soil fertility. Hayer F, Bonnin E, Carrouée B, et al. [11] use the life cycle of crop portfolios to assess sustainable crop rotations using a six-year legume crop cycle. Scott D A, Eberle C, Gesch R W, et al. [12] highlighted the multiple benefits of diversifying crop rotations with specialty oilseeds, including enhanced yields, nitrogen efficiency, and water use optimization. Kebede E [13] explores the significant role legumes play in enhancing soil fertility through biological nitrogen fixation. This process can reduce the need for synthetic fertilizers, thus improving sustainability and reducing environmental impacts. Combined with the national conditions of China's populous country, we finally chose a three-year cycle to arrange the rotation of bean crops.[14]

Due to its unique geographical location, North China has a special climate that affects crop cultivation. Wang Qianqian, Qian Yongfu, Sun Yan, et al. [15] analyzed the characteristics of temperature and precipitation in North China in the past 50 years. Based on the analysis results, we added regional climatic factors to the planting strategy planning model and obtained that the planting planning model with the characteristics of North China was more suitable than other models. At the same time, we combined the research on the damage of crops under extreme weather in the Qin Dahe [16] team and the risk assessment model established by Zhao Sijian, Zhang Qiao, Wang Ke [17] for the risk assessment of agricultural production, and the valuation range of floating crops, such as yield per mu was narrowed. Rezaei E E, Webber H, Asseng S, et al. proposed a solution that adverse climate effects on crops can be offset or reversed by CO_2 fertilization and adaptation options at high latitudes [18], which provides a reference for the subsequent implementation of climate-related crop growth assistance measures.

Finally, we innovatively analyze correlations based on the sales volume and price of different crops to obtain substitutability and complementarity between crops. At the same time, the correlation analysis between expected sales volume, sales price, and planting cost was established, and on this basis, complementary and alternative crops were screened and adjusted to obtain a scientific planting strategy that maximizes benefits. In addition, the screening strategy can add economic value to the crop by ensuring that the crops grown in the countryside are "other products that are more popular in the market in terms of location, time and characteristics" [19]. Enables farmers to align with consumer preferences for agricultural products or foods with form, space, time, identity, and quality characteristics that are not present in traditional raw agricultural products. It is conducive to creating a more suitable market and characteristic rural planting industry [20].

2. Modeling

2.1. The planting model

According to the crop planting situation and land resources, the six types of land A, B, C, D, E, and F are divided into the ABC category, DE1F category, and E2 category. The numbers represent the double cropping sequence.

The planting model is a model that is used to develop a planting plan considering all constraints and influencing factors. The purpose of the cultivation model is to predict the planting scenario for the next few years based on the known yields and sales of the past few years to maximize production and sales.

Consider constraints first.

Constraint 1:The planting area of each plot cannot exceed the total area, and the area of each crop cannot be less than 0.3 acres.

$$\sum_{\substack{i=1 \\ j=1}} x_{m_i n_j z} \leq y_{n_j}, i \leq 15, j \leq 26\,, \tag{1}$$

where m_i represents the first i th crops of the ABC class, $n_j$means the j th plot (the ABC class plots are recorded in order as one of the largest categories of plots), and z means the year(2024-2030 is represented by 1-6), $x_{m_i n_j z}$ represents the planting area of the i th crop in the j th plot in the z th year, y_{n_j} represents the area of the j th plot.

Constraint 2: Avoid heavy cropping (the same crop cannot be planted continuously on the same plot)

$$\begin{cases} m_{n_j(z-1)} \neq m_{n_j z} \\ m_{n_j z} \neq m_{n_j(z+1)} \end{cases}, \tag{2}$$

where $m_{n_j z}$ indicates the type of crop in the j th plot in the z th year.

Constraint 3: Grow legume crops at least once in three years per plot.

$$m^*_{n_j(z+3)} = \begin{cases} m_{n_j(z+2)} \\ m_{n_j(z+1)} \\ m_{n_j z} \end{cases}, \tag{3}$$

where m^*denotes the set of all legume crops, $m^*_{n_j(z+3)}$ indicates that the crop species in plot j of the $z+3$ th year is legumes.

Constraint 4, if the yield of a crop is higher than the expected sales, the excess is treated at half price.

$$\omega_{m_{i,z+1}} = \omega_{m_{i,z}} * (1 + 0.05), \tag{4}$$

Next, consider the constraints of the influencing factors.

Influencing factor 1, expected sales volume. The expected sales volume of wheat and corn in the future has an increasing trend, with an average annual growth rate of between 5%~10%, and the expected annual sales volume of other crops in the future will change by about ±5% compared to 2023.

Influencing factor 2, planting cost. The cost of growing crops is increasing by about 5% per year on average.

Influencing factor 3, yield per mu. The impact of this climate change on agricultural production in North China was assessed based on the Agroecological Zone Model (AEZ) developed and improved by the International Institute for Applied Systems Analysis (IIASA).The AEZ method matches the environmental requirements of each crop and land use type with the environmental characteristics contained in the land resource database according to the land use type, land resource database and potential crop yield, and matches the environmental requirements of each crop and land use type according to the land unit and grid, and calculates the lower limit of the high probability floating range of mu yield to -3.0%.That is, the floating concentration range is [-3.0%, 1.3%], and the probability of yield per mu being in this range is 89.1%. In subsequent calculations, calculations will be made based on this range to reduce the error.

Influencing factor 4, sales price. The average annual increase in the price of vegetables is about 5%, and the price of edible mushrooms can drop by about 1%~5% per year, of which the price of morels decreases by 5% per year.

2.2. The establishment of Spearman rank correlation coefficient model

First, we hypothesize that the data on crop planting and the expected sales volume, planting cost, and sales price do not conform to a normal distribution. Therefore, the Spearman rank correlation coefficient model was established.

The formula for solving the Spearman rank correlation coefficient is (5):

$$r = 1 - \frac{6\sum d_i^2}{N(N^2 - 1)} \tag{5}$$

The calculated Spearman correlation coefficient r is tested to see if it is significantly different from 0. Formulate the null hypothesis $H_0: r = 0$ and the alternative hypothesis $H_1: r \neq 0$.

Construct the statistic to calculate the p-value using the formula (6):

$$r\sqrt{n-1} \sim N(0,1) \tag{6}$$

A two-sided test was performed for the p-value.

3. Results

3.1. Estimation of the results of the implant model

The large data prediction model for the user's electricity consumption is implemented in the Clementine software.

According to the report of the Chinese Meteorological Society, the trend of temperature and precipitation in North China has shown periodic changes in the past 50 years, with a period of 5-6 years. Using the data of the World Weather Information Service, the average temperature and precipitation values over 15 years were fitted trigonometric functions, and the results are as Figure 1.

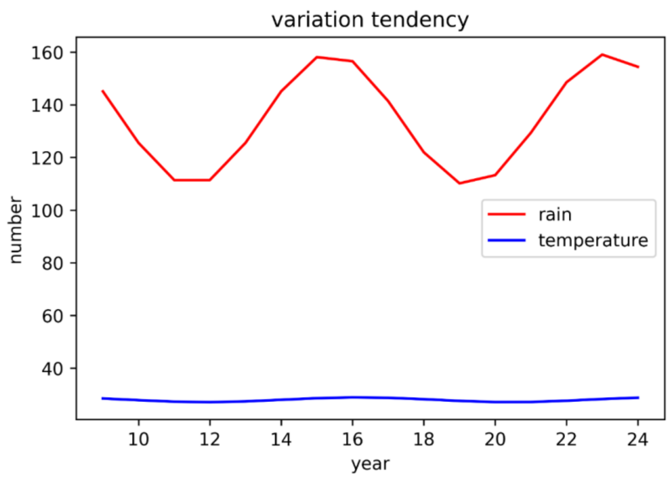

Figure.1. Prediction of Climate Change in North China over the Past 15 Years

With a five-year cycle, the PuLP library of Python is used to construct and solve the linear objective function and constraints, and the optimal decision and maximum benefit are obtained based on the Monte Carlo algorithm by considering the influencing factors.

According to the establishment of the multi-dimensional multivariate mixed integer programming model, and based on the Monte Carlo algorithm, the optimal decision and maximum benefit are obtained, and the profit distribution under the "worst conditions" is obtained by iterating the normalized data for 1000 runs, as shown in Figure 2:

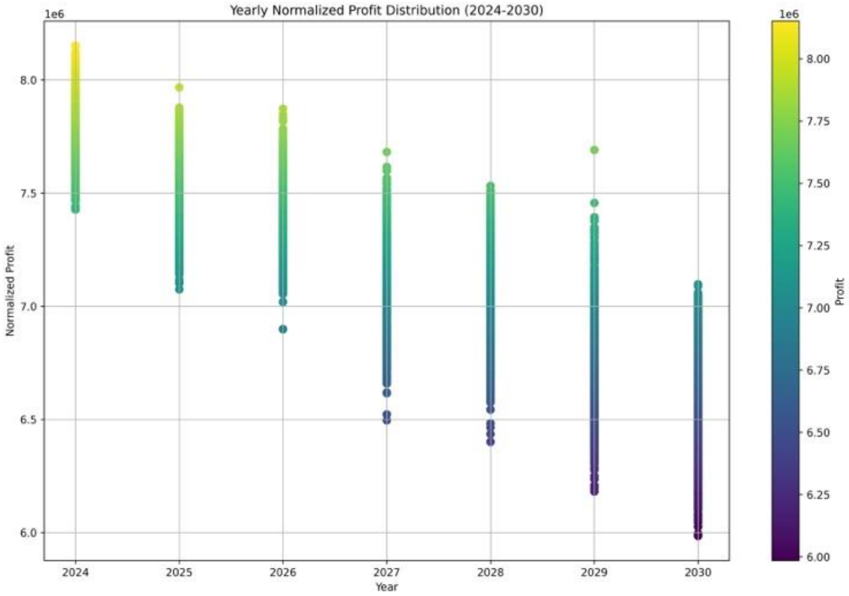

Figure.2. Profit distribution chart after 1000 iterations

Obtain the optimal crop planting strategy for 2024-2030 and calculate the net profit. The profit calculated from 2024 to 2030 under this scenario is as shown in Table 1:

Table.1. The profit calculated under this scenario

Years	Profit (RMB)
2024	7116413
2025	6677299
2026	6959539
2027	6579863
2028	6472285
2029	6189571
2030	5958922

The result satisfies all constraints and considers the worst-case scenario of all influencing factors, so the resulting profit should be the minimum profit, and the actual profit from planting according to this scheme should be greater than or equal to the predicted profit in the table. Through the survey of farmers in North China, the predicted profit is in line with the minimum value of actual profit and meets their livelihood needs, indicating that the predicted value is of practical significance and the planting plan is feasible.

3.2. Solving and testing of Spearman's rank correlation coefficient

Firstly, the normality test of the data is carried out to obtain the W value and significance p-value, and the W value and significance p-value are obtained as shown in Table 2 and Table 3:

Table.2. The W value and P-value of crops

Crops	W-value	p-value	Crops	W-value	p-value
Black beans	0.6902	0.0029	kidney bean	0.64619	0.0009
Grain cowpea	0.4530	4.13e-06	Potato	0.82388	0.0700
Sorghum	0.7050	0.0042	Oily lettuce	0.92646	0.5212
Millet	0.8676	0.1768	Cucumber	0.61769	0.0004
Buckwheat	0.6644	1.0015	Water spinach	0.6004	0.0003
Sweet potato	0.8058	0.0468	Chinese cabbage	0.66444	0.0015
Rice	0.8573	0.1432	White radish	0.70497	0.0042
Sword bean	0.6004	0.0003	Carrot	0.45297	4.13e-06
Elm mushroom	Values are identical				

Table.3. The W value and P-value

	Expected sales volume	Planting cost	Sales price
W-value	0.8022	0.7284	0.3564
P-value	1.11e-10	8.89e-13	<2.2e-16

Conclusion: All data do not conform to a normal distribution. The Spearman rank correlation coefficient model was selected to solve the correlation. To support the hypothesis, the Spearman rank correlation coefficient model was chosen.

The correlation coefficient between crops was calculated and the heat map was plotted as Figure 3.

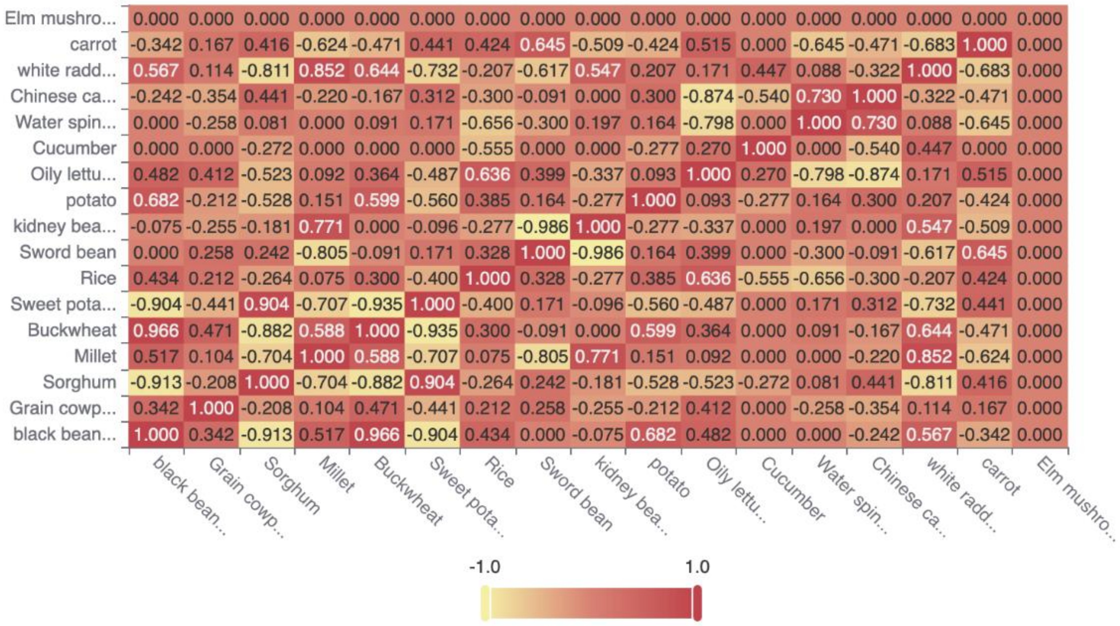

Figure 3. The heat map of the correlation coefficient between crops

The calculated P values are tested by the significance level of 5% and 1%, respectively, and the null hypothesis is denied, and the obtained Spearman correlation coefficient is significantly different from 0.

When the correlation coefficient is greater than 0.6 and less than 0.8, it is a strong correlation. When the correlation coefficient is greater than 0.8, it is extremely correlated. It is believed that there is a positive and strong correlation between the two crops, that is, the two crops are complementary, that is, the fluctuation of the sales volume of one crop can cause the sales volume of the other crop to fluctuate in the same direction. It is believed that there is a negative strong correlation between the two crops, that is, there is substitutability between the two crops, that is, the fluctuation of the sales volume of one crop can cause the sales volume of the other crop to fluctuate inversely.

Therefore, according to the Figure 3, the complementary and substitutable crop pairs are shown in the Table 4:

Table.4. The complementary and substitutable crop pairs (Mark* is strongly correlated)

Complementary		Substitutable	
Carrot	Sword beans	Carrot	Water spinach
White radish	*Millet	Carrot	White radish
White radish	Buckwheat	White radish	Sweet potato
Chinese cabbage	Water spinach	White radish	Sword bean
Oily lettuce	Rice	White radish	*Sorghum
Potato	Black bean	Oily lettuce	Water spinach
Kidney bean	Millet	Oily lettuce	*Chinese cabbage
Buckwheat	*Black beans	Buckwheat	*Black beans
Rice	Oily lettuce	Rice	Oily lettuce
Sweet potato	*Sorghum	Sweet potato	*Sorghum
		Rice	Water spinach
		Sweet potato	*Buckwheat
		Buckwheat	*Sorghum
		Millet	*Sorghum
		Sorghum	*Black bean
		Kidney beans	*Sword bean
		Sword bean	*Millet

To maximize the rural crop economy, we select crops with high economic efficiency in alternative crops. For highly complementary crops, it is planned to arrange sowing and sales at the same time in the future, and for highly substitutable crops of the same category, it is planned to arrange staggered peak sales at the same time in the future.

The correlation coefficients of the Spearman order between the expected sales volume and the selling price and planting cost are shown in Table 5:

Table.5. Spearman rank correlation coefficient

Rank correlation coefficient	Sales price	Planting costs
Expected sales volume	-0.159677	0.8335054

For the calculated Spearman correlation coefficient test, the null hypothesis is denied by the 5% and 1% significance level tests, and the obtained Spearman correlation coefficient is significantly different from 0.

It is concluded that the correlation between the expected sales volume and the sales price is weak, and the correlation with the planting cost is strong. There is a strong positive correlation between expected sales volume and planting costs.

4. Conclusions

Compared to the previous optimal planting scheme planning model, we introduce climate constraints for crop planting, use Monte Carlo's Algorithm to randomize the values, use multivariate hybrid linear programming, and use the PuLP library in Python to construct and solve a linear objective function with multiple constraints. At the same time, we innovatively consider the correlation between crops. A strong correlation between expected sales volume and planting costs is used as a basis for screening and adjusting planting strategies for complementary and alternative crops. Our profit-oriented screening strategy can undoubtedly be more profitable in linear programming solutions. The program not only increased the income of rural areas and provided strong support for the realization of a well-off rural area in an all-around way but also laid a solid foundation for the construction of villages with characteristic products and crop industrialization. At the same time, reducing the types of crops planted in rural areas and increasing the planting area of single crops are conducive to promoting the formation of the upstream and downstream of the planting industry and promoting the scale, diversification, and systematization of the industry. In addition, the analysis of the unique climate of North China also provides a reference for the risk assessment of agricultural cultivation in North China.

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