Research on Crop Planting Strategies Based on Market Factors

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Abstract. This study seeks to investigate optimal agricultural planting strategies in northern China by refining the planting structure to enhance profitability and mitigate the effects of natural risks on crop production. The primary objective is to attain the judicious distribution of agricultural resources and optimize economic gains. This study develops a crop cultivation strategy model with multi-objective linear programming. To improve planting profitability, it thoroughly examines the substitutability and complementarity across crops and utilizes multiple linear regression to refine model constraints, thus alleviating the negative impacts of natural risks on crop yields. The findings indicate that the refined planting strategy enhances annual revenues by 60.93% relative to the pre-optimization condition. Furthermore, the annual profit trajectory under the optimized plan remains remarkably aligned with the original strategy, affirming the model's efficacy and dependability. This paper presents a novel method for optimizing crop planting methods by merging multiple linear regression with multi-objective linear programming, hence improving the model's relevance in practical agricultural decision-making.

Keywords: Multi-Objective Linear Programming, Multiple Linear Regression, Crop Planting Strategies.

1. Introduction

The effective implementation of the rural revitalisation policy has pointed out a clear course for the sustainable development of agriculture. The policy not only maintains the key position of rural development in the overall development of the country, but also emphasises the importance of harmonious cohabitation between human beings and nature [1]. In view of the existing situation in the countryside, the rational use of limited arable land resources, the development of organic planting industry in accordance with local requirements, for the promotion of sustainable growth of the rural economy has enormous practical value. Taking North China as an example, the region belongs to the usual temperate monsoon climate zone, which is marked by rain and heat at the same time. This climatic condition determines that most regions are suitable for cultivating crops for only one season per year. At the same time, the arable land resources in North China are complicated and diverse, largely separated into four types: flat dry land, terraced land, hillside land and watered land, and the plots are spread [2]. Therefore, selecting appropriate crop kinds and optimising planting tactics not only simplify field management, but also enhances productivity and decreases planting risks caused by uncertainty.

Currently, research have concentrated on the effects of different types of land on crop yields [3], and have comprehensively studied the significance of crop rotation systems in boosting agricultural yields [4]. In order to achieve the goals of improved economic benefits, increased food production and water conservation, researchers have established a multi-objective optimisation model of agricultural planting structure and proposed specific strategies for planting structure adjustment with the help of quantitative analysis [5]. However, the research on crop planting strategies for North China still faces some restrictions. In agricultural production practice, potential planting risks have a substantial impact on crop yield and quality. Extreme weather occurrences, such as floods, droughts, typhoons, and insect pests, may lead to crop output decline or even crop extinction, which delivers substantial costs to agricultural production [6]. Taking the example of the abnormally heavy rainfall in Henan in July 2021, the event caused the province's crops to be harmed over an area of 13.07 million mu, with main crops such as corn, peanuts, soybeans, and rice being particularly seriously affected. This experience illustrates that the influence of potential risks on crop yields should be properly considered when establishing agricultural planting methods.

In view of this, this paper takes improving the total profit after crop planting as the research objective, and firstly constructs a multi-objective linear programming model to quantitatively analyse the optimal planting scheme of crops in a certain area in North China between 2024 and 2030. Then, this paper introduces the potential risk factor β, which aims to quantify the specific impact of natural risk on crop yield. In order to reduce the potential impact of natural risk on crop yield, considering the correlation between the expected sales volume, sales price and planting cost, this paper adopts the multiple linear regression method to optimise the constraints of the model, so as to propose a more profitable crop planting strategy, which will provide a certain reference for the future arable land utilisation planning in North China.

2. Algorithm Principle

2.1. Multi-objective Linear Programming

Multi-objective linear programming is a mathematical optimization method that, through many conflicting goal functions and linear constraints, identifies a set of Pareto optimal solutions. This technique seeks to achieve a balance between several objectives, ultimately achieving a comprehensive optimal choice outcome [7].This study uses multi-objective linear programming to obtain the optimal strategy for crop cultivation.

2.2. Multiple Linear Regression

Multiple linear regression is a predictive analysis method in statistics, used to analyze the linear connection between a continuous dependent variable and two or more independent variables [8]. It estimates the model parameters by minimizing the sum of squared errors, hence forecasting the value of the dependent variable.This study employed multi-objective linear regression to develop several linear regression equations for planting expenses and acreage production versus selling price.

3. Crop Planting Strategy Model

3.1. Objective Function

In agricultural production, potential planting risks such as floods, droughts, typhoons, and pests significantly effect crop yield and quality. To accurately assess and address these risks, the data used in this study were obtained from [https://www.mcm.edu.cn/index_cn.html] and historical data and expert analysis [9] were utilized to determine the risk coefficients β for different land plots and potential risks. These coefficients show the extent to which agricultural yield [10] may be influenced under particular risks. The risk coefficients β for different possible dangers on various plots are provided in Table 1.

Table.1. Risk Coefficients β for Different Potential Risks on Various Plots

	Dry flat land	Terraced fields	Slope land	Irrigated land	Standard greenhouse	Smart greenhouse
Drought	0.1	0.15	0.15	0.2	0	0
Flooding	0.2	0.2	0.2	0	0	0
Typhoon	0.3	0.3	0.3	0.3	0.2	0.2
Pest damage	0.3	0.3	0.3	0.3	0.2	0.2

The potential risk factor β is used to adjust the yield per acre, representing the actual yield when a risk occurs. The influencing formula is as follows:

$$Y'_{itj} = Y_{itj} \cdot (1 - \beta) \tag{1}$$

Where Y'_{itj} represents the actual yield per acre considering potential risks, and Y_{itj} represents the yield per acre under normal conditions.

From Table 1 and the formula, it can be shown that both normal greenhouses and smart greenhouses experience a lesser drop in yield when encountering potential dangers, showing that greenhouse farming has a particular advantage in avoiding natural disasters. Therefore, in creating the optimal planting strategy, this article analyzes increasing investment in greenhouse plots to boost their profitability, thereby improving the overall agricultural system's risk resistance. Based on this, the following multi-objective linear programming model is established.

$$\max 0.23\cdot W_1 + 0.23\cdot W_2 + 0.27\cdot W_3 + 0.27\cdot W_4 \tag{2}$$

$$\begin{cases} \max W_1 = \sum_i \sum_j \left(S_{ij}\cdot p_{ij}\right) - \sum_i \sum_t \sum_j \left(X_{yit_1j}\cdot C_{it_1j}\right) \\ \max W_2 = \sum_i \sum_j \left(S_{ij}\cdot p_{ij}\right) - \sum_i \sum_t \sum_j \left(X_{yit_2j}\cdot C_{it_2j}\right) \\ \max W_3 = \sum_i \sum_j \left(S_{ij}\cdot p_{ij}\right) - \sum_i \sum_t \sum_j \left(X_{yit_3j}\cdot C_{it_3j}\right) \\ \max W_4 = \sum_i \sum_j \left(S_{ij}\cdot p_{ij}\right) - \sum_i \sum_t \sum_j \left(X_{yit_4j}\cdot C_{it_4j}\right) \end{cases} \tag{3}$$

Where t_1 represents the plots for single-season planting (dry flat land, terraced fields, and hillside land), t_2 represents irrigated land, t_3 represents standard greenhouses, t_4 represents smart greenhouses, S_{ij} represents the predicted sales volume, p_{ij} represents the selling price, X_{yitj} represents the planting area of the crops, and C_{itj} represents the planting cost of the crops.

3.2. Constraints

In agricultural production decision-making, uncertainty in the market and natural conditions [11] has a considerable impact on crop planting plans. In order to improve the accuracy of prediction and formulate a more comprehensive planting plan, this paper introduces a random variable factor α to simulate the uncertainty of expected crop sales, mu yield, planting cost and sales price caused by market fluctuations and changes in natural conditions, and in this way, ensures that the model can more realistically reflect the actual agricultural production environment. The restrictions of the model are as follows.

(1) Crop Rotation Plot Constraints

In order to maintain soil fertility and avoid pests and diseases, the same crop cannot be planted continuously in the same plot [12] . This paper defines binary variables F_{yitj} that indicate whether crop type *i* was planted in the *j-th* season of plot *t* in year *y*.

$$F_{yitj} + F_{(y+1)itj} \le 1 \tag{4}$$

$$F_{yitj_1} + F_{yitj_2} \le 1, \quad j \in (1,2) \tag{5}$$

(2) Legume Crop Planting Constraints

Since the rhizobacteria of legumes promote soil structure [13], each plot was planted with legumes at least once every three years. Analysing the data, it is clear that flat dry land, terraced land, hillside land must be planted with a particular category of legume crop at least once in any consecutive three years, and irrigated land, ordinary greenhouses and smart greenhouses must be planted with other categories of legume crop at least once in any consecutive three years and involving different seasons. Based on the above requirements, define a binary variable H_{yitj} to represent whether legume crop *i* is planted in plot *t* during the *j-th* quarter of year *y*.

$$\sum_{i \in beans\_c}\left(H_{yitj}+H_{(y+1)itj}+H_{(y+2)itj}\right) \geq 1, \quad \forall t \in A, B, C \tag{6}$$

$$\sum_{i \in beans\_v} \sum_{j=0,1}\left(H_{yitj}+H_{(y+1)itj}+H_{(y+2)itj}\right) \geq 1, \quad \forall t \in D, E, F \tag{7}$$

Among them, A, B, and C represent flat dry land, terraced land, and hillside land, respectively, and D, E, and F represent water-consumed land, ordinary greenhouses, and smart greenhouses, respectively.

(3) Field Management Constraints

In order to facilitate farming operations and field management, the planting of crops is not easy to be too dispersed, and the planting area can not be too small, at the same time, due to a variety of plants easily caused by mixed planting for the water supply of fertilisers for the different types of yield reduction, therefore, the provisions of each kind of plot of land planting a maximum of two kinds of crops, and each kind of crop covers an area of half.

$$\sum_{j} B_{yitj} \leq 2 \tag{8}$$

Where B_{yitj} represents the number of plots where crop *i* is planted in plot *t* during the *j-th* quarter of year *y*.

(4) Crop Yield Constraints

In order to secure supply, crops must be grown to meet projected sales.

$$\sum_{t}\left(X_{yitj} \cdot Y_{itj}\right) \geq S_{ij} \tag{9}$$

(5) Planting Plot Area Constraints

The total area of all crops grown on each plot shall be less than the area of the plot.

$$\sum_{i} X_{yitj} \leq plot_t \tag{10}$$

Where $plot_t$ represents the area of plot *t*.

(6)Expected Sales Volume Constraints

Based on historical data and market trend assessments, this study sees that the predicted sales of wheat and maize indicate an increasing trend, whereas the sales of other crops fluctuate within a particular range.

$$\sum_{j} S_{(y+1)ij}=\sum_{j} S_{yij} \cdot(1+\alpha), \quad i=6,7 \quad \alpha \in[0.05,0.1] \tag{11}$$

$$\sum_{j} S_{(y+1)ij}=\sum_{j} S_{yij} \cdot(1+\alpha), \quad i \neq 6,7 \quad \alpha=-0.05,0.05 \tag{12}$$

(7) Acreage Constraints

Crop yield per acre is affected by a variety of factors such as climate, soil conditions, pests and diseases [14], which are often uncertain, resulting in a $\pm 10\%$ variation in yield per acre from year to year.

$$Y_{(y+1)itj}=Y_{yitj} \cdot(1+\alpha), \quad \alpha=-0.1,0.1 \tag{13}$$

(8) Planting Cost Constraints

Planting costs include seeds, fertilisers, irrigation, labour, etc., which are susceptible to market conditions and grow on average by roughly 5 per cent per year.

$$C_{(y+1)itj}=C_{yitj} \cdot(1+\alpha), \quad \alpha=0.05 \tag{14}$$

(9) Sales Price Constraints

The sales price is affected by a variety of factors such as market demand, average market price, governmental regulation and control [15], and also has uncertainties Among them, food crops are the basic necessities of life, the demand is relatively fixed, and the sales price is stable; the sales price of vegetable crops is affected by seasonal factors and changes in market supply and demand, and according to the analysis of market trends, the sales price of vegetable crops shows a year-on-year growth trend, with an average growth rate of about 5%; the sales price of edible fungi is affected by the market supply and consumer preferences, and overall shows a The sales price of edible fungi, affected by market availability and consumer demand, exhibited an overall pattern of steady fall, with an approximate annual decline of 1 to 5 per cent.

$$p_{(y+1)ij} = p_{yitj} \cdot (1+\alpha), \quad i \in [17,37] \quad \alpha = 0.05 \tag{15}$$

$$p_{(y+1)ij} = p_{yitj} \cdot (1+\alpha), \quad i \in [38,40] \quad \alpha \in [-0.05,-0.01] \tag{16}$$

$$p_{(y+1)ij} = p_{yitj} \cdot (1+\alpha), \quad i = 41 \quad \alpha = 0.05 \tag{17}$$

3.3. Improved Constraint Conditions

It was calculated that after introducing the risk factor β, the profit was lowered compared to the previous one. For this reason, this paper chooses sales price as the dependent variable, and expected sales volume (replaced by mu yield) and planting cost as independent variables, and establishes a multiple linear regression model to determine the quantitative relationship between these variables, and then predicts the sales price under different conditions of planting cost and mu yield, so as to reduce the impact of the risk factor β while increasing profits.

This paper uses SPSS for multiple linear regression analysis, and the regression coefficients are shown in Table 2.

Table.2. Regression Coefficients from Multiple Linear Regression Analysis

Model	Unstandardized Coefficient	Standardized Coefficient	Significance
Constant	5.364	-	.000
Planting Cost	.005	.727	.000
Yield per Acre	-.002	-.538	.000

From the above table, it can be concluded that cost of cultivation and acreage have significant effect on selling price. Increase in cost of cultivation increases the selling price while increase in acre yield leads to decrease in selling price. Thus, the following equation is obtained:

$$p_{itj} = 0.005 \cdot C_{itj} - 0.002 \cdot Y_{itj} + 5.364 \tag{18}$$

Where p_{itj} represents the selling price, C_{itj} represents the planting cost, and Y_{itj} represents the yield per acre.

By doing regression analysis, this study examines the impact of planting costs and acreage on selling prices and determines the relevant regression coefficients. The significance levels of these coefficients are below 0.005, indicating that they are statistically significant and the null hypothesis can be rejected. Therefore, this article concludes that the factors in the model have a substantial predictive value for sales price.

The results before and after the improvement are compared and a line chart is drawn as follows:

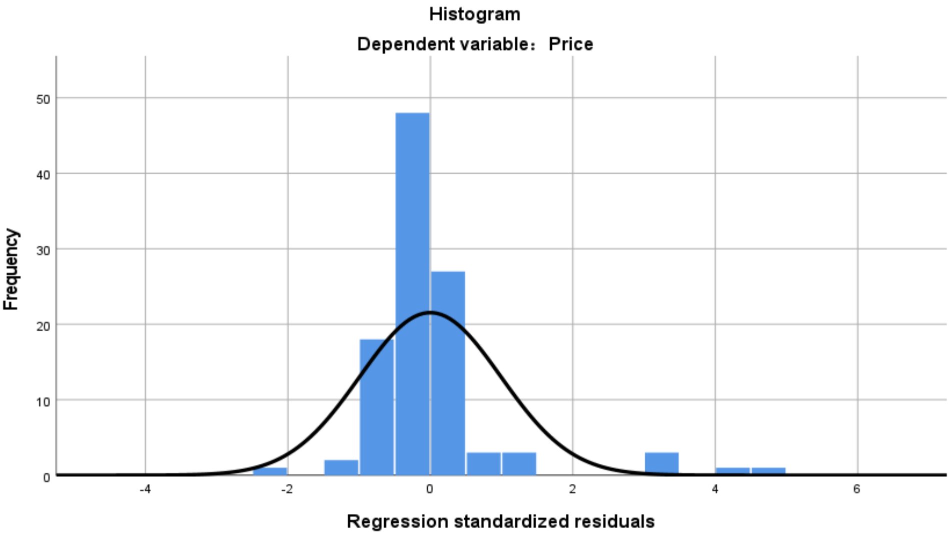

Figure 1. Normalized Residual Histogram

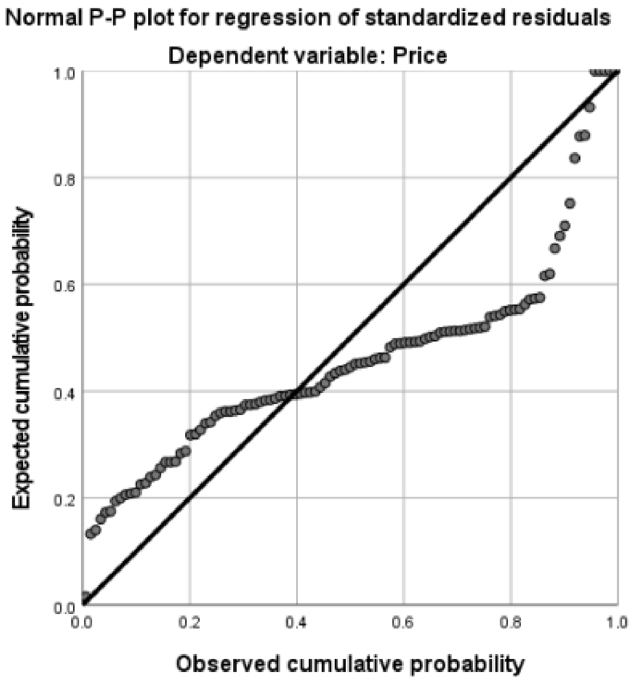

Figure 2. Normal Probability Plot of the Regression Standardized Residuals

By observing Figures 1 and 2, it is observed that the data points largely follow a normal distribution and the residuals are uniformly distributed, indicating a good model fit, thereby proving the validity of the multiple linear regression model.

4. Example Analysis

4.1. Data Preprocessing

The data in this research was preprocessed using Python, and subsequent testing revealed no missing or duplicate values.

4.2. Original Solution Results

Using the objective function and original constraints, the optimal crop planting scheme for the region from 2024 to 2030 is calculated as shown in table 3.

Table.3. Optimal Planting Scheme Solved Using Original Constraints (Part of Q1 2024)

Plot Name	Red Bean	Mung Bean	Runner Bean	Wheat	Maize	Millet	Sorghum	Foxtail Millet
A1	80	0	0	0	0	0	0	0
A2	0	0	0	0	0	0	55	0
A3	0	0	0	0	0	0	35	0
A4	72	0	0	0	0	0	0	0
A5	68	0	0	0	0	0	0	0
A6	0	0	0	0	0	0	55	0
B1	0	0	0	0	0	0	60	0
B2	0	0	0	0	0	0	46	0
B3	0	0	0	0	0	0	40	0

4.3. Improved Solution Results

Using the improved constraints obtained from multiple linear regression, the optimal crop planting scheme for the region from 2024 to 2030 is as shown in table 4:

Table.4. Improved Optimal Planting Scheme (Part of Q1 2024)

Plot Name	**Black Soybean**	**Mung Bean**	**Maize**	**Millet**	**Sorghum**	**Sweet Potato**	**Canavalia Ensiformis**	**Kidney Bean**
A1	0	0	80	0	0	0	0	0
A2	0	0	0	0	0	55	0	0
A3	0	0	0	0	0	35	0	0
A4	0	0	72	0	0	0	0	36
A5	0	0	68	0	0	0	0	0
A6	0	0	0	0	0	55	0	0
B1	0	0	60	0	0	0	0	0
B2	0	0	0	0	0	46	0	0
B3	0	0	0	0	0	40	40	0

4.4. Comparison and Analysis of Solution Results

The results of the answers in Table 3 are compared with those in Table 4 and a line graph is displayed as in Figure 3:

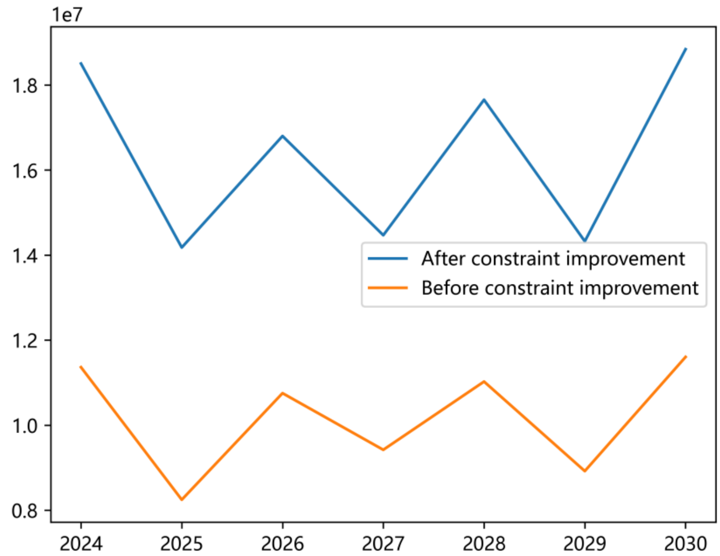

Figure 3. Comparison of Crop Planting Strategies Before and After Constraint Change

Analysis of the line graph reveals that the average annual profit of the original planting strategy is 10188625.12 million yuan, while after optimising the constraints using multiple linear regression, the average annual profit of the crop planting strategy is 1639.63 million yuan, which is 60.93% higher than the pre-optimisation period, and the trend of the annual profit under the optimised strategy is highly consistent with the original strategy. This suggests that the linear regression equation in this study has correctness and stability and the optimised cropping strategy is good for farmers to get more profit.

5. Conclusion

This work explores agricultural planting techniques in a specific location of North China, where a multi-objective linear programming model is built, and a possible risk factor β is introduced to quantify the impact of natural risks on crop yields. To further improve the planting techniques, the paper takes into account the substitutability and complementarity between crops. By utilizing multiple linear regression, the model's constraints are optimized, leading to the proposal of a more profitable planting strategy. The example study reveals that the optimized technique efficiently boosts the annual profit from crop planting. Moreover, the change trends of the optimized strategy are often compatible with the original strategy, so proving the validity and stability of the multiple linear regression model. The results of this study give a scientific basis and practical reference for the optimization of regional agricultural planting methods, and provide vital assistance for boosting agricultural economic benefits and managing with natural dangers. Future research directions could incorporate dynamic risk models to improve the forecasting of natural hazards, integrate multi-dimensional data to optimize model inputs, investigate inter-regional collaborative planting, and merge with smart agricultural technologies to achieve real-time automated decision-making systems. At the same time, it is also vital to focus on the balanced development of ecological and economic benefits to support the sustainability of agriculture.

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