Optimization of Crop Planting Strategies Based on Multi-Objective Linear Programming

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Abstract. Nowadays, rural farmland is facing the problems of how to plant a wide variety of crops according to local conditions, how to maximize economic benefits, and how to promote sustainable development of the environment. This article is based on the research of crop planting, production, and sales data in a rural area in 2023. Multiple multi-objective linear programming models are established to solve the optimal planting plan for the rural area from 2024 to 2030 under different conditions. Firstly, data preprocessing is carried out to obtain expected sales volume and sales unit price. Observing the data, it is found that the planting of grain crops and vegetable crops are independent. Therefore, two multi-objective linear programming models are established separately. Their objective functions are to maximize crop sales revenue and minimize crop planting costs. The two model constraints mainly include: bean planting frequency constraint, planting area constraint, planting range constraint, planting situation and yield relationship constraint, etc. For vegetable crops, there is a two season planting crop constraint. Four multi-objective linear programming models are used to solve the planting plans for grain crops and vegetable crops in two scenarios: when the actual production exceeds the expected sales volume and when the excess is unsold, and when the excess is sold at a 50% discount to the 2023 sales price.

Keywords: Multi-objective Linear Programming, Random Parameters, Prediction Model, Big Data.

1. Introduction

Nowadays, rural farmland is facing the problems of how to plant a wide variety of crops according to local conditions, how to maximize economic benefits, and how to promote sustainable environmental development. Many predecessors have optimized agricultural planting from multiple perspectives. For example, the article "Technical Paths for Improving Crop Planting Efficiency at the Grassroots Level" outlines the possibility of agricultural optimization from a technical perspective, while "Research on the Application of Micro Irrigation Technology in Crop Planting" proposes possible technologies for improving micro irrigation from a clear technical perspective[1][2]. The article 'Effects of Different Crops Planting on Heavy Metals in Soil and Crops' analyzes the technological requirements for increasing crop yields from an environmental perspective. However, the author found that not many people have optimized crop planting strategies from the perspectives of planting block planning and future market sales[3].

After reviewing limited articles, Liang Xinyu applied mixed linear programming to crop planting planning in the article “Study on Crop Planting Strategies Based on Mixed Linear Programming Model”, which provided significant inspiration for this article. At the same time, Tang Shenyi's “two-stage optimization based crop planting” strategy analysis proposed a phased approach, which provided important inspiration for this article[4][5].

This article is based on the research of crop planting, production, and sales data in a rural area in 2023. Multiple multi-objective linear programming models are established to solve the optimal planting plan for the rural area from 2024 to 2030 under different conditions.

Nowadays, rural arable land resources are limited, and it is necessary to fully utilize arable land resources to achieve maximum economic benefits, while also maintaining a good soil ecological environment. Therefore, adapting to local conditions and selecting suitable crops for planting have become major issues that urgently need to be addressed.

This article investigates the land area of 54 arable land plots in a certain rural area, as well as the suitable types of arable land for crops in the village, including flat dry land, terraced fields, hillside land, irrigated land, ordinary greenhouses, and smart greenhouses. At the same time, the crop planting situation in the village in 2023 and the relevant data on crop yield per mu, planting cost, and sales unit price in 2023 were also collected.

Based on the provided data, this article establishes a mathematical model to solve the following problems:

Assuming that the future sales volume, planting cost, yield per mu, and sales price of crops will remain the same as in 2023, crops will be produced and sold immediately. When the total production of a certain crop exceeds the sales volume, the optimal planting plan for the rural area from 2024 to 2030 will be given in two situations: when the excess part is unsold, causing waste, and when the excess part is sold at a 50% discount from the 2023 sales price.

2. The basic funamental of linear program

2.1. Principles of Linear Programming

Linear programming is a powerful and flexible optimization tool that can help decision-makers find optimal solutions under various constraints. Its core principle is to construct a linear objective function and linear constraints, and solve for the optimal solution through mathematical methods such as simplex method or interior point method. Through reasonable modeling, linear programming can be applied to various practical problems, providing solutions for multiple fields such as economics, management, and engineering. In summary, linear programming problems can be simply expressed as optimizing a linear objective function under a series of linear constraints. The article "How to Use Linear Programming Principles to Determine Effective Product Yield"[6] clearly states the principles and components of linear programming in economic yield calculation problems

2.2. Composition of Linear Programming

(1) Decision variables: These are specific numerical values that need to be determined, representing controllable factors in the problem.

(2) Objective function: This is a linear expression about decision variables, typically used to measure a certain benefit (such as maximizing profits) or cost (such as minimizing costs). In this article, the objective function is the economic benefits of rural crops, and the optimal objective is the maximum value.

(3) Constraints: This refers to a set of constraints imposed on decision variables, typically linear equations or inequalities.

3. Result

3.1. Model Assumptions

(1) Assuming that the crop yield in 2023 is the expected sales volume of the crop.

(2) Assuming that the Pearson correlation coefficient between expected sales volume, sales price, and planting cost is greater than 0.8, there is a significant mutual influence.

3.2. Model Solving Approach

Firstly, it is required that in the case where the total crop yield exceeds the sales volume, the optimal planting plan for crops in the rural area from 2024 to 2030 should be provided based on 50% of the 2023 sales price for unsold and excess sales. By observing the data, it can be seen that the cultivation of grains (excluding rice) and vegetables (including rice) is independent. This article establishes multi-objective linear programming models for the planting schemes of grain crops and vegetable crops respectively. The objective function is to maximize the sales revenue of crops and minimize the cost of crop cultivation. Main constraint: Each plot must plant leguminous crops at least once within three years; Each crop cannot be continuously planted in the same plot (including greenhouses); The planting area of crops each year is less than or equal to the total planting area; A multi-objective programming model where the planting area of each crop on a single plot should not be too small. Solve the multi-objective programming model to obtain the optimal crop planting plan for the rural area in the next seven years under two different scenarios.

Afterwards, it is required to comprehensively consider the expected sales volume, yield per mu, planting cost, and sales price uncertainty of various crops, as well as potential planting risks, and provide the optimal planting plan for crops in the village for the next seven years. Firstly, according to the requirements of the question, the uncertainty of expected sales volume, crop yield per mu, planting cost, and sales price can be achieved by introducing random parameters. Subsequently, a multi-objective linear programming model was established to obtain the optimal crop planting plan for the next seven years in the rural area, taking into account uncertainty and potential planting risks.

Finally, it is required to consider the substitutability and complementarity between crops, as well as the correlation between expected sales volume, sales price, and planting cost. Firstly, to ensure the accuracy of the analysis results, all crops are classified into multiple categories. Then, Pearson correlation coefficient is used to analyze the correlation between the sales volume, sales price, and planting cost data of each category of crops. Subsequently, a comprehensive evaluation method was used to establish evaluation models for each type of crop, taking into account the substitutability, complementarity, and risk resistance of planting schemes between crops, and screening the types of crops that can be planted. Subsequently, a multi-objective linear programming model was established for the selected crops, and the optimal planting plan for the rural crops in the next seven years was obtained by comprehensively considering the substitutability and complementarity of crops.

It is worth noting that the sales prices of agricultural products in the next year can be predicted within a certain range through mathematical models. After referring to certain literature, it was found that the prediction model based on LSTM model indicates that there is a high possibility that agricultural product prices will remain within a certain small range of changes in the next year[6]. At the same time, market circulation may cause fluctuations in the sales prices of agricultural products within a certain range, which is usually kept at around 50%[7]. Therefore, this article will discuss two situations separately.

3.3. Data Preprocessing

Based on the planting area and yield per mu of crops in the rural area in 2023, the total yield of each crop in the rural area in 2023 can be calculated and used as the expected sales volume of each crop.

According to the survey data, the crop sales unit price range in the relevant data table for 2023 is obtained by taking the average of the range

The sales unit price of each crop in 2023 (the sales unit price range of vegetables in the second season of smart greenhouses is different from that of irrigated land and ordinary greenhouses, so the intersection of the two sales unit price ranges is taken as the sales unit price range of the vegetable).

Because irrigated land can grow both rice and vegetables, for the convenience of model building, rice is classified as a vegetable crop.

According to the data, it is known that the expected sales volume of wheat and corn in the future has an increasing trend, with an average annual growth rate ranging from 5% to 10%. Therefore, a random number $\beta_1(\beta_1 \in [1.05,1.1])$ is generated for the grain crop model; The expected annual sales volume of other crops in the future will change by approximately ± 5% compared to 2023, so a random number $\beta_2(\beta_2 \in [0.95,1.05])$ will be generated; The future sales volume is:

$$\begin{cases} \mathrm{n}_{ik} = \beta_1 \cdot n_{i-1k} (k \text{ is the wheat and corn number}) \\ \mathrm{n}_{ik} = \beta_2 \cdot n_{2023k} (k \text{ is the crop code for crops other than wheat and corn}) \end{cases} \tag{1}$$

The yield per mu of crops is often affected by climate and other factors, with an annual variation of ± 10%. Therefore, generate a random number, the future yield per mu M_{ijk} is:

$$M_{ijk} = \gamma \cdot M_{2023jk} \tag{2}$$

Due to market conditions, the average annual cost of crop cultivation increases by about 5%. Therefore, if $\mu(\mu = 1.05)$ is generated, then the future planting cost z_{ijk} is:

$$z_{ijk} = \mu \cdot z_{i-1jk} \tag{3}$$

According to the crop yield per mu and crop planting cost in the relevant data table of the survey for 2023, the average yield per mu and average planting cost of each crop under different land types in 2023 can be obtained.

3.4. Model solution

Obtain expected sales volume, planting cost, yield per mu, and sales price data for various crops from preprocessed data.

This article will provide the optimal planting plan for crops in the rural area from 2024 to 2030, and choose to solve the optimal planting plan through a multi-objective linear programming model.

3.4.1 Establishment of Decision Variables

This article needs to determine the planting area of various crops in different land types in different years, as well as the total planting area of various crops. At the same time, the coefficient of determination α is introduced to distinguish the relationship between the objective function under different sizes of total crop yield and expected sales volume. Let these three decision variables be:

$$x_{ijk} \quad y_{ik} \tag{4}$$

Among them, x_{ijk} represents the planting area of crop k in plot j in the i-th year;

y_{ijk} represents the total planting area of crop k in the i-th year;

α represents the 0-1 variable used to determine the relationship between the total yield of each crop and the expected sales volume.

3.4.2 Establishment of Objective Function

The optimization objective of this article is to maximize the sales revenue of crops, and the optimization objectives are to maximize the sales profit of grain crops and vegetable crops respectively. Establish corresponding objective functions separately.

Establishment of objective function for a cereal crop:

$$\begin{cases} object1 = \max \sum_{k=1}^{15} (am_{ik} n_{ik} + (1-\alpha) y_{ik} m_{ik}) \\ object2 = \min \sum_{2024}^{2030} x_{ijk} z_{ijk} \\ object = object1 - object2 \end{cases} \tag{5}$$

Among them, m_{ik} represents the unit price of crop k in the i-th year;

n_{ik} represents the expected sales volume of crop k in the i-th year;

z_{ijk} indicate the cost of planting crop k on plot j in year i.

For the situation where more than 50% of the 2023 sales price is reduced for sale

$$\begin{cases} object1 = \max \sum_{k=1}^{15} (a(m_{ik} n_{ik} + 0.5 m_{ik} (y_{ik} - n_{ik})) + (1-\alpha) y_{ik} m_{ik}) \\ object2 = \min \sum_{2024}^{2030} x_{ijk} z_{ijk} \\ object = object1 - object2 \end{cases} \tag{6}$$

Establishment of objective function for a vegetable crop:

$$\begin{cases} object1 = \max \sum_{k=1}^{26} (\alpha m_{ik} n_{ik} + (1-\alpha) y_{ik} m_{ik}) \\ object2 = \min \sum_{i=2024}^{2030} x_{ijk} z_{ijk} \end{cases} \tag{7}$$

$$object = object1 - object2$$

For the situation where more than 50% of the 2023 sales price is reduced for sale

$$\begin{cases} object1 = \max \sum_{k=1}^{26} (\alpha (m_{ik} n_{ik} + 0.5 m_{ik} (y_{ik} - n_{ik})) + (1-\alpha) y_{ik} m_{ik}) \\ object2 = \min \sum_{i=2024}^{2030} x_{ijk} z_{ijk} \end{cases} \tag{8}$$

$$object = object1 - object2$$

3.4.3 Establishment of Constraints

Constraints on planting range:

$$\begin{cases} i \in \{1, 2, \cdots, 2030\} \\ j \in \{1, 2, \cdots, 26\} \\ k \in \{1, 2, \cdots, 15\} \end{cases} \tag{9}$$

Among them: i is a year between 2024 and 2030

j is the serial number of 26 plots in three types of land types: arid land, terraced fields, and hillside land

K is the serial number of 15 food crops.

Number of bean planting constraints:

To facilitate the growth of other crops, it is required that all land in each plot (including greenhouses) be planted with leguminous crops at least once every three years. In this model, leguminous plants are considered to be planted only once every three years and six seasons. The formula is as follows:

$$\sum_{k=2}^{4} (x_{ijk} + x_{i+1jk} + x_{i+2jk} + x_{ij+28k} + x_{i+1j+28k} + x_{\partial i+2j+28k}) > 0 \,\middle|\, 1 \le j \le 28 \tag{10}$$

Among them, $k \in \{2, 3, 4\}$ represent the identification numbers of legume crops in vegetables.

Discontinuous planting constraint:

To prevent crop yield reduction, it is required that each crop cannot be continuously planted in the same plot (including greenhouses). In this model, continuous planting is considered to be done on an annual basis[8]. The formula is as follows:

$$x_{ijk} = 0 \,\middle|\, x_{i-1jk} \ne 0 \tag{11}$$

Land area constraint:

Require the sum of all crop planting areas to be less than or equal to the planting area, and establish independent constraints for irrigated land planted with rice in the second season. The formula is as follows:

$$\begin{aligned} &\sum_{k=1}^{26} x_{ijk} \le S_{ij} \,\middle|\, 1 \le j \le 28 \cup 37 \le j \le 56 \\ &x_{i(j-28)1} + \sum_{k=2}^{26} x_{ijk} \le S_{ij} \,\middle|\, 29 \le j \le 36 \end{aligned} \tag{12}$$

S_{ij} is the area of each plot per year.

Planting area constraint:

For the convenience of farming operations and field management, it is required that the planting area of various crops should not be too small. The formula is as follows:

$$x_{ijk} \ge c_{jk} \,\middle|\, x_{ijk} \ne 0 \tag{13}$$

Among them, c_{jk} represents the minimum planting area of crop k on the plot numbered j.

Planting situation and yield constraints:

$$y_{ik} = \sum_{j=1}^{26} (x_{ijk} \cdot M_{ijk}) \tag{14}$$

Among them, Mijk represents the yield per mu of crop k on plot j in the i-th year.

Two season crop planting constraints:

According to the data, rice is planted in a single season and rice crops will not be planted in the second season. Some vegetables cannot be planted in irrigated fields or ordinary greenhouses during the second season.Chinese cabbage, white radish, and red radish can only be planted in the second season of irrigated land. Edible fungi can only be planted in the second season of ordinary greenhouses:

$$\begin{aligned} &x_{ij1} = 0 \,|\, 29 \le j \le 56 \\ &x_{ijk} = 0 \,|\, 29 \le j \le 52, 2 \le k \le 19 \\ &x_{ijk} = 0 \,|\, 1 \le j \le 28 \cup 37 \le j \le 56, 20 \le k \le 22 \\ &x_{ijk} = 0 \,|\, 1 \le j \le 36 \cup 53 \le j \le 56, 23 \le k \le 26 \end{aligned} \tag{15}$$

3.5. Result diagram

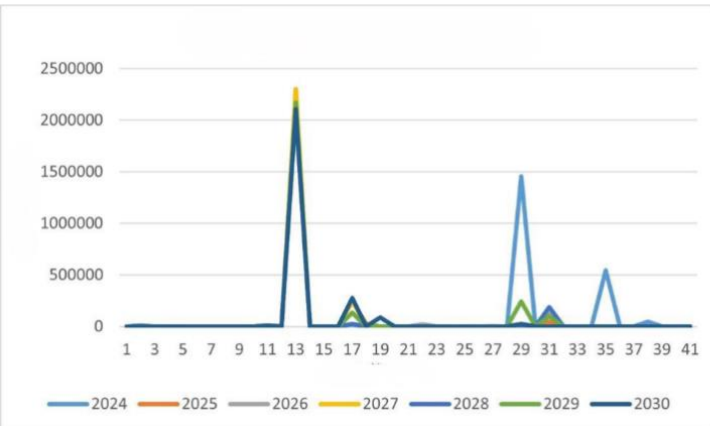

Figure 1: Crop yield chart from 2024 to 2030 under normal price sales conditions for excess parts

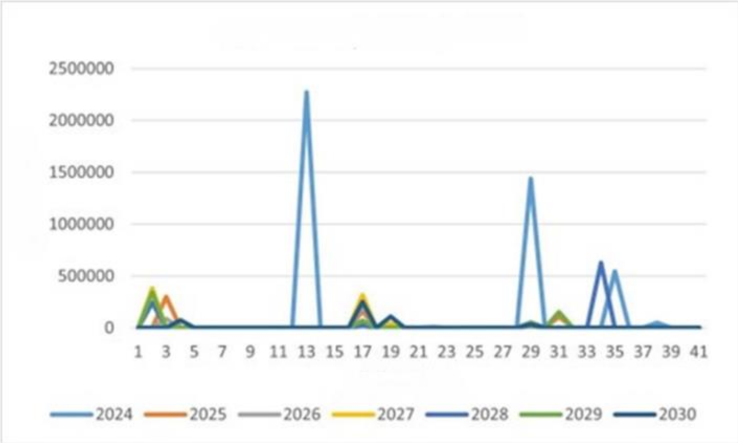

Figure 2: Crop yield map from 2024 to 2030 under the condition of selling the excess portion at 50% price

In the two images listed above, the horizontal axis represents the crop number and the vertical axis represents the yield of the crop, in kilograms.

As shown in Figure 1 and Figure 2, the horizontal axis represents the number of crops planted, the vertical axis represents the quantity of crops planted, the color of the line represents different years, and the meaning of the line is the planting method with the highest profit in the i-th year.

At the same time, we noticed that without considering surplus sales, there were no significant changes in the planting strategies of various crops, especially the 13th crop, which is not in line with the actual situation. After conducting reasonable market research, we used scenario two to calculate that agricultural products exceeding market demand will be sold at 50% of their original price. According to the research, we obtained the best planting strategy for the mountain village in North China Plain from 2024 to 2030, and the final total net income was 110 million yuan.

4. Conclusions

After addressing the drawback that linear programming cannot handle problems involving time factors well, linear programming will become a very simple and accurate model for predicting future trends and planning the optimal planting method. After comparing the forecast data of agricultural product demand in Guangdong Province for the next ten years, this article believes that it is very reasonable to establish two scenarios based on sales volume. The specific results are as follows:

When adopting the plan of selling agricultural products at their original price that exceed the sales volume of previous years, the yield of crops numbered 13, 29, 35, etc. will be higher from 2024 to 2030. The total net income for 2024-2030 is 100 million yuan by adding the net income from planting grains and vegetables obtained under this condition.

In the process of establishing this model, the author spent a lot of time reviewing past agricultural planting literature to find the planting conditions and yields of different types of crops in the region. At the same time, they investigated the market prices of different agricultural products in different regions, and finally completed the establishment of this prediction model after summarizing them. This article has provided reasonable planting methods for agricultural products in the next six years, but at the same time, it is aware of the shortcomings of this model. For possible market price changes, this article only introduces a random parameter. In the future, relevant agricultural product price prediction models can be established and combined with this model to obtain more reasonable planting plans.

References

[1] Jia Qiuwen. Technical path of improving crop planting efficiency at grass roots level[J]. Chinese Sci Tech Journal Database (full text edition) Natural Science. 2025, 04: 024-027.

[2] Ma Fengxia. Application of micro sprinkler irrigation technology in crop planting [J]. Seed Science & Technology. 2025, 1(43): 74-76,97.

[3] Huang Chengjian, Li xiang, Liu Xiaokang, Pan Tingjie, Lei Ning, Luo Fang, Zhao Siyi. Effects of Different Crops Planting on Heavy Metals in Soils and Crops [J]. Crop Magazine. 2025, 2: 180-188.

[4] Liang Xinyu,Deng Chuanyu,Wang Jinhai.Crop planting strategy based on mixed linear programming model[J]. Statistical and Application, 2025, 2(14): 94-102.

[5] Tang Shenyi, Wang Wenjie,Zhang Hu,Jiang Guirong. Analysis of crop planting strategy based on two-stage optimization[J]. Journal of Smart Agriculture, 2025, 5(5): 68-74, 79.

[6] Liu Chunsheng. Agricultural product price research group of Zhuzhou Price Bureau. An analysis of the factors affecting the current price rise of agricultural products -- an investigation and Reflection on the agricultural product market in Hunan Province[J]. Price: Theory&Practice, 2011 ,10: 21-22.

[7] Hui Yun, Bai Wei, Liu Jiang. Comparative study of agricultural product price prediction models based on LSTM and Gru[J]. Journal of Ningxia Normal University, 2025, 4: 96-104.

[8] Ma Huiping, Peng Zhengfeng. Causes and Countermeasures of obstacles in tree peony continuous cropping[J]. China Horticultural Journal, 2011, 27 (04): 122-123.