Mathematical Modeling and Algorithm Application
ISSN: 3006-0842 | Vol. 6, No. 1, 2025

Research on Planting Strategies for Crops in the Mountainous Areas of North China

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Abstract: This study focuses on the planning of rural planting strategies in the mountainous regions of North China from 2024 to 2030, with the core objective of addressing market dynamics, enhancing the economic benefits of agricultural output, and promoting the sustainable development of rural economies. The research employs data preprocessing and visualization techniques to abstract practical issues into a 0-1 linear programming model, aiming for profit maximization as the optimization goal while incorporating multiple constraints to refine planting strategies. Ultimately, this study utilizes the Monte Carlo simulation method for randomized crop selection, visualizes yield data in relation to the planting area of each farmland, and integrates the results into tabular formats. Furthermore, the study provides practical insights and optimization strategies based on empirical analysis.

Keywords: Linear Programming, Visualization, Monte Carlo Method, 0-1 Programming.

1. Introduction

A rural area located in the mountainous region of North China, with 1201 acres of land (divided into 34 plots including flat dry land, terraced fields, hillside land, and irrigated land) and 20 greenhouses (16 ordinary greenhouses and 4 smart greenhouses), mainly used for growing grains, vegetables, and edible fungi. Due to climate restrictions, most plots can only be planted once a year. During the planting process, it is also necessary to consider factors such as land type, growth patterns, and market demand. The village needs to plan a planting strategy for 2024-2030 to adapt to market changes, increase income, develop organic agriculture, and promote sustainable development of the rural economy. The aim of this study is to model and analyze the crop planting patterns in specific rural areas, in order to develop the optimal crop planting strategies between 2024 and 2030. Research needs to consider two different scenarios comprehensively: in the first scenario, if the total yield of a crop exceeds the expected sales volume per season, the excess will face the risk of unsold goods, leading to resource waste; In the second scenario, the excess crops can be sold at a discount of 50% of the 2023 sales price. The core of this article is to scientifically plan the planting area, types, cultivated land types, and planting years of crops, combined with the planting cost and sales price in 2023, in order to maximize profits. In the research process, it is necessary to consider the growth patterns of crops, the convenience of farming operations, and the feasibility of field management, and conduct in-depth exploration of various constraints. Compared to dynamic programming (which considers the temporal coupling of multi-stage decision-making) and nonlinear programming (which may lead to local optima), 0-1 programming method is more suitable for solving such discrete planting decision-making problems. For example, the question of whether to plant crop k on plot i during season j is essentially a binary choice problem, and the 0-1 variable can directly map this logic. In addition, 0-1 programming is more concise and clear in expressing linear constraints such as area limitations and crop repetition limitations.

2. Agroecological Characteristics of Land Types

The topography of mountainous areas in North China is complex, with significant micro-ecological variations across different plots:

Flat drylands (32% of total area): Gentle terrain but limited irrigation conditions, with high sand content in the soil. Suitable for drought-resistant grains (e.g., millet, buckwheat), requiring special attention to the impact of intra-annual precipitation distribution on seedling emergence (average annual precipitation: 500-600mm, concentrated in July-August).

Terraced fields (28%): Distributed along contour lines with soil-water conservation functions, yet fragmented plots result in low mechanization levels. Ideal for high-value cash crops (e.g., chili peppers, shiitake mushrooms), necessitating cost-benefit alignment with labor-intensive practices like manual weeding.

Sloping lands (25%): Gradient >15°, featuring poor soil fertility and susceptibility to erosion. Priority given to perennial crops (e.g., walnuts, prickly ash) or barren-tolerant forage (e.g., alfalfa), complying with soil conservation policies.

Irrigated lands (15%): Equipped with advanced water infrastructure, these lands have seen a significant increase in double cropping capabilities, primarily focusing on water-intensive vegetables such as Chinese cabbage and tomatoes, as well as cash crops like soybeans. The input-output ratio per unit area has improved to 2.3 times that of drylands, reflecting enhanced irrigation efficiency and productivity (based on 2023 data).

3. Analysis of plot characteristics and yield per unit area

Before conducting a preliminary review of the data, it is essential to consider the various types of land characteristics, land area, yield per unit area, planting costs, and sales prices, as detailed in recent agricultural reports. No abnormalities or

duplicate data items were found. However, there is a phenomenon of missing data in the description of terrain, and this article adopts the method of forward filling to deal with it. Studying the distribution of crop planting areas in different planting regions in 2023 may provide reference value and significance for studying crop planting trends from 2024 to 2030. By visualizing the data, Figure 1 was generated. As shown in Figure 1, the top five crops in terms of planting area in 2023 are wheat, foxtail millet, soybeans, corn, and mung beans. Subsequently, merge the data from the two tables for subsequent data analysis and processing.

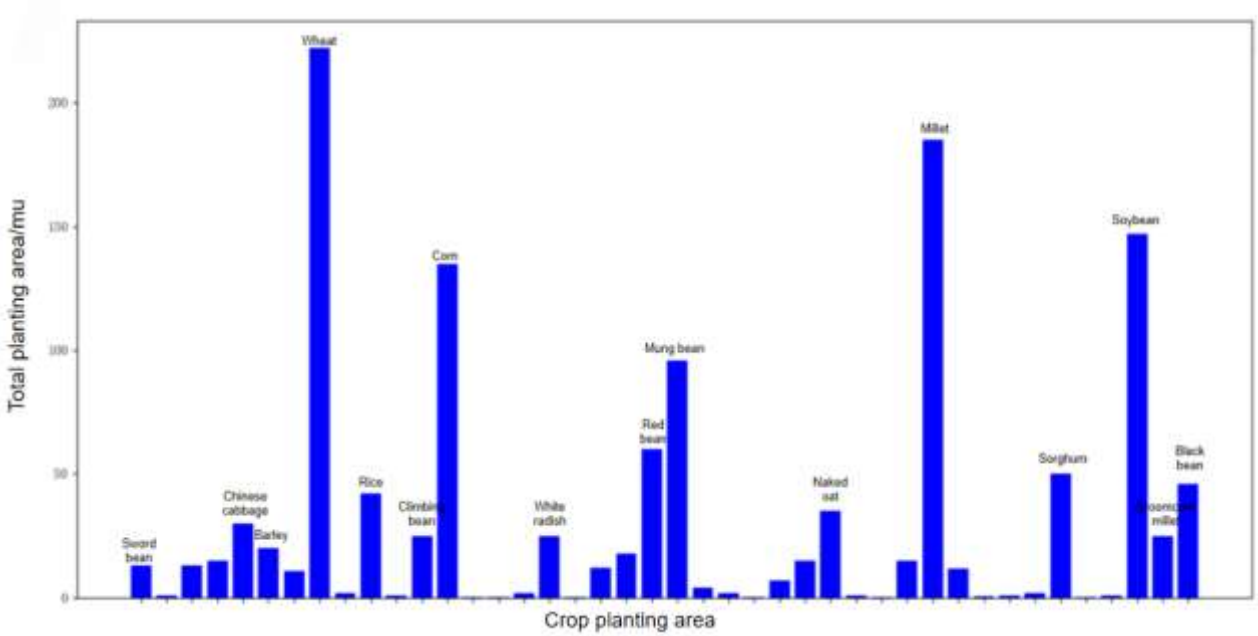


Figure 1. 2023 Crop Planting Areas

3.1. Model establishment and solution

3.1.1. Set decision variables

The decision variable is X [i, j, k, t], which represents whether crop k is planted on plot i in season j of year t (1 if planted, 0 if not planted)

Physical Meaning of 0-1 Variables: Decision variable X_{i, j, k, t}$ implies three logics:

(1). Spatial-temporal exclusivity: Only one crop can be planted in the same plot during the same season;

(2). Crop adaptability: For instance, intelligent greenhouses are ideally suited for planting off-season, high-value crops;

(3). Policy compliance: Basic farmland should prioritize ensuring an adequate planting proportion of food crops.

Scientific Basis for Crop Rotation Constraints: The rule that leguminous plants (such as soybeans, adzuki beans) are planted once every three years stems from the nitrogen - fixing mechanism of rhizobia. Continuous planting will lead to the imbalance of the rhizosphere microbial community and trigger diseases (such as soybean cyst nematode disease), while spaced planting can increase the soil nitrogen content by 12-15% (referring to the crop rotation research data of the Acta Agriculturae Boreali - Sinica in 2022).

Risk Control of Area Threshold: The regulation that limits the planting area of a single crop to no more than 10% of the total is grounded in the market risk dispersion theory. For instance, in 2023, the corn planting area in China reached 663.2835 million acres, which is approximately 6.63million acres. Despite a 2.7% increase in the planting area compared to the previous year, the centralized listing of corn in autumn led to a price drop of 15%, resulting in a profit loss of about 200,000 yuan. This outcome underscores the risks associated with an over-concentrated market.

3.1.2. Determination of objective function

For flat dry land, terraced fields, and hillside land

$$Q1 = \sum_{i=2024}^{2030} \sum_{i\in(flat、ladder、mountain)}^{16} \sum_{k=1}^{15} (P_k \cdot Y_{i,k} \cdot A_i - C_{i,k} \cdot A_i) X_{i,1,k,t} \quad (1)$$

For irrigated land

For ordinary greenhouses

$$Q2 = \sum_{i=2024}^{2030} \sum_{i\in(water)}^{16} \sum_{k=16}^{37} (P_k \cdot Y_{i,k} \cdot A_i - C_{i,k} \cdot A_i) X_{i,j,k,t} \quad (2)$$

$$Q_3 = \sum_{t=2004}^{2030} \sum_{k=17}^{34} (P_k \cdot Y_{i,k} \cdot A_i - C_{i,k} \cdot A_i) X_{i,1,k,t} + \sum_{t=2024}^{2030} \sum_{k=38}^{41} (P_k \cdot Y_{i,k} \cdot A_i - C_{i,k} \cdot A_i) X_{i,2,k,t} \quad (3)$$

For smart greenhouses

$$Q_4 = \sum_{t=2004}^{2030} \sum_{k=17}^{34} (P_k \cdot Y_{i,k} \cdot A_i - C_{i,k} \cdot A_i) X_{i,j,k,t} \tag{4}$$

Objective function

$$Q_{total} = Q_1 + Q_2 + Q_3 + Q_4 \tag{5}$$

3.1.3. Determination of Constraints

0-1 distribution parameter constraint

$$\sum_k x_{i,j,k,t} = 1 \tag{6}$$

Repetitive constraint

$$\sum_k x_{i,j,k,t} = 1 \tag{7}$$

The area designated for cultivation must not be excessively small to ensure adequate space for proper growth and development of the crops. Additionally, it is imperative that the area allocated for each type of crop does not surpass 10% of the overall total area to maintain a balanced and diversified agricultural ecosystem. This regulation helps in preventing over-reliance on a single crop and promotes sustainable farming practices.

Furthermore, leguminous plants, which are known for their nitrogen-fixing properties and beneficial impact on soil health, should be systematically planted on each individual plot of land once every three years. This rotational planting schedule is crucial for replenishing soil nutrients, enhancing soil fertility, and reducing the risk of soil depletion and pest infestations. By adhering to this practice, farmers can ensure long-term soil productivity and sustainable agricultural yields.

$$X_{i,j,k,t} + X_{i,j,k,t+1} + X_{i,j,k,t+2} = 1 \tag{8}$$

3.2. Establishment and Solution of 0-1 Model

0-1 programming, also known as binary integer programming, is a type of optimization problem where decision variables can only take the values 0 or 1 [1]. This characteristic makes 0-1 programming highly effective in addressing problems with clear binary choices. By appropriately formulating and solving 0-1 programming problems, optimal resource allocation schemes can be identified [2]. In the context of crop planting plans, decisions can be made for each plot of land regarding whether to plant a specific crop (1) or not (0) [3]. According to the problem statement, to achieve maximum planting profit, a 0-1 model is established under the assumption that the variables meet the linear programming conditions, where 0 represents no planting and 1 represents full planting [4].

3.3. The Application of Monte Carlo Method

3.3.1. Introduction to the Monte Carlo method

The fundamental principle of Monte Carlo simulation is rooted in probability theory and mathematical statistics. Its core lies in transforming the problem to be solved into a probabilistic model, leveraging computers to generate massive amounts of random numbers that conform to specific probability distributions, simulating the operational state of the system under different random scenarios, and then performing statistical analysis on the simulation results to obtain approximate solutions to the problem[5]. In this problem, we used Monte Carlo simulation to estimate the income distribution under different planting strategies, as well as the impact of unsold or discounted sales beyond expected sales volume on income.

Using Monte Carlo random selection of crops, visualize the yield of the solution and the planting area of each cultivated land. Finally, by applying the Monte Carlo method, we simulated multiple possible planting schemes and calculated the corresponding economic benefits [6].

By employing this method, the article not only enables visual inspection of yield distribution across various planting strategies, but also facilitates an assessment of the associated risks and benefits. For instance, one can delve into how market fluctuations or natural disasters might affect overall earnings, particularly when a specific crop occupies a substantial planting area.

Furthermore, the Monte Carlo method takes into account various uncertainties in crop planting, including weather fluctuations and the likelihood of disease and pest outbreaks, which pose significant prediction challenges in real-world agricultural scenarios. By simulating these uncertain factors, we can more comprehensively evaluate the stability and risk resistance of different planting strategies.

Ultimately, combining the results of Monte Carlo simulations can provide decision-makers with a scientific planting plan recommendation to maximize planting profits and reduce potential risks.

3.3.2. Probabilistic Modeling of Market Risk

Introducing triangular distribution to simulate market demand fluctuations, with parameters based on historical data from 2018-2023:

Expected sales volume Dk: Taking the average sales volume over the past 6 years;

Optimistic sales volume $D_{r\ \text{optimistic}} = D_r \times 1.2$ (corresponding to market demand growth scenario).

Pessimistic sales volume Dk pessimistic=Dk×0.8 (corresponding to market contraction scenario).

In Scenario 1 (excess inventory), production exceeding Dk directly incurs loss costs; in Scenario 2(discounted sales), the surplus portion is sold at 50% of the 2023 price, with additional consideration for warehousing costs (0.2 yuan/kg).

Through 10,000 Monte Carlo simulations, the profit distributions under both scenarios are obtained, as shown in Table 1:

Table 1: Profit Distribution Table

Indicator	Scenario1 (Mean±SD)	Scenario2 (Mean±SD)	Difference
Expected profit	482.3±65.8	521.7 ± 82.4	+8.2%
Maximum profit	615.4	689.3	+12.0%
Minimum profit	328.7	365.2	+11.1%
Profit distribution under different scenarios	385.6	412.9	+7.1%

Scenario 2, which employs a discounted sales mechanism, has been shown to substantially improve profit expectations and bolster risk resistance capabilities. However, it is crucial to implement robust cash flow management strategies to mitigate the increased pressure from high volatility.

4. Practical Implications of Optimal Strategies

4.1. Land Use Optimization Plan

The optimization plan for land use is shown in Table 2:

Table 2: Land use optimization

Land Type	Core Crop Combination	Rotation Cycle
Smart greenhouses	Morel mushrooms → Pleurotus nebrodensis → Strawberries(Off-season)	Annual 3 crops
Ordinary greenhouses	Lettuce → Spinach → Baby pak choi(Leafy vegetables)	Annual 4 crops
Irrigated land	Tomatoes (spring) + Chinese cabbage (autumn)	Annual double cropping
Terraced fields	Chili peppers → Corn → Soybeans (Legume crop rotation)	3-year cycle
Hillside land	Chinese prickly ash + Alfalfa (Understory economy)	Perennial
Flat dry land	Foxtail millet → Buckwheat → Mung beans (Drought-resistant crops)	Once a year

4.2. Risk hedging strategy

Spatial dispersion: To mitigate the risk of catastrophic loss, it is advisable to strategically distribute high-value crops, (such as the highly sought-after morels, across multiple greenhouses. This approach ensures that if a single facility were to experience a failure, whether due to technical issues, environmental factors, or other unforeseen circumstances, the overall crop yield would not be entirely compromised. By spreading the crops across different locations, the impact of any single point of failure is significantly reduced, thereby safeguarding the investment and ensuring a more reliable supply.

Temporal staggering: To address the issue of market saturation and the resultant price fluctuations, it is prudent to implement a temporal staggering strategy for the sowing of leafy vegetables. This involves planting the vegetables in successive batches, with each (batch being sown at 15-day intervals. This method helps in spreading out the harvest periods, thereby preventing a sudden influx of produce in the market at any given time. By doing so, farmers can mitigate the risk of price shocks that often occur when a large volume of produce is available simultaneously, leading to a glut and depressed prices.

Product upgrading: To enhance the economic value of surplus vegetables (and mitigate the risk of overstock, it is beneficial to engage in primary processing activities. For instance, transforming excess vegetables into dehydrated products can significantly increase their added value by 30-50%. This not only addresses the issue of potential waste but also converts the overstock risk, as outlined in Scenario 1, into a viable source of revenue. By processing the surplus into a more durable and marketable form, farmers can tap into new market segments and achieve better returns on their produce, thereby optimizing their overall profitability.

5. Conclusions

This study addresses the optimization of long-term, multi-plot, and multi-crop planting strategies in mountainous regions of North China by constructing a coupled framework of 0-1 linear programming and Monte Carlo simulation. The results indicate:

Model Effectiveness: The 0-1 programming accurately captures the discrete nature of planting decisions. By incorporating crop rotation constraints and area thresholds, it achieves a balance between profit maximization and ecological sustainability.

Strategy Robustness: Scenario 2's discounted sales mechanism increases profits by 8.2%, but requires supporting storage and processing facilities.

Practical Value: Prioritizing high-value-added edible fungi

in smart greenhouses, implementing a "vegetable + grain" double-cropping system in irrigated areas, and developing agroforestry-pasture composite systems on slopes all significantly enhance per-unit-area benefits.

Method Scalability: The model can integrate climate prediction data (e.g., precipitation probability) to further improve decision-making capabilities in response to extreme weather events.

Future research could incorporate sustainability indicators such as carbon sink trading revenue and organic fertilizer substitution costs to improve the multidimensional optimization system for mountainous agriculture.

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