

OPTIMAL PLANTING STRATEGY BASED ON GOAL PROGRAMMING

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Abstract: In order to maximize the income of agriculture, this paper established linear programming models for the two cases of more than half selling and more than half selling with the constraints of plot area, continuous cropping restrictions, legume crop rotation, planting plots should not be dispersed and crop planting adaptability restrictions. Then it was solved by genetic algorithm, and the optimization results were divided into four categories according to the category of crops: grain, vegetables, edible fungi and beans. The uncertainty risk is measured by calculating the standard deviation of the expected sales volume, yield per mu, planting cost and sales price of crops, and the objective function of minimizing the risk is determined by the weighted sum of the four risk variances. Then, under the condition that more than half price is sold, a double objective optimization model with the objective function of maximizing income and minimizing risk is established, which is solved by NSGA-II algorithm. The substitution and complementarity are incorporated into the risk model through the risk weighting mechanism, and the objective function is updated. Then, the Pareto frontier graph is generated by using NSGA-II algorithm. Compared with the results of problem 2, it is found that after considering the substitution and complementarity of agricultural products, the optimal solution set becomes more replaceable, more selective, and more extensive search space.

Keywords: Double objective optimization; Genetic algorithm risk model; NSGA-II algorithm; Pareto frontier

1 INTRODUCTION

The development of rural agriculture has promoted the revitalization of rural economy, the protection of ecological environment and the progress of rural society. It is an important pillar for the realization of Rural Revitalization and sustainable development. Selecting appropriate crops and optimizing planting strategies make field management easier, reduce labor intensity and production costs, and reduce planting risks caused by uncertain factors such as climate and market fluctuations, so as to stabilize farmers' income.

Heydari and Mosadegh developed a fuzzy GP model to optimize crop cultivation patterns in Iran, integrating goals for profit maximization, water conservation, and labor efficiency[1,2]. Their approach reduced water usage by 18% while increasing net profit by 12% compared to traditional practices. Similarly, Arani and Sadeghieh applied GP to dynamic cell formation in apple orchards, achieving a 15.08% yield improvement through optimized planting material allocation and intercropping strategies[3]. These studies underscore GP's versatility in reconciling economic and ecological targets. Jia Chen et al. proposed a linear programming-GP hybrid model for North China's mountainous regions, incorporating variables like planting area, seasonal rotations, and market prices. Their framework reduced fertilizer use by 22% and irrigation water by 19% while maintaining yield levels, demonstrating GP's role in promoting sustainable intensification. Complementing this, Alabdulkader et al. optimized Saudi Arabia's cropping patterns using GP, achieving a 14% increase in gross revenue with 30% less land degradation risk. These findings align with Pastori et al.'s work in Africa, where GP-based strategies enhanced food security by 25% in drought-prone zones.

This paper first needs to judge the possible substitution and complementarity between crops. Based on the analysis of endogenous risk, a bi objective programming model with the goal of maximum return and minimum risk is established. NSGA-II algorithm was used to find the optimal planting scheme, and the sensitivity of the model was tested by introducing exogenous economic risk. The yield and price of each crop can be obtained, and the price cross elasticity of each agricultural product can be calculated. According to the price cross elasticity, we can judge whether crops are alternative or complementary, and form the table of alternative relationship and complementary relationship. The substitution and complementarity conditions of agricultural products are added into the constraint conditions to establish the relationship among planting cost, substitute price and sales volume. The substitution and complementarity will be incorporated into the risk model through the risk weighting mechanism, and the objective function will be updated. For the solution using non dominated sorting genetic algorithm.

2 PRELIMINARY

2.1 Assumption

It is assumed that the expected sales volume, planting cost, yield per mu and sales price of various crops in the future will remain stable relative to 2023. That is to say, the sales data of 2023 will be used as the sales target for each year in the future. The crops planted each season are only sold in the current season, and there is no retention. The recovery

cost and labor, equipment use, transportation and other related expenses are not considered. When beans are planted on different plots for 3-year rotation, in order to simplify the model, only one kind of beans is planted on this plot and no other crops are planted.

2.2 Notations

The symbols used in the paper are listed in Table 1.

Table 1 Symbols Notations

Symbols	Notation
P_j	Sales price of the jth crop
C_j	Planting cost of the jth crop
Y_j	Yield per mu of the jth crop
S_j	Expected sales of crop J
$C_{i,j}$	Cost per kilogram of the j-th crop in the i-th plot
$Y_{i,j}$	Yield per mu of the j-th crop in the i-th plot
A_i	Area of plot I

3 PLANTING COST AND YIELD PROFIT

3.1 Basic Analysis of The Crops

In order to formulate reasonable planting strategies, the village should accurately understand the profit distribution of different crops. By observing the profit differences of different crops, we can better evaluate their economic benefits, market demand and the utilization rate of land resources. By analyzing the expected sales volume, we can identify the crops with high market demand, so as to increase the planting area of these crops, avoid unsalable and waste of resources caused by planting too many crops with low demand, and maximize profits. The profit histogram of 41 crops per mu is shown in Figure 1.

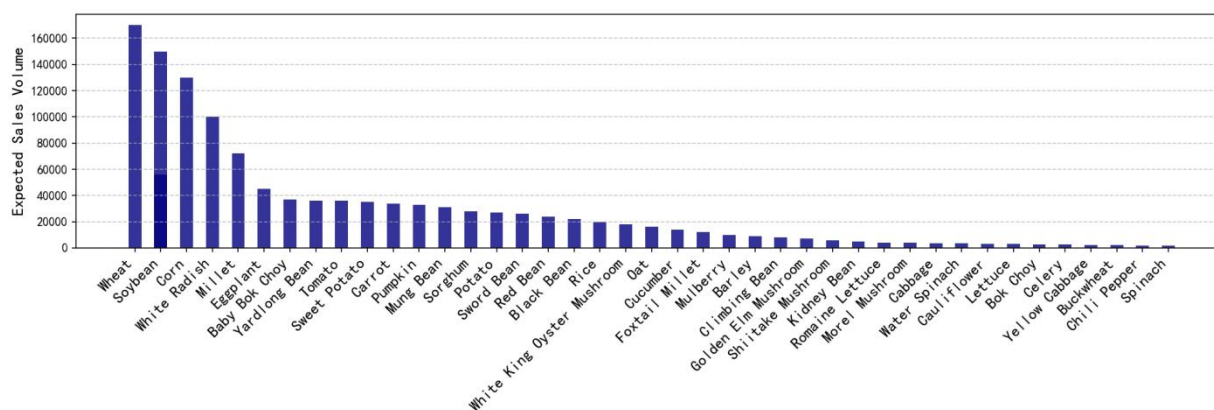


Figure 1 Expected Sales Volume

3.2 Optimal Planting of Crops

The planting area of crops J in each plot or greenhouse shall not exceed the maximum area of the plot. In addition, in order to facilitate farming operations and field management, the area of crops planted in a single plot (including greenhouse) should not be too small. This article defines that the planting area of each crop in a single plot (including greenhouse) shall not be less than 0.2% of the plot area. For irrigated land, ordinary greenhouses and smart greenhouses that can be planted in two seasons, only cowpeas, beans and kidney beans can be planted. According to common sense, cowpea and concaavalis usually prefer a warm climate and are suitable for planting in the first season of spring or summer; Kidney bean has a wide range of adaptability. It is common to plant in the first season in warm areas, but it can also be planted in the second season in high temperature and frost free areas. Because the village is located in the northern mountainous area and the temperature is low throughout the year, only beans are planted in the first season. The flat dry land, terrace and hillside are suitable for planting one season of grain crops every year, that is, no other crops except one season of grain crops are planted. Irrigated land is suitable for planting one season of rice or two crops of vegetables every year. If two seasons of vegetables are planted on a irrigated land, a variety of vegetables (except Chinese cabbage, white radish and red radish) can be planted in the first season for the convenience of management; In

the second season, only one of Chinese cabbage, white radish and red radish can be planted. In addition, according to seasonal requirements, Chinese cabbage, white radish and carrot can only be planted in the second season of irrigated land.

4 GENETIC ALGORITHM FOR THE MAXIMUM PROFIT

Genetic algorithm (GA) is an optimization algorithm simulating natural selection and genetic mechanism, which is used to solve complex optimization and search problems. The core idea of genetic algorithm is to gradually find the optimal solution by simulating the evolution process in nature. By simulating the process of natural selection, crossover and mutation, genetic algorithm gradually optimizes the solution in the solution space to find the approximate optimal solution of the problem. Its flexible search mechanism and global optimization ability make it have a wide application prospect in dealing with complex optimization problems.

4.1 Visualization and Solutions

In order to intuitively present the optimization characteristics of the "initial seed+local greedy search" algorithm and the cooperative shielding effect of three smoke bombs. After 17.5 iterations, it reaches 6.7677s and is stable, which verifies the effective mining and convergence reliability of the algorithm for the optimization space, and also provides support for parameter optimization. The interval is closely connected without blank, and the total shielding interval is [6.0869,12.8546] s (6.7677s), which not only verifies the synergy effect of "less overlap and no blank" and the rationality of the duration of a single bomb (both<20s), but also provides a theoretical basis for the actual launch. Precise timing reference.

For grain crops, sweet potato with the largest profit per mu is mainly planted after optimization. For vegetables, after optimization, Chinese cabbage, lettuce, lettuce and cucumber are mainly planted. For edible fungi, the yield of Yuhuanggu is the largest, so Yuhuanggu is mainly planted after optimization. After optimization, legumes are mainly planted with red beans, soybeans and black beans. It is not difficult to see that the crops planted after optimization are those with larger profits per mu. Analysis of grains (excluding beans) shows that wheat, millet and corn account for the largest proportion before optimization, while sweet potato accounts for much higher proportion after optimization than other crops.

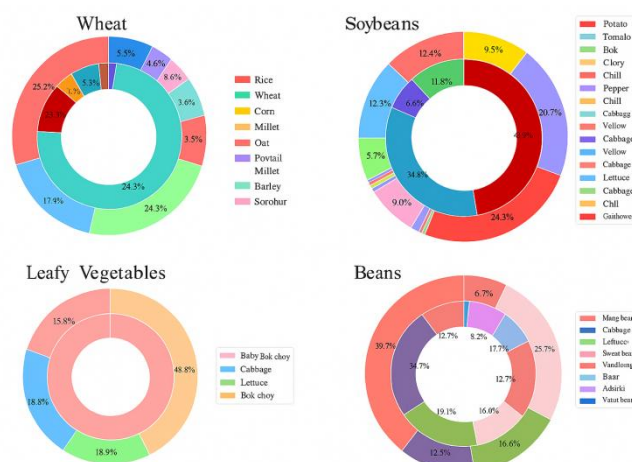


Figure 2 Proportion of Crops before and after Optimization

According to Figure 2, sweet potato has the highest profit per mu, so it is reasonable that the proportion of sweet potato is much higher than that of other crops. According to the analysis of vegetable crops, before optimization, Chinese cabbage and potato accounted for the most, while after optimization, lettuce and cucumber accounted for the most, and the profit per mu in line with both was the largest. Analysis of edible fungi crops can be obtained. After optimization, only *Pleurotus nebrodensis* and *Pleurotus eryngii*, the two most profitable edible fungi, are planted. Analysis of grain (excluding beans) shows that before optimization, soybeans and mung beans are mainly planted, and after optimization, black beans are mainly planted, which has the largest profit in grain beans. In conclusion, the results of this paper are accurate and reliable.

4.2 Endogenous Economic Risk

Agricultural production is vulnerable to natural disasters, climate change and market fluctuations. Therefore, it is very important to consider the risk and uncertainty factors in the model. In the existing studies, most farmers' attitudes towards risk are risk averse, so this paper establishes a dual objective programming model with the maximum rate of return and the minimum value of risk to optimize the planting area of crops and the planting structure proportion of different crops.

In actual agricultural production, if the yield of a crop exceeds the market demand, price reduction is a common way to deal with it, and price reduction can reduce the waste and loss caused by slow sales. In the double objective optimization model, in addition to maximizing profits, it is also necessary to minimize risks. The treatment of 50% price reduction for the excess part can balance these two objectives to a certain extent and provide a more robust planting scheme. Therefore, for the second question, this article only considers that the excess part is sold at a 50% price reduction.

4.3 Endogenous Economic Risk

After solving the double objective optimization model, we considered the potential planting risk. Through literature review, we found that there are many risks in the process of crop planting, mainly including natural disaster risk, food safety risk, logistics risk, policy risk and information asymmetry risk [3]. Among them, logistics risk is considered to be one of the most important risks. According to the AHP evaluation results of literature, the weight of logistics risk is as high as 0.393, ranking first among all risk factors, indicating that it has a great impact on the planting and sales of agricultural products.

Logistics risks are mainly manifested in the processing, transportation, storage and distribution of agricultural products, especially vegetable agricultural products, which have high requirements for logistics speed and conditions. If the conditions in the logistics process are not up to standard (such as improper temperature control), the products will rot and deteriorate, thus reducing sales.

Because there are many links involved in the logistics of agricultural products, including harvesting, transportation, storage and distribution, the logistics cost of each link may rise due to risks. Especially in the rural areas of this paper, the infrastructure is not perfect, which increases the difficulty and cost of logistics. These costs are finally transferred to the market price, weakening the market competitiveness of products and affecting the sales volume.

In addition, the logistics risk makes agricultural products unable to stabilize the supply market, which may lead to a situation of short supply or oversupply. When the supply exceeds the demand, the price will drop and the farmers' income will be damaged; If the supply exceeds the demand, the demand of consumers may be restrained due to the high price, resulting in the reduction of sales [4-10].

4.4 Alternative and Complementary Constraints

The substitution relationship means how to adjust the planting area and sales volume of another crop as a substitute product when the price or sales volume of one crop changes. A_{jk} are the price cross elasticity of alternatives. If the two crops J and K are complementary, their sales and prices usually change at the same time. When the price of one crop fluctuates greatly, the sales volume or price of another crop will also be affected. This complementary effect can be expressed by similar correlation coefficients in the calculation of standard deviation. The stronger the complementarity, the greater the fluctuation correlation between the two crops.

The optimal planting plan is shown in Figure 3. The abscissa represents profit and the ordinate represents risk, which are the two objective functions of the model. The purple dot is case 1, which represents the optimal solution set of problem 2. The green point is case 2, which represents the optimal solution set of problem 3. It can be seen from the model that the greater the profit of the model, the smaller the risk. It can be seen from the figure that the optimal solution set of case 2 is larger than that of case 1, and more inclined to the lower right. Through comparison, it can be judged that after the optimization of substitutability and complementarity among various crops, the optimal solution set of case 2 has greater substitutability, more selectivity and wider search space.

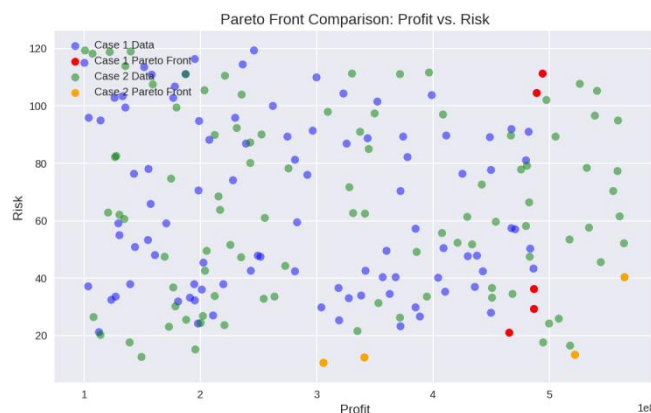


Figure 3 Pareto Front Comparison Chart

5 CONCLUSION

In this study, we focused on optimizing crop - planting strategies for a rural area in the mountainous region, aiming to enhance production efficiency and mitigate planting risks. Through comprehensive data analysis and model

construction, we addressed three key issues and achieved meaningful results. We conducted meticulous data pre - processing and visualization, confirming the absence of significant errors in the provided data. By formulating linear programming models under two scenarios (excess produce being unsellable and sold at half - price), with constraints such as land area, crop rotation restrictions, non - dispersion of planting plots, and crop adaptability, we maximized revenue. this study has successfully developed a comprehensive and practical approach to optimize crop - planting strategies in rural areas. By incorporating multiple factors such as revenue maximization, risk minimization, and crop relationships, we have provided valuable decision - making tools for farmers.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

REFERENCES

- [1] Sow S, Kumar N, Rana L, et al. Suitable Planting Material with Integrated Nutrient Management Can Enhance Productivity, Nutrient Use Efficiency and Profitability of Sugarcane. *Journal of Soil Science and Plant Nutrition*, 2025, 25(2): 3652-3675.
- [2] Jimoh A, Beath H, Markides C N, et al. Enhancing solar mini-grid utilisation in farming communities: crop strategies to reduce costs and improve energy access. IOP Publishing Ltd, 2025.
- [3] Dong M, Hong Q I, Zhang Q, et al. The Impact of Sowing Methods on the Seed Germination Environment and Cotton Emergence and Growth. *Scientia Agricultura Sinica*, 2025, 58(12): 2346-2357.
- [4] Kubesch J O C, Simon K J, Kennedy D W, et al. Optimizing late winter plantings of cool-season annual forages in the southern United States. *Crop, Forage & Turfgrass Management*, 2025, 11(1).
- [5] Tom W, Mark S, Andrew S, et al. Catchment woodland planting and the benefits to flood reduction. *Forestry: An International Journal of Forest Research*, 2025.
- [6] Talla A, Swain D K, Srivastava R K, et al. Integrating Climatic Factors and Agronomic Management for Optimal Hybrid Rice Yield and Quality. *Communications in Soil Science and Plant Analysis*, 2025(5/7): 56.
- [7] Nishimura K. Dairy Cattle Feed Design Support Program Linked to Optimal Planting Plan for Self-Supplied Feed. *Japan Agricultural Research Quarterly*, 2025, 59(1).
- [8] Mrope F M, Chilinga F, Nyerere N. Mathematical modeling of powdery mildew disease in cashew plants with optimal control and cost-effectiveness analysis. *Modeling Earth Systems and Environment*, 2025, 11(4): 1-17.
- [9] Shen F, Jiang Y, Yang Y, et al. Long-term impacts of stand density on soil fungal and bacterial communities for targeted cultivation of large-diameter *Larix olgensis*. *Forest Ecology and Management*, 2025: 591.
- [10] Brown A, Soutor M, Ellison S. Impact of plant density on stem diameter, plant height, and branching in hemp (*Cannabis sativa* L.). *Agrosystems, Geosciences & Environment*, 2025, 8(2).