Optimizing Planting Planning Based on Linear Programming Pulp Model

Jia Cao [1], Min Tan [2, *, #], Qiangwei Wu [3, #], Yikun Zhou [4, #]

[1] School of Computer Science and Engineering, Hunan University of Science and Technology, Xiangtan, China, 411100

[2] School of Mathematics and Statistics, Hunan University of Science and Technology, Xiangtan, China, 411100

[3] School of Physics and Electronic Scinece, Hunan University of Science and Technology, Xiangtan, China, 411100

[4] College of Mechanical Engineering, Hunan University of Science and Technology, Xiangtan, China, 411100

* Corresponding Author Email: mtan@hnust.edu.cn

[#]These authors contributed equally.

Abstract. To achieve sustainable rural economic development and make full use of cultivated land resources, solve the problem of rural land planting planning and improve planting benefits. Based on the data in Problem C of the 2023 mathematical modeling competition, the concept of random growth rate is introduced to deal with the uncertainty of growth rate. The Gibbs sampling algorithm is used to screen the random growth rate to make it more in line with the actual situation. A pulp linear programming model is established. The decision variables are set as binary variables. The objective function is determined as maximizing the total income of crops. According to different land types (flat dry land, terraced fields, slopes, irrigated land, ordinary greenhouses, intelligent greenhouses, etc.), planting constraint conditions are set, including the number of planting seasons and types of planted crops. At the same time, the constraints of legume rotation and non-negative and binary variable constraints are considered. Finally, the model is solved based on the pulp algorithm. Through data processing and model calculation, the results of two situations are obtained. The first situation is that excess products are unsalable and cause waste. The second situation is that the excess products are sold at 50% of the sales price in 2023. The incomes of vegetables, grains and edible fungi and the total income in each year from 2024 to 2028 under the two situations are calculated respectively. For example, the total income in 2024 under the first situation is 595,766.81, and the total income in 2024 under the second situation is 2,921,016.2. The total income in the second situation is generally higher than that in the first situation, indicating that selling the excess products at a reduced price can improve planting benefits. This research provides a basis for optimizing planting strategies. In the future, more factors can be included to improve planting planning and promote rural economic development.

Keywords: Linear Programming, Pulp Model, Optimization Problem, Gibbs Sampling, Random Growth Rate.

1. Introduction

In this paper, it is set against the important goal of sustainable rural economic development. In view of the actual situation where crop planting is affected by various complex factors such as land types, climatic conditions, market demand, and planting costs, the crucial importance of scientifically planning planting strategies is emphatically emphasized. First, the researchers meticulously process various types of collected data. Through a series of scientific data processing methods, they obtain processed data that can better reflect the actual planting situation. Next, considering the characteristic that the growth rate of crops is not fixed but there is uncertainty under different environments and conditions, we innovatively introduce the concept of random growth rate. In order to make the introduced random growth rate more in line with the actual planting situation and experimental requirements, the Gibbs sampling algorithm is simultaneously used to screen it to ensure the scientificity and reliability of the data. On this basis, a pulp linear programming model is further established, and according to the actual planting situation and research goals, a series of relevant constraint conditions including land type constraints, legume rotation constraints, and non-negative and binary variable constraints are added. Finally, in-depth analysis of the data is conducted to draw conclusions with practical guiding significance are drawn.

2. Relevant theories

First, let's introduce the concept of Random Growth Rate. The concept of random growth rate and its handling methods have been widely applied in theoretical biology, as studied by M J P et al. [1].Random growth rate refers to the situation in a certain system or process where the growth rate is not fixed but shows random changes. It reflects that due to the influence of various uncertain factors, the growth speed has uncertainty at different times or under different circumstances.

Next, we will focus on Gibbs Sampling. Gibbs sampling, as a Markov chain Monte Carlo method, has been proven to have rapid convergence in multi-dimensional probability distributions, as discussed by Aditi L et al in [2] and Gibbs sampling is a Markov chain Monte Carlo method used to draw samples from a probability distribution. It approximates the target distribution by sequentially sampling from the conditional distribution of each variable. In a multi-dimensional probability distribution, each time other variables are fixed and one variable is sampled according to its conditional distribution. Continuous iterations form a Markov chain. After many iterations, the samples approximately follow the target distribution. This method has applications in multiple fields, but its convergence speed is affected by distribution characteristics and initial states.

Finally, we will present the Pulp Model. The pulp model is a tool for solving optimization problems. It can help us find the optimal decision-making scheme under given constraint conditions to maximize or minimize the objective function. It usually consists of three parts: decision variables, objective function, and constraint conditions. Decision variables are the variables for which we need to make decisions. The objective function is the goal we hope to optimize. Constraint conditions are the restrictions on decision variables as shown in Figure 1.

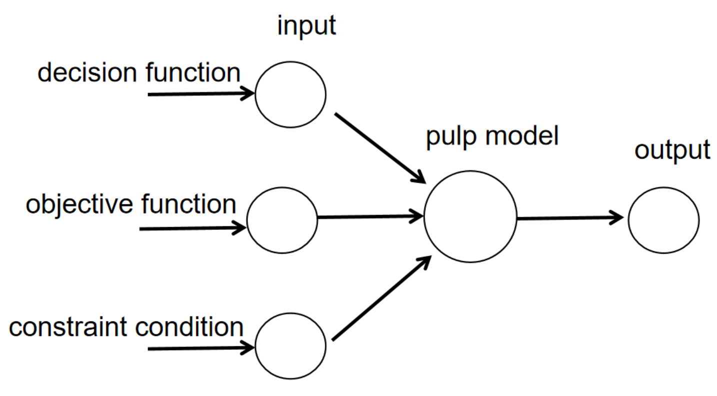

Figure 1. pupl model structure

By using the pulp model, we can convert practical problems into mathematical models and solve them using optimization algorithms to obtain the optimal solution. It has wide applications in many fields such as production planning, resource allocation, logistics management, and more.

3. Experiment

After data processing of the known data collected in 2023, we obtain relevant factors that affect whether crops are planted, such as land type, crop type, and whether legumes are planted. These factors affect the total planting income by influencing the planting situation.

Since the relevant planting situations from 2024 to 2028 are affected by various factors, for the expected sales volume, planting cost, yield per mu, and sales price of various crops in the future, we need to introduce random growth to simulate the fluctuations of relevant factors in the future. At the same time, in order to make the random growth rate more in line with and appropriate for our experiment, we use the Gibbs sampling algorithm to conduct secondary screening on the random growth rate. We stipulate that the crops planted in each season are sold in the current season. Therefore, we can make predictions based on the data of 2023 and assume that the expected output is greater than the actual sales volume, resulting in a supply exceeding demand. Pontes G S D R et al proposed multi-objective models for crop rotation planning problems in [3], which resonates with our method of using the pulp model to optimize planting planning and Moraes R L et al adopted a linear programming approach to generate optimal configurations for neutron source distribution in subcritical systems in [4], providing a robust reference framework for our study.

First situation: Excess products are unsalable, causing waste.

Introduce constraint conditions, take maximizing total income as the objective function and add binary decision variables, establish a linear programming pulp algorithm model, predict the planting situation in the next five years, and then obtain the maximum planting benefit to provide guarantee for reasonable planting in rural areas.

Second situation: Based on the first situation, the excess products are sold at 50% of the sales price in 2023.

Introduce relevant constraint conditions, take maximizing total revenue as the objective function and add binary decision variables, establish a linear programming pulp algorithm model, predict the planting situation in the next five years, and then obtain the maximum planting benefit to provide guarantee for reasonable planting in rural areas.

After predicting and calculating the total revenue of the above two situations, we compare them to obtain the maximum total revenue planting.

So now, our first step is to define the objective function. The goal is to maximize the total revenue of crops. And in the case of solving for maximizing the total revenue of crops, we can obtain the optimal planting scheme in year t, and then calculate the situation with the largest output value. The revenue of each crop j in year t can be expressed as:

$$Max = \sum_{i=1}^{M} \sum_{j=1}^{N} \sum_{t=1}^{2} (S_i \cdot a_i \cdot A_j \cdot X_{i,j,t} - C_{i,j} \cdot A_j \cdot X_{i,j,t}) \tag{1}$$

In the above formula, i represents crops, M represents the total quantity of crops, j represents plots, N represents the total quantity of plots. t represents the planting season of crops, X represents decision variables, S represents the unit sales price of crops, a represents the yield per mu of crops per unit area, C represents the planting cost of crops, and A represents the planting area of crops.

Secondly, we will define the decision variables and The decision variable is a binary variable:

$$x_{i,j,t} = \begin{cases} 1 \\ 0 \end{cases} \tag{2}$$

Here, i represents the ith plot, j represents the jth crop, and t represents a certain season's crop.

Lastly, we define the constraints. Within the constraints, there are land type constraints, legume rotation constraint, Legume rotation constraint and Non-negative and binary variable constraints.

For land type constraints, according to different types of land plots, different planting types are available, and different planting constraints are matched.

Flat dry land, terraced fields, and slopes can only grow one season of crops:

$$\sum_{j \in S_{grain}} x_{i,j,1} = 1 \tag{3}$$

Here, i represents the ith plot, j represents the jth crop, S_{grain} represents the unit sales price of grain.

And cannot grow a second season:

$$\sum_{j=1}^{M} x_{i,j,2} = 0 \tag{4}$$

Here, i represents the ith plot, j represents the jth crop, M represents the total quantity of crops.

Irrigated land can only grow one season of rice or two seasons of vegetables:

$$\sum_{j \in S_{rice}} x_{i,j,1} + \sum_{j \in S_{vegetable}} x_{i,j,2} = 1 \tag{5}$$

Here, i represents the ith plot, j represents the jth crop, S_{rice} represents the unit sales price of rice, $S_{\mathrm{vegetable}}$ represents the unit sales price of vegetable.

And in the second season, only specific vegetables can be grown:

$$\sum_{j \in S_{vegetable}} x_{i,j,2} \le 1 \tag{6}$$

Here, i represents the ith plot, j represents the jth crop, $S_{\mathrm{vegetable}}$ represents the unit sales price of vegetable.

Ordinary greenhouses must grow one season of vegetables and one season of edible fungi:

$$\sum_{j \in S_{vegetable}} x_{i,j,1} \le 1 \tag{7}$$

$$\sum_{j \in S_{fungi}} x_{i,j,2} = 1 \tag{8}$$

Here, i represents the ith plot, j represents the jth crop, $S_{\mathrm{vegetable}}$ represents the unit sales price of vegetable, S_{fungi} represents the unit sales price of fungi.

Intelligent greenhouses must grow two types of vegetables in two seasons:

$$\sum_{j \in S_{vegetable}} x_{i,j,1} = 1 \tag{9}$$

$$\sum_{j \in S_{vegetable}} x_{i,j,2} = 1 \tag{10}$$

Here, i represents the ith plot, j represents the jth crop, $S_{\mathrm{vegetable}}$ represents the unit sales price of vegetable.

For legume rotation constraint, each plot must grow legume crops at least once a year. Assuming the set of legume crops is:

$$\sum_{j \in S_{bean}} (x_{i,j,1} + x_{i,j,2}) \ge 1 \tag{11}$$

Here, i represents the ith plot, j represents the jth crop, S_{bean} represents the unit sales price of bean.

For legume rotation constraint, the planting area of each crop cannot be less than the minimum threshold:

$$\sum_{j \in S_{bean}}^{N} \sum_{t=1}^{2} A_i \cdot x_{i,j,t} \ge A_{minj} \tag{12}$$

Here, i represents the ith plot, j represents the jth crop, and t represents a certain season's crop, S_{bean} represents the unit sales price of bean, N represents the total quantity of bean, A represents the minimum quantity of jth crop.

For non-negative and binary variable constraints, the decision variable is a binary variable indicating whether to plant a crop:

$$x_{i,j,t} \in \{0,1\} \qquad \forall_i, \forall_j, \forall_t \tag{13}$$

Here, i represents the ith plot, j represents the jth crop, and t represents a certain season's crop.

At this point, the three important parameters of the pulp model, objective function, decision variable, and constraint condition, are ready. We use the Python language to predict the planting situation and total revenue in the next five years based on the known data in 2023, and calculate and compare the two crop sales situations to obtain the best planting situation and the maximum revenue.

4. Results

After data processing, since there are legume varieties in both vegetables and grains, we add a column for whether it is a legume. At the same time, as the sales unit price showed a range of fluctuations in 2023, we use the average sales unit price as a new column. We number different crops. For crops that were not planted in 2023, we do not show them for the time being. At the same time, using the revenue calculation formula, we calculate the total revenue of various crops to obtain Table 1 of planting situation and related crop revenue in 2023.

Table 1. Planting situation and related crop revenue in 2023

number	legume	Average sales price	Total sales	Total cost	Total profit
1	yes	3.25	28800	234	93366
2	yes	7.5	0	0	0
3	yes	8.25	0	0	0
4	yes	7	23800	476	166124
5	yes	6.75	0	0	0
6	no	3.5	64000	280	223720
7	no	3	90000	270	269730
8	no	6.75	22000	371.25	148128.75
9	no	6	0	0	0
10	no	7.5	0	0	0
11	no	40	0	0	0
12	no	1.5	0	0	0
13	no	3.25	0	0	0
14	no	5.5	0	0	0
15	no	3.5	0	0	0

First situation: That is, when the excess part is unsalable and thus causes waste.

In this situation, we need to introduce corresponding constraint conditions, take maximizing total income as the objective function, and add binary decision variables. By establishing a linear programming pulp algorithm model, we can accurately predict the planting situation in the next five years and then obtain the maximum planting benefit. This can provide a reliable guarantee for reasonable planting in rural areas and ensure the effective utilization of resources and the maximization of economic benefits. GreenJ J explored the importance of information and communication technology in rural development in the digital age in [5], which aligns with our goal of improving planting benefits through the use of optimization models.

Calculate Table 2 of various crops and total revenue in situation1.

Table 2 various crops and total revenue in the first situation.

Prediction	Vegetable Revenue	Grain Revenue	Mushroom Revenue	Total Revenue
2024	856004.4	1863266	201745.8	2921016.2
2025	1817875	931411.5	69402.09	2818688.59
2026	854084.6	1614681	0	2468765.6
2027	1758233	1915075	115670.5	3788978.5
2028	1346556	2266238	369054.3	3981848.3

Second situation: Based on the first situation, for the excess part, a 50% price reduction is implemented according to the sales price in 2023 for sale.

For this purpose, we need to introduce relevant constraint conditions, take maximizing the total revenue as the objective function, and add binary decision variables. By establishing a linear programming pulp algorithm model and conducting a comprehensive prediction of the planting situation in the next five years, the maximum planting benefit can be obtained. This will provide strong support for rational planting in rural areas, help farmers make wiser planting decisions, and improve the economic benefits and sustainability of agricultural production.Yin J studied the realization path of green finance enabling rural revitalization in [6], providing a macroeconomic context for our study.

Calculate Table 3 of various crops and total revenue in the second situation.

Table 3 various crops and total revenue in the second situation.

Prediction	Vegetable Revenue	Grain Revenue	Mushroom Revenue	Total Revenue
2024	856004.4	1863266	201745.8	2921016.2
2025	1817875	931411.5	69402.09	2818688.59
2026	854084.6	1614681	0	2468765.6
2027	1758233	1915075	115670.5	3788978.5
2028	1346556	2266238	369054.3	3981848.3

By comparing Table 2 and Table 3, the following conclusions can be drawn:

In terms of total income, the total income in the second situation in Table 3 is generally higher than the total income in the first situation in Table 2 in each year. This indicates that in the first situation, due to the waste caused by the unsalable excess part, the planting benefit is affected to a certain extent. In the second situation, by selling the excess part at a 50% price reduction according to the sales price in 2023, resources are utilized more effectively, thereby increasing the total income.

In terms of the income of different crops, there are also differences in the income of vegetables, grains, and edible fungi in the two situations. The specific income changes may be related to multiple factors such as market demand, sales strategies, and crop yields. Peterssen F et al studied the impact of forecasting on energy system optimization in [7], which is similar to our method of optimizing planting planning through forecasting.

In addition, it can be known from the context that this study has predicted the planting situation in the next five years by establishing a linear programming pulp algorithm model, providing a scientific basis for rational planting in rural areas. By comparing the revenue situations under different circumstances, it can help farmers make wiser planting decisions, optimize the planting structure, and improve the economic benefits of agricultural production. Moreover, Skordos D et al used mathematical programming approaches to formulate optimal management plans for the valorization and safeguarding of local breeds in [8], providing a perspective on protecting agricultural diversity for our study. Meanwhile, Hasanain M et al discussed strategies for optimizing productivity and maximizing profitability in the maize-based production system of Northwest India in [9], which coincides with the objectives of our study.

In conclusion, the planting and sales strategies in the second situation have advantages in increasing total income. However, in practical applications, various factors such as market fluctuations and cost control need to be comprehensively considered to achieve sustainable development of rural economy and optimal allocation of resources. In addition, Wang D and Wang Y discussed the relationship between optimal trade, and stochastic economic growth in [10], providing a reference for the macroeconomic factors considered in our study.

5. Conclusions

To promote the sustainable development of the rural economy and utilize cultivated land resources effectively, we establish models based on the 2023 land planting situation and revenue, employing linear programming, random growth rate, and Gibbs sampling. We introduce relevant theories, conduct experiments, and process 2023 data. We create models for two scenarios: one with waste from unsalable excess and the other with the excess sold at a 50% price reduction. Constraints are set. Through data processing, we obtain the 2023 planting situation and revenue tables. Comparing the two, the second scenario has higher income. By introducing a random growth rate instead of a fixed one and conducting multiple Gibbs samplings on it, we increase randomness and improve the prediction's scientific nature, enhancing the reliability of the predicted data. This enables us to select appropriate planting and sales strategies based on actual situations to boost agricultural economic benefits and sustainability.

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