Predictive Planting Strategy Optimization Model for Crops Based on Linear Programming

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Abstract. Cropping strategies are important for crop planning in rural land. In rural areas, it is necessary to make full use of limited cultivated land resources, select suitable crops, make field management more convenient, reduce the planting risks that may be caused by various uncertain factors, maintain profits, and optimize planting strategies plays a vital role. In this paper, the method of linear programming is used to study the specific background of a simulated low temperature region in the North China Plain, and the optimal planting strategy model and the maximum return expectation optimization model are constructed with the goal of profit maximization. According to the unsalable market and the fluctuation of crop planting cost, the planting strategy with the goal of profit maximization is obtained by introducing RANDN random variables and RANDN functions, combined with the greedy algorithm to continuously optimize and approximate the global optimal solution with the local optimal solution.

Keywords: Linear Programming, Normal Distribution, RANDN Functions.

1. Introduction

Cropping strategies play an important role in the day-to-day management of the land on which crops are grown, the maintenance of the fertility of the land, and the profitability of income. At the same time, the expected planting cost, expected sales volume, expected sales price and unsalable situation of crops will fluctuate with the market situation, and the planting strategy needs to be adjusted according to the expected situation, so that crop planting can obtain the maximum profit under the condition of maintaining reasonable land ecological use constraints. In this paper, a low-temperature area in the North China Plain from 2024 to 2030 was taken as the research object, and a quantitative study was carried out from the perspectives of planting plot allocation, planting seasons, greenhouse use, heavy cropping, and sales fluctuations.

Dobor L, Barcza Z, Hlásny T assessed the impact of climate change on crop planting dates and yields [1], and Wu B, Li Q proposed a crop planting and type ratio (CPTP) method [2] for estimating crop acreage in complex and diverse agricultural landscapes. Sandhu N, Yadav S, Kumar Singh V studied the impact of modern management and breeding on the cultivation of rice crops [3]. Nambirajan A, Vahdat M, Sadegheih A presented an integrated strategic framework for large-scale crop planning: sustainable climate-smart crop planning and agri-food supply chain management [4], which was analyzed from the perspective of market operation. Amirahmadi E, Ghorbani M, Moudrý J do the effects of different plots of land such as dry land and irrigated land under compost conditions on the cultivation of crops such as winter wheat was considered [5]. Iswardani W considers the effective use of production factors, a production plan can be formulated that can most effectively meet the future market demand of hydroponic vegetable production, so as to achieve the best production cost and profit [6].

The above research is limited to a certain aspect, but the actual planting strategy should be affected by global factors and adjusted in time, and it is not a simple superposition of various factors. Moreover, especially in the market, the previous research was limited to putting forward strategic concepts and failed to give specific model analysis, which needs to be improved for the guidance of actual planting strategies. In this paper, the factors of planting area allocation, seasonal climate influence, market sales and other factors are comprehensively considered, and the optimal planting strategy model is given, and the research on approximating the global optimal solution is carried out by combining the greedy algorithm and linear programming, which provides a strong reference for the actual planting strategy. The data used in this paper are from the website of the National Mathematical Contest in Modeling.

2. Planting strategy model establishment

2.1. Optimal planting strategy model [7]

First, this paper obtains constraints based on the planting limits and crop growth characteristics given by regional assumptions.

(1) Adaptability constraints of plot type and crop type:

Define ternary decision variables:

$$\begin{cases} x_{i,j,k,t} \le a_{i,j,k,t} \cdot S_j \\ i \in \{1,...,41\},\ j \in \{A_{1,...,}F_4\}, \\ k \in \{1,2\}, t \in \{2024,......,2030\} \end{cases} \tag{1}$$

Where $x_{i,j,k,t}$ is acre planted in t of year k on land in category j crops of category i, $a_{i,j,k,t}=1$ is indicating that crop i can be planted on plot j in the k quarter of t year, $\{A_{1,...,}F_4\}$ is the crop plot number.

(2) The planting area of each plot (and greenhouse) per quarter cannot be greater than the total area of the plot, which is expressed as:

$$\begin{cases} \sum_i x_{i,j,k,t} \le S_j \\ i \in \{1,...,41\},\ j \in \{A_{1,...,}F_4\} \\ k \in \{1,2\}, t \in \{2024,......,2030\} \end{cases} \tag{2}$$

(3) Seasonal planting restrictions:

The planting method of ordinary greenhouses is relatively fixed, and only one season of vegetables and edible fungi can be planted every year, except for Chinese cabbage, carrots, and carrots:

$$\begin{cases} \sum_{i \in \{38,...,41\}} x_{i,j,1,t} \le S_j \\ \sum_{i \in \{17,....,34\}} x_{i,j,2,t} \le S_j \\ j \in \{E_1,...,E_{16}\}, D_j = D_5, t \in \{2024.....2030\} \end{cases} \tag{3}$$

The smart greenhouse can grow two seasons of vegetables other than Chinese cabbage, carrots and carrots every year:

$$\begin{cases} \sum_{i \in \{17,...,34\}} x_{i,j,k,t} \le S_{F\,j} \\ j \in \{1,2,3,4\}, D_j = D_6 \\ k \in \{1,2\}, t \in \{2024.....2030\} \end{cases} \tag{4}$$

(4) Restraint on heavy planting is prohibited:

For each plot j, the same crop i cannot be planted in succession for two or two consecutive seasons in the adjacent plot. Using the 0-1 decision variable, the sum of the 0-1 decision variables of the same crop in the same two seasons and two adjacent crops in the same year cannot be greater than 1.

$$\begin{cases} a_{i,j,k,t} + a_{i,j,k+1,t} \le 1 \\ a_{i,j,k+1,t} + a_{i,j,k,t+1} \le 1 \end{cases} \tag{5}$$

(5) Limits on the frequency of planting of legume crops:

Each plot (and greenhouse) needs to be planted with legume crops (grain beans or vegetable legumes) at least once in 3 years:

$$\begin{cases} \sum_{t'=t}^{t+2} \sum_{i \in \{1,\ldots,5\}} x_{i,j,k,t'} \ge S_j \\ j \in \{A_1,\ldots,F_4\}, k \in \{1,2\}, t \in \{2024,\ldots,2028\} \end{cases} \tag{6}$$

(6) Considering the flat and dryland, terraced and hillside lands are suitable for one crop per year of food crops other than rice:

$$\begin{cases} \sum_i x_{i,j,1,t} \le S_j, i \in \{1,\ldots,15\} \\ j \in \{A_{1,\ldots,}F_4\}, t \in \{2024,\ldots,2030\} \end{cases} \tag{7}$$

Here are two cases to get the respective objective functions:

$$P_{i,t} = x_{i,j,k,t} \cdot q_i \tag{8}$$

Where $P_{i,t}$ is total production of category i crops in year t.

Situation 1: More than part of the unsalable, resulting in waste:

$$Max: Q_1 = \sum_{t=2024}^{2030} \sum_{k=1}^{2} \sum_i (r_i \cdot \min(p_{i,j,k,t}, Y_i) - c_i \cdot \sum_j a_{i,j,k,t} \cdot x_{i,j,k,t}) \tag{9}$$

Where $\min(p_{i,j,k,t}, Y_i)$ is representing the normal sales volume in the k quarter of the year t, taking the production volume and the expected sales volume to the minimum, c_i indicates the cost of planting, Q is the profit.

Situation 2: The excess part will be sold at a reduced price of 50% of the 2023 sales price.

$$Max: Q_2 = \sum_{t=2024}^{2030} \sum_{k=1}^{2} \sum_i (r_i \cdot \min(p_{i,j,k,t}, Y_i) + 0.5 \cdot r_i \cdot \max(p_{i,j,k,t} - Y_i, 0) - c_i \cdot \sum_j a_{i,j,k,t} \cdot x_{i,j,k,t}) \tag{10}$$

Where $\max(p_{i,j,k,t} - Y_i, 0)$ is indicating the portion of the sales volume that exceeds the expected amount, $p_i^{'} = 0.5 p_i$ indicating the reduced sales price of the excess of the i crop.

2.2. Maximum-benefit expectation optimization model

According to the assumption, the expected sales volume of crops, the yield per acres, and the changes of edible fungus crops are in a fixed range according to the assumption, and the changes have obvious uncertainties, so this paper introduce RANDN variables, assume that they obey the normal distribution, and use the RANDN function to generate RANDN numbers that obey their distributions as the objective function into the expected total return.

(1) The expected sales volume of wheat and corn is defined by 5%~10% per year:

$$\begin{cases} Y_i(t) = Y_i(2023) \cdot (1+\alpha_{i,t}) \\ \alpha_{i,t} \in [0.05, 0.10], i \in \{6,7\}, t \in \{2024, ..., 2030\} \end{cases} \tag{11}$$

Where Y is the expected sales volume of the i crop, α is the growth ratio.

Expected sales volume changes for other crops in the range of [-0.05,0.05]:

$$\begin{cases} Y_i(t) = Y_i(2023) \cdot (1+\theta_{i,t}) \\ \theta_{i,t} \in [-0.05, 0.05], \forall i \notin \{6,7\}, t \in \{2024, ..., 2030\} \end{cases} \tag{12}$$

(2) Change in yield per acre:

The yield per acre of crops varies by 10% from year to year:

$$\begin{cases} q_i(t) = q_i(2023) \cdot (1+u_{i,t}) \\ u_{i,t} \in [-0.1, 0.1], i \in \{1, ..., 41\}, t \in \{2024, ..., 2030\} \end{cases} \tag{13}$$

Changes in the cost of cultivation:

Growing costs are growing by an average of 5% per year:

$$\begin{cases} c_i(t) = c_i(2023) \cdot (1+0.05)^{t-2023} \\ i \in \{1, ..., 41\}, t \in \{2024, ..., 2030\} \end{cases} \tag{14}$$

(3) Changes in selling prices:

The selling price of vegetable crops is increasing by 5% per year:

$$\begin{cases} r_i(t) = r_i(2023) \cdot (1+0.05)^{t-2023} \\ i \in \{17, ..., 37\}, t \in \{2024, ..., 2030\} \end{cases} \tag{15}$$

The sales price of edible mushroom crops decreases by 1%~5% every year:

$$\begin{cases} r_i(t) = r_i(2023) \cdot (1-v_{i,t}) \\ v_{i,t} \in [0.01, 0.05], i \in \{38, ..., 41\}, t \in \{2024, ..., 2030\} \end{cases} \tag{16}$$

After considering the uncertainties, the objective function should be the maximization of the expected total return, which is solved in two cases:

Situation 1: More than part of the unsalable, resulting in waste.

$$Max : E[Q_1] = \sum_{t=2024}^{2030} \sum_{k=1}^{2} \sum_{i} E[r_i(t) \cdot \min(p_{i,j,k,t,}, Y_i(t)) - c_i(t) \cdot \sum_j a_{i,j,k,t} \cdot x_{i,j,k,t}] \tag{17}$$

Scenario 2: The excess part will be sold at 50% of the 2023 sales price.

$$Max : E[Q_2] = \sum_{t=2024}^{2030} \sum_{k=1}^{2} \sum_{i} E[r_i(t) \cdot \min(p_{i,j,k,t,}, Y_i(t)) + r_i{}'(t) \cdot \max(p_{i,t,k} - Y_i(t), 0) - c_i(t) \cdot \sum_j a_{i,j,k,t} \cdot x_{i,j,k,t}] \tag{18}$$

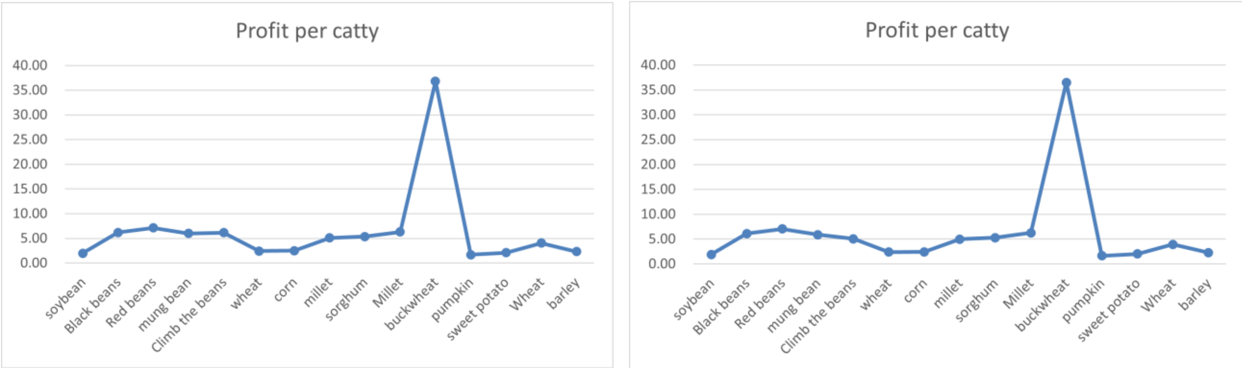
Thereinto:

$$\begin{cases} p_i{}'(t) = 0.5 \cdot p_i(2023) \\ p_{i,k,t} = \sum_j a_{i,j,k,t} \cdot x_{i,j,k,t} \cdot q_i(t) \end{cases} \tag{19}$$

3. Results

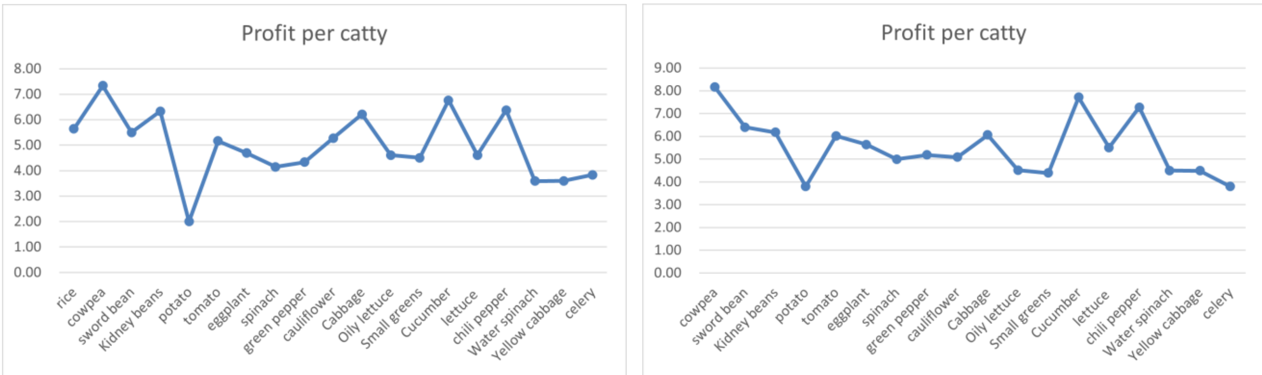
3.1. Results and analysis of optimal planting strategy model

According to the crop planting situation in 2023, this paper can obtain the planting profit per unit area of various crops, that is, this paper can take the total profit as the objective function, and then obtain the constraints according to the characteristics and limitations of the planting crops in different plots and greenhouses, and linear programming to find the planting strategy when the income is maximized, which is regarded as the optimal planting scheme. Therefore, the data was preprocessed, and the profit per acres area was used as the standard to arrange each crop in descending order to obtain the yield profit of the crop. Planting profit per mu of each crop is shown in Figure 1 and Figure 2.



(1) Flat dryland (2) Watered land for

Figure 1. Profit per acres of some crops



(1) Watered land (2) Smart greenhouse

Figure 2. Profit per acres of some crops

As can be seen from the first and second plots in Figure 1 and Figure 2, different crops will have different profits on the same type of planting plot, and there are obvious differences when the same crop is planted on different planting plots, so the allocation of priority planting plot area can be carried out on this basis. The algorithm for solving the model is as follows:

(Step 1) The plots that need to be planted are divided into 7 categories, and 4 two-dimensional arrays are generated for "planting crops";

(Step 2) According to the constraints, the 0-1 variable $a_{i,j,k,t}$ for crops that cannot be grown on each plot is set to 0;

(Step 3) Add an array of bean counts to each plot to determine whether the legume crop has been planted in the last three years to ensure soil fertility;

(Step 4) Add an array of duplicate planting counts to each plot to determine if the same crop is planted consecutively;

(Step 5) According to the profit per acres area of each crop, each planting crop is arranged in descending order, and the crop planting priority sequence arranged by profit is generated for each plot;

(Step 6) Combined with the idea of greedy algorithm [8], the crops with high profits per acres area are preferentially planted in order to obtain the local optimal solution [9] [10];

(Step 7) The model is continuously optimized by linear programming, so that the obtained local optimal solution is close to the global optimum.

The result is shown in the table below:

Table 1. Strategies for planting first season crops

Parcel name	soybean	Black beans	Red beans	mung bean	Climb beans	wheat	corn	millet
A1	0	21.876	0	0	0	0	0	0
A2	0	21.831	0	0	0	0	0	0
A3	0	0	13.175	0	0	0	29.17	0
A4	0	0	42.831	0	0	55.402	68.008	0
A5	0	0	0	0	0	46.768	35.581	0
A6	0	0	0	0	19.428	40.341	0	0
B1	0	0	0	0	4.597	28.000	0	0
B2	0	0	0	0	0	25.123	0	55.611
B3	0	0	0	0	0	30.388	0	55.201
B4	0	0	0	58.402	0	0	0	44.129
B5	0	0	0	25.342	0	0	0	33.284
B6	0	0	0	16.715	0	0	0	0
B7	26.592	0	0	0	0	0	0	0

Table 2. Strategies for planting second season crops

Parcel name	Cucumber	lettuce	Water spinach	Yellow cabbage	Chinese cabbage	White radish	carrot	Elm mushroom
A1	0	0	0	0	15	0	0	0
A2	0	0	0	0	10	0	0	0
A3	0	0	0	0	5	9	0	0
A4	0	0	0	0	0	6	0	0
A5	0	0	0	0	0	10	0	0
A6	0	0	0	0	0	0	12	0
B1	0	0	0	0	0	0	0	0
B2	0	0	0	0	0	0	0	0
B3	0	0	0	0	0	0	0	0.600
B4	0	0	0	0	0	0	0	0.600
B5	0.367	0	0.333	0	0	0	0	0.600
B6	0	0	0	0	0	0	0	
B7	0	0	0	0	0	0	0	

Planting schemes is shown in Table 1 and Table 2. This paper uses a table to show a representation of the planting strategy for each plot, which shows a portion of the year and the rest of the strategies can also be represented in this way.

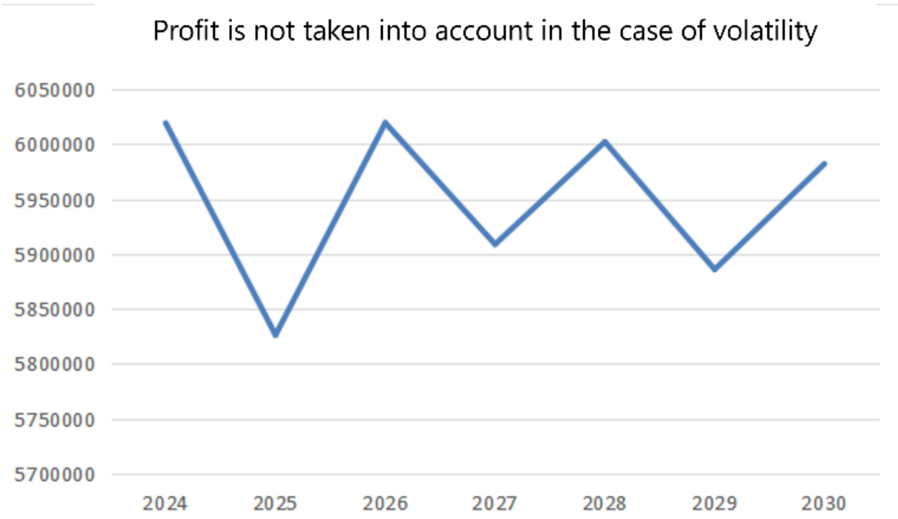


Figure 3. 7-year profit without taking into account volatility

Total crop planting profit for each of the next 7 years is shown in Figure 3, which fluctuates between 5,825,000 yuan and 6,025,000 yuan, which is in a reasonable range and maximizes the profit and income. However, since fluctuations in sales prices and planting costs have not been taken into account, the trend is also volatile.

3.2. Maximum Benefit Expectation Optimization Model Results and Analysis

In this model, the expected sales volume, yield per acres, planting cost and sales price uncertainty of various crops and potential planting risks should be comprehensively considered, and the optimal planting scheme of crops in this region in 2024~2030 should be given.

In the model of this region, the planting changes of related crops are given, in which the expected sales volume, yield per acres, and edible mushroom crops are in a fixed range, and the changes have obvious uncertainties, so this paper introduce RANDN random variables, and assume that they obey the normal distribution, and use the RANDN function to generate RANDN random numbers [11] that obey its distribution as the predicted value, and the objective function can be transformed into the expected value of total return.

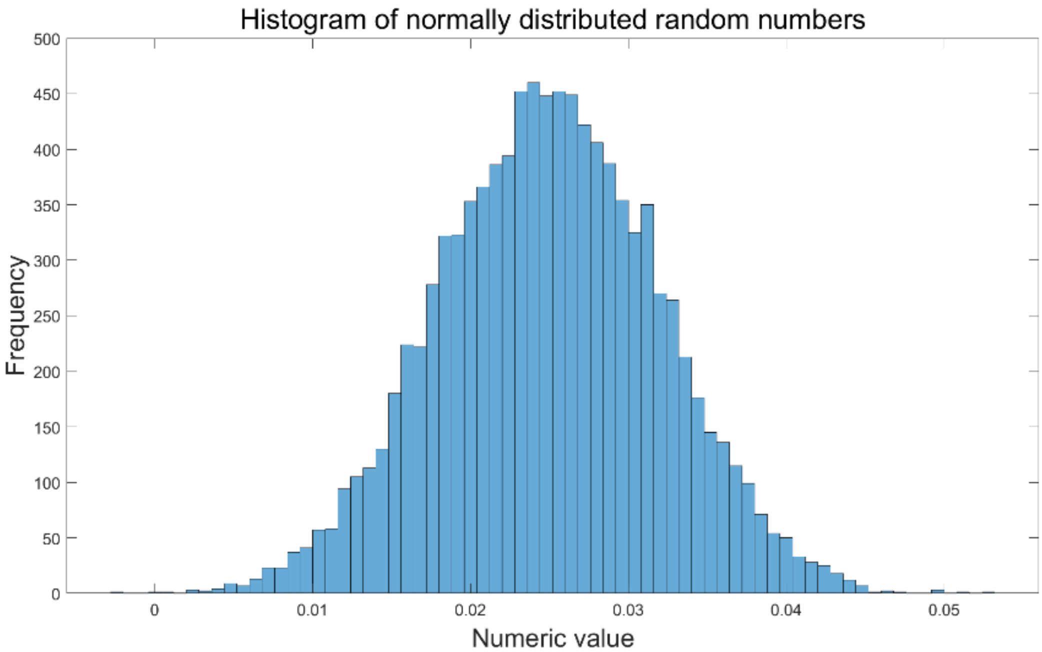


Figure 4. An example of a RANDN function that generates a random number

An example of a normal distribution is shown in Figure 4. As shown in Figure 4, the RANDN function is used to generate random numbers [12] that obey the normal distribution, which can be used as the values for the fluctuations of planting costs and selling prices in the next year, so that the planting strategy can adapt to the adjustment of the fluctuation range.

In addition, the rest of the crop is planted with the same or constant percentage change, which still applies to the constraints of the optimal planting strategy model.

Then, through linear programming, the planting strategy under the maximization of expected profit at this time is also obtained, and the planting table diagram shown in Figure 3.4 is obtained, and the comparison chart of the expectation theory shown in Figure 5 is obtained based on this.

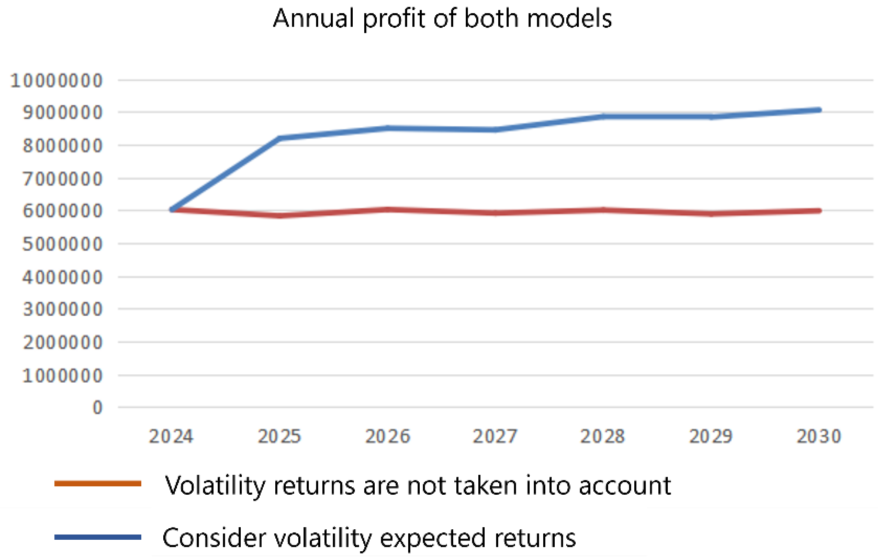


Figure 5. Comparison of annual profits in both cases

Comparison of profits between the two models is shown in Figure 5. As can be seen from Figure 5, the expected profit has risen significantly after considering the volatility, and the overall trend is on the rise, while the range is relatively stable when the volatility is not considered, which is in line with the established understanding. The results show that the RANDN function simulation has played a good role and provides a feasible path for the optimization of planting strategy.

4. Conclusions and outlooks

In this paper, when considering the optimal planting strategy, the preferential planting crops were determined based on the profit per acres, the planting conditions and crop growth characteristics of the plots were reused, the constraints were determined, and the selection constraints of the planting crops were carried out, and the optimal planting strategy model was established. When considering the influence of various market factors on the fluctuation of planting crops, the RANDN function is used to generate the values within a certain known range, and the prediction of the next year is carried out, and the maximum return expectation optimization model is established, and the expected profit is significantly improved. In the planting plan under the existing background, the total income in 7 years is 41642943 yuan without considering market fluctuations, and the average annual income per mu is 4957 yuan. After considering the market fluctuations, the total income for 7 years was calculated to be 57902987 yuan, and the average annual income per mu of land was 6893 yuan, which achieved the optimization goal. Through the two models, the maximum planting profit under this method is obtained, which solves the problem of decision-making and optimization of planting strategy, provides constructive suggestions for the development of planting agriculture, and also provides research ideas for planning problems such as industrial production and resource allocation.

In this paper, the idea of greedy algorithm is used in the planning model, and the profit per acres is taken as the priority planting object, and the global optimal solution cannot be directly obtained.

Under the revenue maximization model, high-profit crops obviously have more advantages in planting strategies, so the diversity of crop types is not large enough, and they are in a disadvantageous position to cope with the diversified needs and fluctuations of the market.

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