Research on optimal planting strategy risk based on Monte Carlo method

Shiyi Guan *, Can Gao

School of Information Management and Mathematics, Jiangxi University of Finance and Economics, Nanchang, China, 330032

* Corresponding Author Email: Shirley000333@163.com

Abstract. With the increasing uncertainties posed by global climate change, frequent natural disasters, and market fluctuations, along with evolving policy changes, crop cultivation is encountering an array of risks and challenges. While risk factors associated with crop growth and marketing have been extensively studied over the years, there remains a significant gap in research focused on developing optimal planting programs that effectively incorporate these risk factors. This paper addresses this gap by utilizing an open data set as a case study. It draws upon existing planting schemes and sets annual profit maximization as its primary objective. By integrating the Monte Carlo method, the research aims to formulate a sustainable planting strategy that consistently enhances annual profits despite prevailing uncertainties. The proposed planting strategy not only minimizes potential losses arising from various risks faced during the planting and marketing processes but also enhances production efficiency. Furthermore, it contributes to the overall development of agricultural production by fostering resilience against unpredictable challenges. This approach not only supports farmers in making informed decisions about their planting schedules and crop selections but also promotes long-term sustainability in agricultural practices. Ultimately, the findings of this research hold the potential to significantly benefit both individual farmers and the broader agricultural sector.

Keywords: Monte Carlo Principles, Risks, Planting Strategies.

1. Introduction

Under the dual pressures of global population growth and accelerating urbanization, the agricultural sector is facing major challenges to ensure food supply and achieve sustainable development. Predicting future planting and sales trends, exploring efficient crop planting strategies, and integrating crop growth characteristics, environmental adaptability and modern technology are the keys to increasing yields, optimizing resource allocation, and reducing environmental burdens. Scientific forecasting of land and market demand aims to ensure food security, promote ecological balance and rural economic development, and lay the foundation for sustainable agriculture.

In the field of modern agricultural management, with the impact of risk management and climate change, scholars began to pay attention to the construction of a more comprehensive agricultural risk prevention system. Li et al. discussed the modern smart agricultural management system based on the concept of "five in one", emphasized the importance of comprehensive management, and provided a new perspective for improving agricultural management efficiency [1]. In terms of planting risk, Jin et al. conducted a detailed analysis of crop seed planting in Jilin Province, identified a variety of risk factors, and proposed corresponding quality improvement strategies [2]. At the same time, Deng Zhenyong et al. (2012) studied the influence of climate warming and drying on agricultural planting structure in four provinces (autonomous regions) in Northwest China and proposed corresponding adjustment plans [3]. In terms of specific crop insurance mechanisms, Wang's research focused on the meteorological index insurance pricing of tea in Hubei Province, and provided theoretical basis for insurance product design through risk regionalization, indicating the key role of meteorological factors in agricultural insurance [4]. In addition, Tong et al. studied the application of financial instruments in agricultural risk management through the empirical analysis of cotton planting in Jinan [5]. Finally, Zou et al. put forward a series of technical measures for the risk assessment of rice varieties cultivation in Anhui province, emphasizing the importance of scientific assessment means in ensuring agricultural production safety. These studies jointly reflect the close correlation between risk management and resource allocation optimization in modern smart agriculture construction, as well as the necessity of continuously improving planting quality and economic benefits [6]. There are few studies on the optimization of planting plan for predicting natural factors and factors such as crop planting cost and sales. Therefore, this paper takes open data set as an example to explore effective crop planting strategies, aiming at improving agricultural production efficiency and realizing optimal allocation of resources. By combining modern technology and traditional farming methods, it provides scientific basis for sustainable agricultural development.

The rest of this article is organized as follows. The second section introduces the basic principle of Monte Carlo method. In the third section, Monte Carlo method is used to build a model to predict the annual average rate of change of various risk factors. Section 4 quantifies the impact of risk factors on annual profits by combining the average annual change rate of risk factors with existing planting models [7]. The fifth section summarizes the full text.

2. Monte Carlo Fundamentals

2.1. Theoretical basis

According to Bernoulli's theorem of large numbers, N independent repeated experiments are carried out, and the frequency of event A occurs with the increase of the number of experiments $\frac{n_A}{N}$ converges in probability to the probability of event A occurring p_A. According to Hinchion’s theorem of large numbers, an independently equally distributed sequence of random variables $x_1, x_2, x_3, ..., x_n$, have mathematical expectations μ, A sample taken from a random sequence is denoted as a set X_S, then there is $E(X_S) = \mu$, that is, as sample n increases, the sample mean converges to the population mean. According to Chebyshev's theorem of large numbers, a sequence of random variables is set $x_1, x_2, x_3, ..., x_n$, pairings are uncorrelated and expectations exist $E(X_i) = \mu_i$, the variance exists and has a common bounded upper limit, i.e. : $D(X_I) = \sigma_i^2 < M$, as the sample size increases, the sample mean converges to the population mean. Among them, Bernoulli's theorem of large numbers reveals the relationship between frequency and probability. Hinchion’s theorem of large numbers reveals the relationship between arithmetic mean and mathematical expectation. Chebyshev's theorem of large numbers reveals the relationship between sample mean and real expectation. Compared with synching’s theorem of large numbers, Chebyshev's theorem of large numbers does not require random traversal of the same distribution and is more general. In general, the theorem of large numbers connects mean values in mathematical statistics with expectations in probability theory.

2.2. Monte Carlo method

Monte Carlo method, also known as statistical simulation method and statistical experiment method, is a numerical simulation method that takes probabilistic phenomena as the research object due to the development of science and technology and the invention of electronic computers in the mid-1940s, and is a calculation method to obtain statistical values according to sampling survey method to infer the characteristic quantity of position. By constructing a probabilistic model and conducting random experiments on a digital computer, the method is suitable for simulation experiments on discrete systems, especially for some problems that are difficult or even impossible to be solved by analytical methods.

Monte Carlo method is a method and strategy based on the theorem of large numbers, which uses the frequency of sample occurrence to estimate the probability, so it obtains an approximate solution rather than an exact solution [8]. With the increase of the sample, the approximate solution is closer and closer to the exact solution.

Assumption required calculation $I=\int_a^b g(x)dx$, where the integrand function $g(x)$ in $[a,b]$ internally integrable, let's choose a probability density function $f_X(x)$ way to sample, And the probability sum of the sampled function at $[a,b]$ is guaranteed to be 1, namely $\int_a^b f_X(x)dx=1$, then the original integral can be written as formula (1).

$$\begin{aligned} I &= \int_a^b \frac{g(x)}{f_X(x)} f_X(x)dx \\ &= \int_a^b \frac{g(x)}{f_X(x)} dx \cdot \int_a^b f_X(x)dx \\ &= \int_a^b \frac{g(x)}{f_X(x)} dx \end{aligned} \tag{1}$$

Sampling is done in the form of probability density function $f_X(x)$, With N samples, the above equation can be written in discrete form: $I^{'}=\frac{1}{N}\sum_{i=1}^{N}\frac{g(x_i)}{f_X(x_i)}$, then there is $I^{'}\approx I$.

3. Experiment

This section will take open data sets as an example to discuss how to formulate corresponding planting strategies in the face of possible risks in agricultural production and marketing, so as to improve agricultural production efficiency and realize optimal allocation of resources. The data in this paper comes from a public data set of a contest (https://cumcm.cnki.net/cumcm/Login/LoginIndex). The specific process of the experiment is shown in Figure 1.

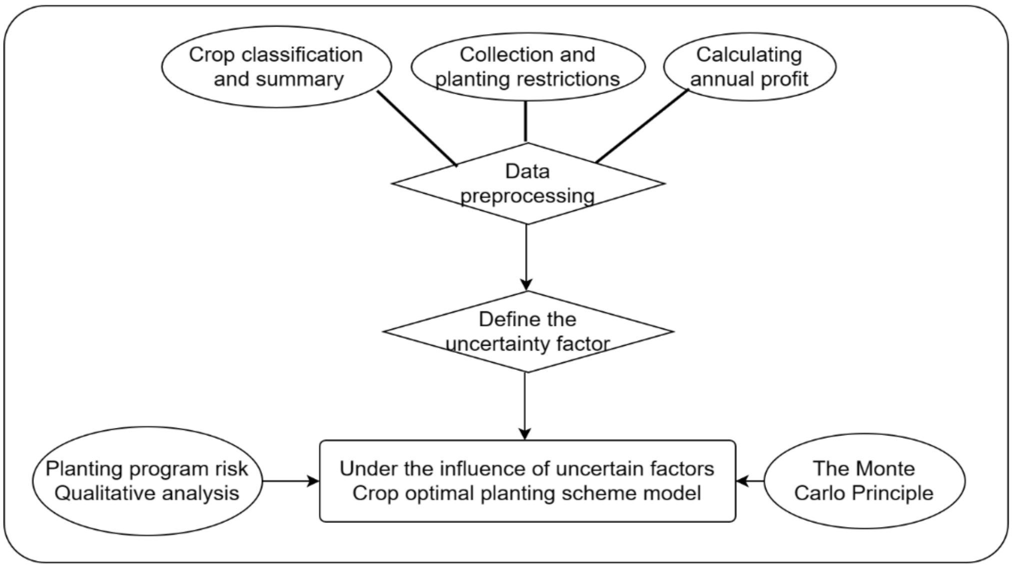

Figure 1. Research flow chart

3.1. Identify the impact factors affecting the planting scheme

In real life, many factors, such as climate, natural disasters, market conditions and economic environment, all constitute a series of uncertain factors affecting crop output, sales and profitability. These factors are not only complex and changeable, but also interwoven, and jointly affect every link of agricultural production. Specifically, natural conditions such as light, precipitation and wind, which are climate factors, have a crucial impact on the yield and quality of crops. At the same time, natural disasters such as floods, droughts, pests and diseases often have a direct and serious impact on agricultural production, resulting in crop reduction or even collapse. In terms of market conditions, the price, demand and competition pattern of agricultural products directly affect the sales strategy and profitability of farmers. In addition, the economic environment, such as national policies, agricultural production costs and international agricultural product market trends, also has a profound impact on the overall efficiency of agricultural production.

Based on the publicly available data set, the following four impact factors are obtained.

(1) Expected sales

Suppose that the average annual rate of change of the expected sales volume of wheat and corn is α_1, α_1 satisfy: $5\% \le \alpha_1 \le 10\%$; Suppose the average annual rate of change of the expected sales of other crops in the future is α_2, α_2 satisfy: $-5\% \le \alpha_1 \le 5\%$.

(2) Acre yield

The per acre yield of crops is often affected by climate and other factors, and the average annual rate of change of per acre yield is β, β satisfy: $-10\% \le \beta \le 10\%$.

(3) Planting cost

Due to the influence of market conditions, the planting cost of crops will also change to a certain extent, and the average annual change rate of planting cost is σ, σ satisfy: $0\% \le \sigma \le 5\%$.

(4) Selling price

The selling prices of grain crops were basically stable. The average annual change rate of the selling price of vegetable crops is set as λ_1, λ_1 satisfy: $\lambda_1 \approx +5\%$; The average annual change rate of the selling price of edible fungi is set as λ_2, λ_2 satisfy: $-5\% \le \lambda_2 \le -1\%$; the average annual change rate of the selling price of Morchella is set as λ_3, λ_3 satisfy: $\lambda_3 \approx +5\%$.

3.2. Analysis of planting scheme under the influence of single factor

Based on the Monte Carlo method, the values of other uncertain factors remain unchanged, the value of an uncertain factor is randomly floated within the value range of 1%, and the value is substituted into the existing planting scheme [9], and the total profit of the planting scheme under different floating ranges is calculated respectively. The line diagram for risk analysis of planting scheme as shown in figure 2 and 3 was obtained.

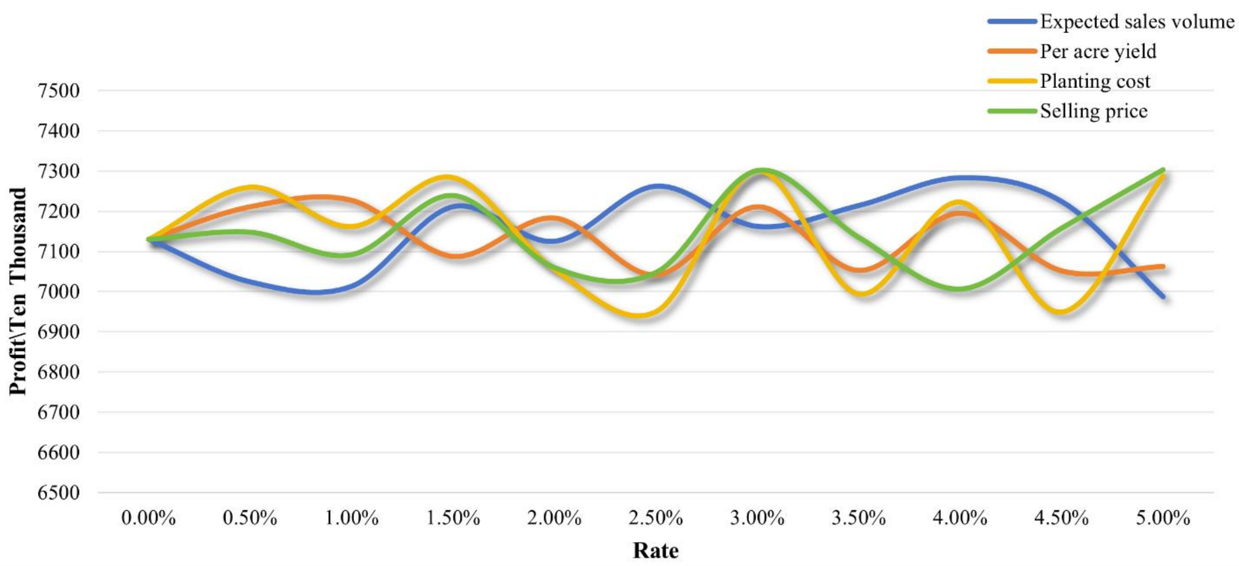

Figure 2. Line diagram of risk analysis of planting scheme I

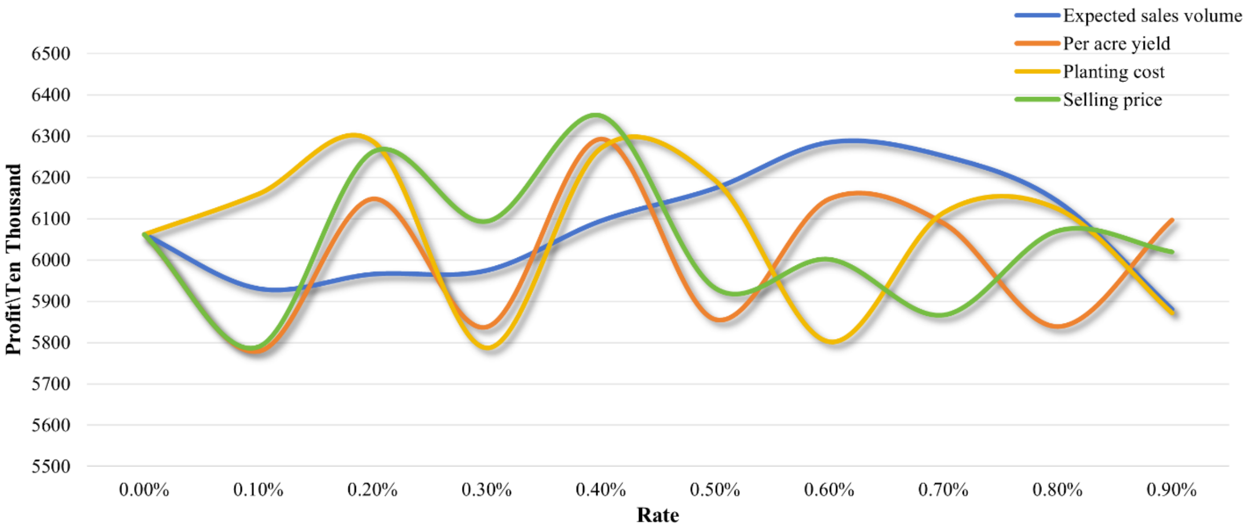

Figure 3. Line diagram of risk analysis of planting scheme II

According to figure 2 and 3, under the consideration of a certain risk factor in the process of crop planting, production and sales, the annual profit of the planting scheme obtained through the existing planting scheme planning model will be affected with a large fluctuation range.

Therefore, if the risks in the future planting and sales process are not predicted, sowing according to the previous planting plan will lead to large profit fluctuations, further causing instability in farmers' income and decreased planting willingness, affecting rural economic development and causing social instability.

Therefore, the text incorporates the above risk factors into the factors that need to be considered in optimizing the planting plan, and combine the Monte Carlo idea to comprehensively consider the average annual change rate of the four uncertain factors of expected sales volume, per mu yield, planting cost and selling price of various crops, as shown in formula (2). Where, i, j and k are planting field number, planting season number and crop number respectively. T_{ikj} , z_{ikj} , c_{ikj} , w_{ikj} Respectively represents the total output, unit price of sales, area, planting cost, planting or not of the j crop planted in the k season in the i-planting site.

$$\sum_i \sum_k \sum_j (T_{ikj} \times (1+\beta) \times z_{ikj} \times (1+\lambda_j) - x_{ikj} \times c_{ikj} \times (1+\sigma)) \times w_{ikj} \tag{2}$$

4. Result

After several simulations, the average annual rate of change of the four uncertainty factors in each year from 2024 to 2030 under the goal of maximizing total profit is obtained, as shown in Table 1.

Table 1. The average annual rate of change of the four uncertainty factors from 2024 to 2030.

Year	Rate of change							
	Expected sales		Acre yield	Planting cost	Selling price			
	Wheat and corn	Other crops			Grain	Vegetable	Toadstool	Other edible fungi
2024	7.42%	5.03%	6.40%	5.01%	0%	5.02%	-5.00%	-2.33%
2025	7.48%	5.05%	6.87%	5.03%	0%	5.01%	-5.00%	-2.47%
2026	7.51%	5.00%	7.13%	4.99%	0%	5.04%	-5.00%	-2.39%
2027	7.49%	4.98%	7.04%	5.00%	0%	4.98%	-5.00%	-2.51%
2028	7.50%	4.99%	6.76%	4.98%	0%	5.00%	-5.00%	-2.34%
2029	7.51%	5.01%	6.91%	5.02%	0%	4.99%	-5.00%	-2.38%
2030	7.52%	5.02%	7.22%	5.03%	0%	5.01%	-5.00%	-2.29%

The above values of the average annual change rate are substituted into some existing planting schemes to calculate the annual profit and verify the influence of the above influencing factors on the annual profit. In each simulation, if the total profit difference between the simulated scheme and the current optimal planting scheme is large, the current optimal planting scheme is updated to the scheme with greater total profit; If the total profit difference is not large, the risk of this scheme and the current optimal scheme is qualitatively compared. If the risk of this scheme is smaller, the current optimal scheme is updated to this simulation scheme. On the basis of a large number of simulations, the optimal crop planting plan under the influence of uncertainty factors from 2024 to 2030 can be obtained. The change trend of total profit is shown in Figure 4, and the partial results of planting plan are shown in Table 2.

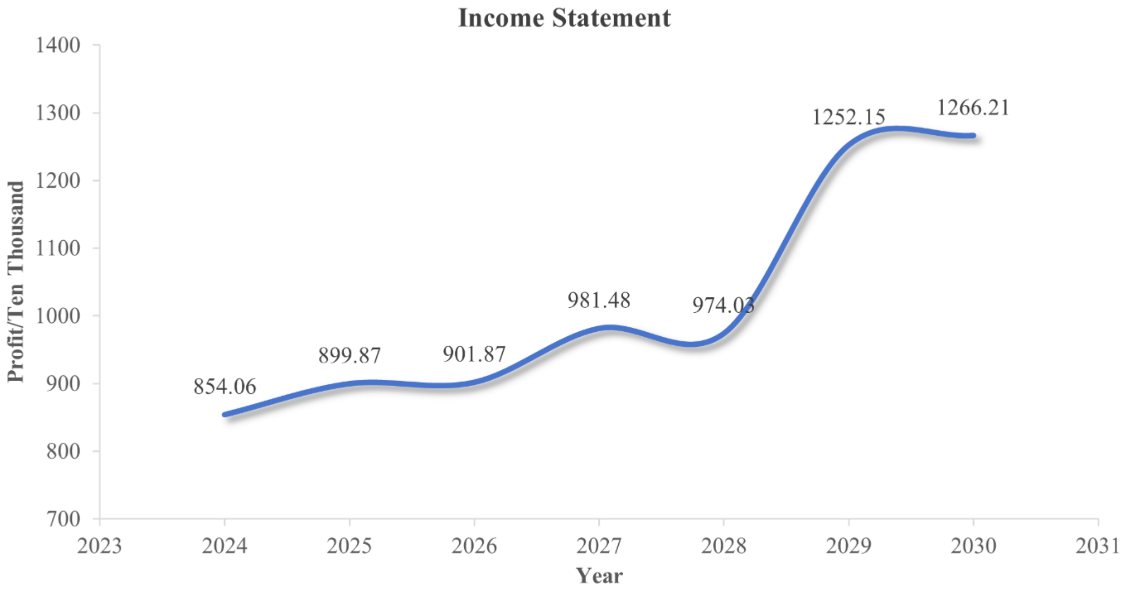

Figure 4. Total profit trend chart

Table 2. Omit table of optimal planting scheme of crops under the influence of uncertain factors

Season	Cultivated land	2024		…	2027		…	2030	
		Crop	Area/acres	…	Crop	Area/acres	…	Crop	Area/acres
Phase one	A1	Corn	56	…	Pumpkin	40	…	Buckwheat	30
		Pumpkin	24	…	Buckwheat	40	…	Sweet potato	50
		/	/	…	/	/	…	/	/
	A2	Corn	55	…	Sorghum	25	…	Pumpkin	55
		/	/	…	Broomcorn millet	20	…	/	/
		/	/	…	Buckwheat	10	…	/	/
…	…	…	…	…	…	…	…	…	…
Phase two	F3	Spinach	0.6	…	Brassica chinensis	0.6	…	Brassica chinensis	0.6
		/	/	…	/	/	…	/	/
		/	/	…	/	/	…	/	/
	F4	Eggplant	0.6	…	Water spinach	0.6	…	Eggplant	0.6
		/	/	…	/	/	…	/	/
		/	/	…	/	/	…	/	/

According to Table 2 and Figure 4, the following conclusions can be drawn:

After a comprehensive analysis of the annual crop planting situation in various types of planting areas, it was found that sweet potato and pumpkin were mainly planted in food crops, cucumber and water spinach were mainly planted in vegetable crops, and elm yellow mushroom was mainly planted in edible fungi.

Observing Figure 4, it can be intuitively seen that the annual total profit from 2024 to 2023 generally presents an upward trend. Among them, the total profit in 2028 has a downward trend, because in order to meet the constraint condition that each planting field must plant one season of pulses in three consecutive years, more planting fields in 2028 choose to plant pulses crops with relatively small profit per unit area.

After introducing four uncertain factors to optimize the objective function, the annual total profit has increased significantly compared with 2023, and the annual profit is between 8 million and 13 million. Therefore, the optimal planting plan under the common influence of multiple risks can be obtained, and the annual profit increases significantly over time, which is feasible.

5. Conclusion

In this paper, considering the risks that crops may face in the process of planting and marketing, this research first combined Bernoulli's theorem of large numbers, Synching’s theorem of large numbers and Chebyshev's theorem of large numbers as the theoretical basis of Monte Carlo method, and derived the Monte Carlo method by integrating examples. Based on the stochastic characteristics of Monte Carlo method, a risk factor assessment model is established to roughly predict the comprehensive annual average impact rate of risk factors in the next 7 years. By using the open data set and combining the existing planting plans, the crop planting plan from 2024 to 2027 was optimized, which effectively increased the annual forecast profit, expected growth of about 48.26% and provided an effective optimization plan for the planting strategy under the influence of various risks.

In the future, based on this optimal planting strategy model, further explore the impact of more risk factors such as climate change and market demand on agricultural planting, and optimize Monte Carlo simulation results by combining big data and artificial intelligence technology. At the same time, the composition of planting cost and its changing trend are analyzed deeply, and the cost control strategy is formulated. In addition, Monte Carlo principles are applied to agricultural supply chain risk assessment to provide a comprehensive risk management solution. Through these studies, it is expected to promote the scientific and intelligent management of agricultural planting risk, help farmers and agricultural enterprises to cope with market challenges, achieve sustainable development, and enhance economic and social benefits.

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