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Robust Optimisation Based Dynamic Programming Model for Crop Planning and Planting

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Abstract

Cultivated land is the basis of food production. Reasonable planning of cultivated land is crucial to increase food production, optimize resource utilization and maximize the economy. With the acceleration of global population growth and urbanization, cultivated land resources are becoming increasingly tense. Therefore, scientific planning of cultivated land can improve land use efficiency, ensure food supply, and prevent soil degradation and environmental pollution. In addition, reasonable cultivated land planning can also promote the improvement of agricultural productivity, increase farmers ' income, and provide stable food security for national economic development. Through literature review, this paper discusses the application of robust optimization technology in crop planning, and establishes a mathematical model based on actual data, aiming to provide sustainable farming schemes for rural agriculture. In the design process, we comprehensively considered the economic benefits, land fertility and crop diversity, and finally came up with a set of farming programs that can meet the needs of farmers and contribute to ecological protection to promote the healthy development of the rural economy.

Keywords: Cultivated Land Planning, Food Security, Robust Optimization, Sustainable Development, Crop Planting

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1 | Introduction

For the people and the country, arable land is always the most important guarantee for food production, so rational planning of arable land helps to increase food production, optimise the use of resources and maximise the economy. The key to arable land planning is to balance food production, environmental protection and economic benefits. As the global population grows and urbanisation accelerates, arable land resources are becoming increasingly tight. Scientific planning of arable land can not only improve land use efficiency and ensure food supply, but also prevent soil degradation and environmental pollution. In addition, rational arable land planning can increase agricultural productivity, promote farmers' income growth and provide a stable food base for economic development. Through modern farming techniques and crop rotation systems, we can achieve sustainable agricultural development and guarantee food security, while achieving a win-win situation in terms of economic benefits and ecological protection.

2 | Literature Review

In recent years, with the increase of uncertainty in agricultural production, the application of robust optimisation techniques in crop planning has gradually been paid attention to.Fu et al [1] proposed a multiple water allocation strategy under uncertainty conditions by means of an interval two-stage stochastic robust planning model, which effectively solved the optimisation problem of water resources in agricultural production.Yuan et al [2], on the other hand, researched the resource coupling of the water-land-food relationship, constructed a robust optimisation model to help solve the uncertainty of resource allocation in agricultural management and further promote the development of sustainable agriculture.

For crop rotation and production planning, Bhatia and Rana [8] optimised crop allocation using a linear programming model and proposed a mathematical approach to rationally allocate the acreage of different crops, focusing on resource constraints and the need to maximise returns. The model not only improves the overall efficiency of crop production, but also provides farmers with a scientific basis for decision making to cope with challenges such as uneven resource allocation and climate change.Fikry et al [3] proposed a robust crop rotation optimisation model considering water scarcity and net return uncertainty to provide farmers with a solution to maximise returns under resource constraints.Ke et al [4] studied uncertainty in multi-location cropping systems and developed an optimal production planning model to improve the overall efficiency of cross-regional cropping systems and ensure stable production in the face of variable conditions. In addition, Bhatia and Rana [8] used linear programming to optimise a crop allocation model, demonstrating a wide range of applications of mathematical optimisation methods in crop cultivation.

In terms of crop planting scheduling, Zhang and Swaminathan [5] proposed a method to improve crop productivity by optimising planting schedules, emphasising the importance of reasonable planting time for yield enhancement.Lin et al [6], on the other hand, proposed a solution for multi-objective crop planning by using a dynamic and simplified population optimisation algorithm, which particularly demonstrated its superiority in the areas of groundwater resource management and water-saving planting planning.Amini [9] addressed the limitations of traditional methods in facing complex objectives through fuzzy multi-objective planning. planning.Amini [9] addressed the limitations of traditional methods in facing complex objectives through fuzzy multi-objective planning and proposed a flexible optimisation scheme for crop planning.

Irrigation scheduling is also an important part of crop planning.Nguyen et al [10] optimised irrigation scheduling through an ant colony algorithm with an advanced crop system model, which greatly improved the efficiency of water resources and provided technical support for efficient crop production.Wang et al [7] proposed a water-saving cropping optimisation method in a crop planning study on the semi-arid Loess Plateau, which promoted the efficient utilisation of water resources in arid areas.

In summary, the application of robust optimisation, linear programming, ant colony algorithms and fuzzy optimisation in crop planning and management has provided important theoretical and technical support for sustainable agricultural development. These studies have effectively solved the uncertainty problems faced in agricultural production by optimising water allocation, crop rotation, planting timing and irrigation scheduling.

3 | Data Sources and Preprocessing

We have obtained information about arable land in a village, such as the number of arable land and the type of plots, the type of crops grown on arable land in the village in the year 2023, and the number of seasons of cultivation and the unit price of crops sold in the village. In order to make the crop sales in this village get higher economic benefits in the future and not to damage the soil environment of the cultivated land, this paper needs to establish a mathematical model by combining the actual cultivation situation in this village in 2023 with the information given by the network. In order to process and analyse the data, a careful overview of the information provided in the annexes is required. Due to the small size of the data and the relative simplicity of the information, a preliminary collation and correlation process can be undertaken.

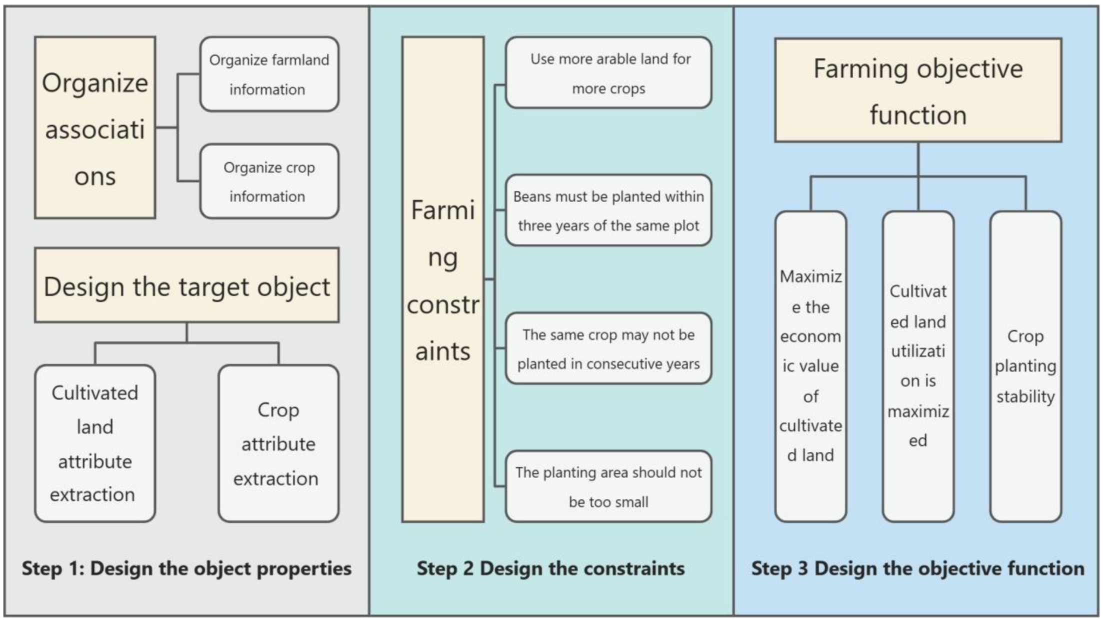

Figure 1 Flow chart of data pre-processing

4 | Modelling

This paper deals with the optimisation problem of crop cultivation and cropland allocation based on comparative data analysis. The actual planting process has several constraints, including that all arable land must be planted with legumes at least once in three years, and the same land cannot be planted with the same crop for two consecutive years. In addition, the planting area of each crop should not be too small to ensure its economic efficiency, and the planting area should also avoid being too dispersed to facilitate management and reduce costs. These constraints need to be fully considered in the optimisation model to develop the optimal planting strategy.

4.1 Constraints on the most appropriate planting programme

In designing rural farming programmes, it is important to look at the immediate interests of farmers. It is important to put yourself in the shoes of the farmer to bring about better and more economically viable benefits to the village that meet the needs of sustainable development. This includes considering the maintenance and improvement of land fertility, ensuring that farming profits are maximised, and increasing the abundance of crop varieties. By optimising cropping schemes, sustainable land use can be achieved, improving farmers' incomes and quality of life, as well as contributing to the development of rural economies. These factors must be taken into account when designing farming programmes to ensure that the needs and interests of farmers are maximised.

(1) The goal of economic value:

In designing farming programmes, priority should be given to crops that have a high demand and price in the market. These crops may include high-yielding food crops, vegetables, etc. By growing these crops with high economic value, farmers can make better profits and have the opportunity to expand their farming operations. At the same time, care needs to be taken to ensure that farmers do not make meagre profits or even lose money. This means that when choosing crops, factors such as the cost of cultivation, the unit price of sale and the yield of the crop need to be taken into account to ensure that farmers are able to make a reasonable profit.

$$\text{Economic value} = \text{crop yield} \times \text{crop unit price} - \text{planting cost} \tag{6}$$

(2) Targets for land fertility:

Firstly, to avoid soil nutrient imbalances, there is a need to ensure that planting planning takes into account the balance of soil fertility and to avoid problems caused by successive plantings of the same crop. Secondly, legume crops have the property of symbiosis with inter-root microorganisms, which can provide more nitrogen and improve the soil environment, which is beneficial to the growth of other crops. Therefore, planting legume crops should be considered in the planting optimisation model to improve soil nitrogen content. Finally, a reasonable crop rotation plan should be developed to ensure that different types of crops are planted in different time periods to maintain the balance and diversity of soil fertility. By taking these constraints into account and integrating them into the objective function, an optimal cropping programme can be achieved that improves land fertility, increases crop yield and quality, and reduces the risk of soil degradation.

$$\text{land fertility} = \frac{\text{required nutrient element content}}{\text{The content of available nutrient elements in the soil}} \times 100\% \tag{7}$$

(3) Crop abundance targets:

In the management of rural arable land, a balance should be struck between economic development and the sustainable development of the land from the perspective of the countryside, without neglecting the individual needs and overall interests of rural farmers. In addition to ensuring the richness of crop varieties, attention should be paid to factors such as ecological protection, social needs and cultural heritage. These should be taken into account in the optimisation model of agricultural cultivation to achieve sustainable rural development and farmers' well-being. By integrating economic, ecological, social and cultural factors, the optimal planting programme is developed to promote healthy land development, increase the yield and quality of agricultural products, and protect the ecological environment and cultural traditions.

$$\text{Crop abundance} = \frac{\text{Number of different crops planted}}{\text{Total number of crops planted}} \times 100\% \tag{8}$$

The framework of a multi-objective constrained model for farming in the countryside has been developed. However, further detailed calculations need to be devised in this paper for the different types of abnormal marketing situations mentioned in Problem 1 in order to provide a more comprehensive addition to the model.

4.2 Constraints on the most appropriate planting programme

We analyse the annexed data to explore the optimal planting timing and cropland allocation options for different crops. When dealing with constraints, these can be combined with dynamic programming algorithms for crop and cropland matching to design multiple allocation strategies. Next, this paper develops a constraint model to solve the optimisation problem in agricultural cultivation. In this paper, four constraints are extracted, which are related to economic conditions, land crop types, land nutrients and land utilisation.

(1) Economic condition constraint: economic maximisation, i.e. giving priority to the most economically productive crop in the cropping programme.

$$\text{Maximize } \sum_{i=1}^{3}\left(x_i \times \text{economic}_{\text{value(i)}} + y_i \times \text{economic}_{\text{value(i)}}\right) \quad (1)$$

(2) Land crop type constraints: consider the continuity of growing legumes, i.e., after growing legumes for three years, other crops are preferred for cultivation.

$$x_i = 1, \text{if } y_{i-1} = 0 \text{ and } y_{i-2} = 0 \text{ for } i = 1,2,3 \quad (2)$$

(3) Land nutrient constraints: avoiding successive plantings of the same crop to protect the nutrient balance of the land and the stability of the ecosystem.

$$y_i \neq y_{i-1}, \text{for } i = 1,2,3 \quad (3)$$

(4) Land utilisation constraints: ensure that planting areas are not too small to fully utilise land resources.

$$\sum_{i=1}^{3}(x_i + y_i) \geq \text{min\_planting\_area} \quad (4)$$

In summary, the objective function is defined as the product of the economic value and the land use rate while maximising the economy, taking into account the constraints of land nutrients and land use rate, so that the set can take into account the sustainable use of land. Namely:

$$\text{Maximize}\left(\sum_{i=1}^{3}\left(x_i \times \text{economic}_{\text{value(i)}} + y_i \times \text{economic}_{\text{value(i)}}\right)\right) \times \text{land}_{\text{utilization}} \quad (5)$$

Where, x_i denotes the area of the first$i$ Area planted with legumes in year,

y_i Indicates the number of years$i$ Area planted with other crops in year,

$\text{economic}_{\text{value(i)}}$ Indicates the economic value of the crop planted in the first i Economic value of crops grown in year,

$\text{land}_{\text{utilization}}$ Weighting coefficients indicating land-use rates.

4.3 Planning model solution process

After adding the appropriate attributes and constraints for the two objects, arable land and crops, this paper chooses to use a dynamic programming algorithm to solve the model with the goal of pursuing the highest economic efficiency. For the two different possible scenarios, it is indeed necessary to establish two different calculations and discuss them in a categorised manner.

(1) Scenarios where sales volume exceeds some of the waste:

In this case, when the sales volume of a crop exceeds a certain threshold, the excess is wasted. We can define a waste volume indicator to measure the extent of waste. Assuming that the threshold value is T and the sales volume of the excess portion is S, the wastage volume can be expressed as

$$W = \max(S - T, 0) \tag{9}$$

where waste is 0 if S is less than or equal to T. Otherwise, waste is $S - T$.

(2) Scenarios where sales exceed half price:

In this case, when the sales volume of a crop exceeds a certain threshold, the excess is sold at half price. We can define a half-price sales amount indicator to measure the impact of half-price sales. Assuming that the threshold is T, the sales volume of the excess is S, and the unit price is P, the half-price sales amount can be expressed as

$$H = \max\left(0, (S - T) \times \frac{P}{2}\right) \tag{10}$$

where the half-price sales amount is zero if S is less than or equal to T. Otherwise, the half-price sales amount is the excess sales multiplied by half the unit price.

During the computation process, many constraints are designed in this paper, resulting in excessive time and space complexity of the code. In order to optimise the calculation logic, improvements can be made starting from the data used for the calculation. Firstly, pre-processing and optimisation of the data can be considered. Secondly, one can consider using approximation algorithms or heuristics to solve the problem. In addition, other optimisation techniques such as distributed computing and parallel computing can be considered to speed up the computation process. However, no detailed optimisation is performed in this paper.

4.3 Results of the optimal planting programme

According to the above logic to design a new algorithmic process, the code is compiled, run after the final selection of the best six-year crop planting programme. This paper only extracts 24 years of planting programme data for example, six years of planting specific programmes see the answer form file. The following figure shows the optimal planting programme of this paper through dynamic programming in 2024 and 2023 profit ratio chart.

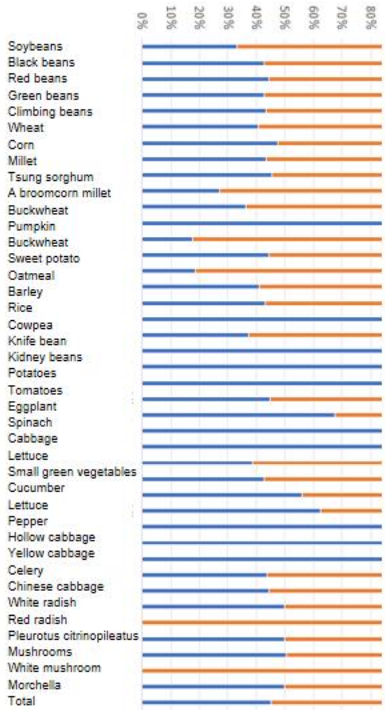

Figure 2 Profit percentage chart

From the figure 2, it can be seen that the share of total profit in 2024 is more than 50%, i.e., the profit in 2024 is more than the profit in 2023. In this paper, the optimality of the scheme is reflected from the maximisation of profit.

4 | Model sensitivity analysis

With fluctuating data over the next five years, it is necessary to design different prediction functions for different scenarios, taking into account the characteristics of different crops and market trends, in order to accurately predict key indicators such as future sales volumes, prices and growing costs. By building appropriate forecasting models, farmers and ranchers can develop more effective cropping strategies to adapt to market changes and maximise economic benefits. Therefore, for wheat, maize and other crops, appropriate forecasting functions need to be established separately so that data can be forecasted and analysed over the next five years to provide strong support for agricultural production and business decisions.

(a) For the case of expected sales, the trend in sales growth for wheat and maize is approximated as an exponential function, while the change in sales for the other crops is a stochastic function, and the exponential function of the trend in sales growth for wheat and maize is expressed as:

$$S_{\frac{\text{wheat}}{\text{corn}}}(t) = S_0 \times e^{rt} \tag{11}$$

Where $S_{\frac{\text{wheat}}{\text{corn}}}(t)$ is the volume of wheat or maize sold at time t; S_0 is the initial sales volume; r is the growth rate; e is the base of the natural logarithm and t is the time.

(b) In terms of selling prices, the selling prices of food crops are basically stable; the selling prices of vegetable crops have increased by an average of about 5 per cent per year; and the selling prices of edible mushrooms have declined by about 1 to 5 per cent per year, with morel mushrooms declining by 5 per cent. The sales price of vegetable crops can be expressed as a linear function of.

$$P_{vegetables}(t) = P_0 \times (1 + r_v)^t \tag{12}$$

Where $P_{vegetables}(t)$ is the selling price of vegetable crop at time t;P_0 is the initial selling price, and r_v is the annual growth rate, set at 0.05.

The sales price of edible mushrooms is expressed using an exponential function:

$$P_{mushrooms}(t) = P_0 \times (1 - r_m)^t \tag{13}$$

Where $P_{mushrooms}(t)$ is the selling price of edibles at time t, and P_0 is the initial selling price, and r_m is the annual decline rate, which is set to 0.01 (common edible fungi) or 0.05 (morel mushrooms).

(c) For the cost of cultivation, the cost of cultivating crops has increased exponentially at an average annual rate of about 5 per cent.

The cost of cultivation is expressed as an exponential function:

$$C(t) = C_0 \times e^{rt} \tag{14}$$

where.$C(t)$ is the crop planting cost at time t; C_0 is the initial planting cost.

(d) For acreage yield, the acreage yield per cropland is affected by weather and other factors, with a variation of ± 10 per cent per year from 2023. The change in yield per cropland over the next five years is stochastic in nature. The acre yield is expressed as a stochastic function:

$$Y(t) = Y_0 \times (1 + r) \times (1 + \in) \tag{15}$$

Where $Y(t)$ is the acre yield per cultivated field at time t; Y_0 is the initial acre yield; r is the average annual growth rate, which can be set to zero; $\in$ is a representation of random fluctuations from year to year, satisfying a normal distribution with mean 0 and standard deviation 0.1 (i.e., within ± 10 per cent variation from year to year).

In the face of crop cultivation after market changes, the multi-objective constraint model developed in the previous paper is combined with the consideration of the potential risks and uncertainties of farmers' cultivation. Through real-time algorithms and function analysis of different scenarios, the cropping scheme can be optimised for arable land. Uncertainty constraints are taken into account to cope with the uncertainty caused by market changes. Next, in order to optimise the original multi-objective constraint model and consider robustness, a robust optimisation model is developed. Robust optimisation models are better able to select decision options with optimal performance in the face of uncertainty and risk. In this paper, the uncertain parameters chosen by the robust optimisation model are: mu yield, planting cost and selling price, and the robustness constraints of this paper are:

$$g_i(x) + \delta_i \leq 0, i = 1,2,\cdots,m \tag{19}$$

$$h_j(x) + \epsilon_i = 0, i = 1,2,\cdots,p \tag{20}$$

Where x is the decision variable, and $f(x)$ is the objective function, and $g_i(x)$ and $h_j(x)$ are the constraint functions. δ_i and ϵ_i are parameters representing uncertainty, denoted as error margins or disturbance terms.

In order to determine the target interval for the future sales volume of wheat and maize, this paper uses the idea of linear programming with MATLAB. According to the problem description, the annual growth rate of sales volume of wheat and maize is between 5% and 10%. Next, the idea of linear programming is used to carry out the calculation of the target interval for the future sales volume of wheat and maize. The lower limit is $S \times (1 + 0.05)$ and the upper limit is $S \times (1 + 0.10)$, where S is the current annual sales volume.

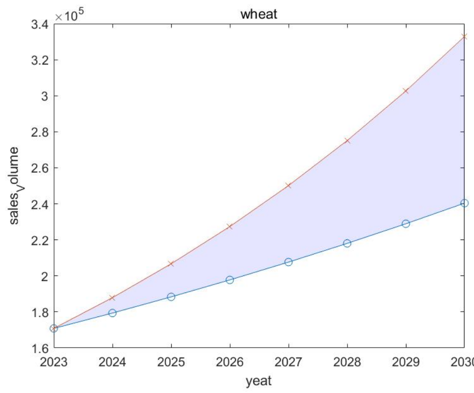

Figure 3 Projected wheat sales volume

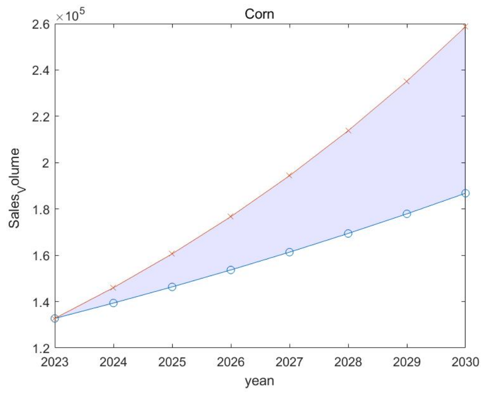

Figure 4 Projected maize sales volumes

When confronted with a stochastic function such as acre yield, this paper chooses to determine its most productive and least productive moments through forecasting calculations and uses the least productive moments as the basis for the calculations in order to reduce the risk borne by the farmer.

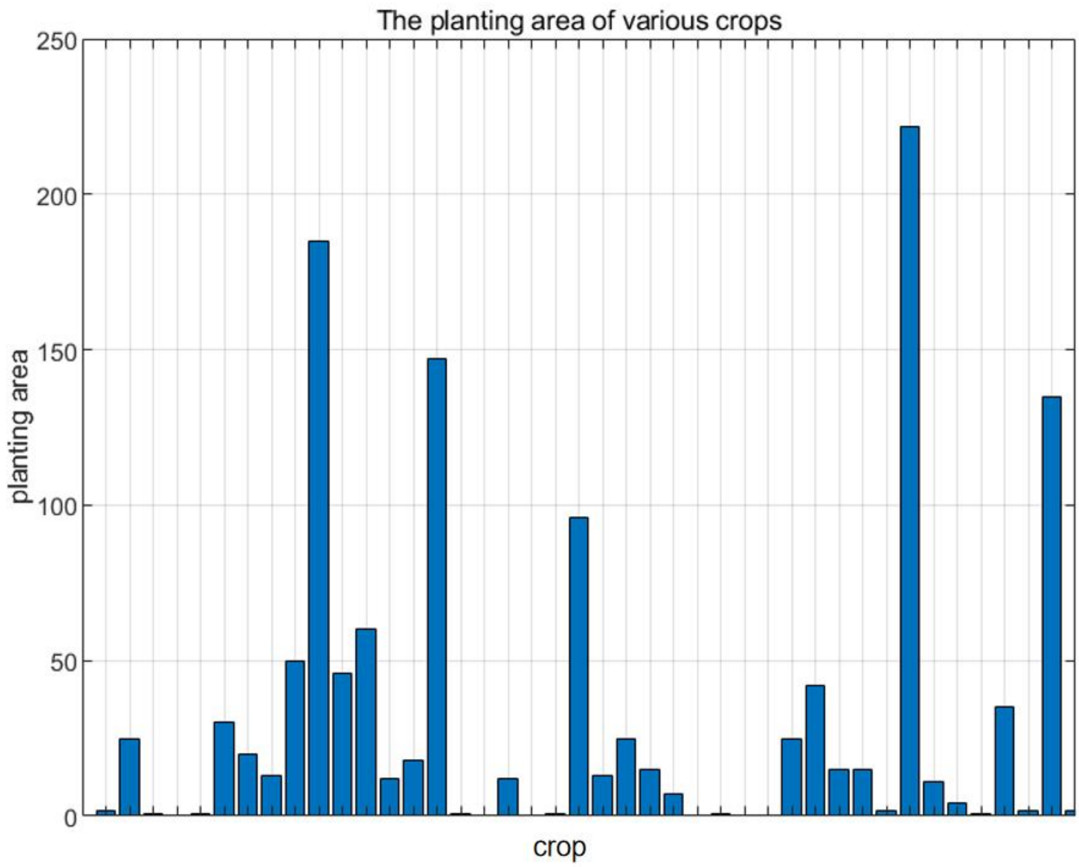

Figure 5 Histogram of area under cultivation by crop

4 | Conclusion

In this paper, we design a complete rural agricultural farming programme through abstract design and needs analysis of rural farming. In the design process, we have considered the economic nature of rural farming, sustainability and human science perspectives. We are committed to designing better and better mathematical models in the interest of farmers and the long-term development of the land in order to provide personal reflections beneficial to rural farming. Rural agriculture is highly malleable, so in the modelling process, we always think about how to maximise the benefits to farmers and the long-term development of the land to provide better rural farming solutions.

References

[1] Fu Q, Li T, Cui S, et al. Agricultural multi-water source allocation model based on interval two-stage stochastic robust programming under uncertainty [J]. Water Resources Management, 2018, 32: 1261-1274.

[2] Yuan M, Zheng N, Yang Y, et al. Robust optimization for sustainable agricultural management of the water-land-food nexus under uncertainty[J]. Journal of Cleaner Production, 2023, 403: 136846.

[3] Fikry I, Eltawil A, Gheith M. A robust crop rotation optimisation model with water scarcity and net return uncertainty considerations[J]. IEEE Access, 2021, 9: 128938-128950.

[4] Ke S, Guo D, Niu Q, et al. Optimized production planning model for a multi-plant cultivation system under uncertainty[J]. Engineering optimization, 2015, 47(2): 204-220.

[5] Zhang Y, Swaminathan J M. Improved crop productivity through optimised planting schedules[J]. Manufacturing & Service Operations Management, 2020, 22(6): 1165-1180.

[6] Lin C C, Deng D J, Kang J R, et al. A dynamical simplified swarm optimisation algorithm for the multiobjective annual crop planning problem conserving groundwater for sustainability[J]. IEEE Transactions on Industrial Informatics, 2020, 17(6): 4401-4410.

[7] Wang Y B, Wu P T, Zhao X N, et al. The optimization for crop planning and some advances for water-saving crop planning in the semiarid Loess Plateau of China[J]. Journal of Agronomy and Crop Science, 2010, 196(1): 55-65.

[8] Bhatia M, Rana A. A mathematical approach to optimise crop allocation-A linear programming model[J]. Int. J. Des. Nat. Ecodynamics, 2020, 15(2): 245-252.

[9] Amini A. Application of fuzzy multi-objective programming in optimisation of crop production planning[J]. Asian J. Agric. Res, 2015, 9(5): 208-222.

[10] Nguyen D C H, Ascough II J C, Maier H R, et al. Optimization of irrigation scheduling using ant colony algorithms and an advanced cropping system model[J]. Environmental modelling & software, 2017, 97: 32-45.