Research on Optimisation Models for Crop Planting Planning

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Abstract. In response to the current problem of low crop yields due to generally low crop yields and plot utilisation, this paper aims to improve plot utilisation to increase crop yield. The increase in yield cannot be realised as there is no better solution provided at present. Crop yield growth is facing a bottleneck as there is no better solution to achieve yield increase. This paper takes yield maximisation as the core objective, and establishes a multi-objective linear programming model for the situation where more than the stagnant part of the wasted and wasted crops are sold at a reduced price of 50% of the selling price, and finally seeks out the optimal planting scheme for the two different scenarios. The practical application and verification of the model not only proves its feasibility and effectiveness in actual agricultural production, but also further highlights the far-reaching significance of the research results for promoting agricultural modernisation, enhancing agricultural production efficiency and promoting sustainable agricultural development.

Keywords: Optimal Cropping Programmes for Crops, Data Processing and Analysis, Multi-objective Planning.

1. Introduction

Crops play a pivotal role in China and are the basis of the national economy and the key to guaranteeing food security. Making full use of land resources and developing organic crops in accordance with local conditions is of great practical significance to the sustainable development of the economy. However, at present, crop cultivation suffers from the problems of poor plot utilisation and low crop yields caused by irrational crop cultivation schemes. [1]. Therefore, it is important to optimise planting strategies to improve crop yields.

Multi-objective linear programming model involves the problem of finding the optimal solution among multiple objectives, including weighting method, constraint method and intelligent optimisation algorithm. Xiong Qingru suggests that in daily life, we often encounter the problem of how to rationally allocate and use limited resources to maximise the 'benefit'. When the objective function and its constraints of this kind of problem are linear, we can solve it by the method of linear programming. [2] We adopt the strategy of fuzzifying the objective function, thus reducing the multi-objective problem to a single-objective problem and establishing a multi-objective optimisation model. The advantage of the model is that it can provide an explicit optimal solution set, and there are multiple algorithms to choose from to deeply analyse and solve the problem from different perspectives. The drawbacks of the model proposed by Li Liuxing are the computational complexity leading to long time consuming when facing a large number of sets and the limitation on the number of targets[3].

This paper is the first to apply multi-objective linear planning to crop planting planning, which complements the key issues that have not been adequately addressed in the field of crop planting in the past, extends the traditional crop yield planning model, incorporates multi-dimensional factors such as planting quarter, crop profit and sales, and finally arrives at the crop planning plan planted in each quarter for each kind of plot, which improves the efficiency of planting and yield of crops. In order to better describe the model proposed in this paper, the paper is divided into five parts. The first chapter introduction firstly introduces the background of the crop planting problem, then explains the current research status of multi-objective planning models, and finally describes how this paper solves the crop planting planning problem. The second chapter related theory part introduces the principle and method of multi-objective linear planning model implementation. The third chapter section experiments describes the model idea and the detailed process of modelling. The fourth section conclusion describes the experimental results as well as the related conclusions, and the fifth section summarises the whole paper.

2. The basic funamental of multi-objective linear programming

Multiple linear regression analysis studies the regression analysis between a dependent variable and multiple independent variables and establishes multiple linear regression equations of the dependent variable on multiple independent variables based on the actual observed values of the dependent variable and multiple independent variables [4]. The model is a mathematical optimisation technique for solving decision problems with multiple competing objectives. In a multi-objective linear optimisation (MOLP) problem, the sub-objectives are often in conflict with each other, i.e., obtaining a better solution for one objective may lead to poor performance of other objectives. Unlike traditional single-objective linear programming, MOLP aims to optimise multiple objective functions simultaneously to find a balanced solution that satisfies all objectives [5].

Dependent and independent variables are set up according to the needs of the objective, assuming that they have a linear relationship, and a mathematical model is developed.

$$y_j = \beta_0 + \beta_1 x_{1j} + \beta_2 x_{2j} + \cdots + \beta_m x_{mj} + \varepsilon_j \qquad (j = 1,2,\ldots,n) \tag{1}$$

Then the unknowns are set up, and the least squares estimator is performed according to the linear regression equation. The relevant constraints are set up through the relevant factors, and according to the different condition priorities, the decision makers are considered to have different preferences for different objectives and constraints,[6] and different weights are given to each objective and constraint, and the relevant inequalities are listed. Firstly, the decision variables are determined according to the demand, then the objective function is determined according to the weights and the constraints are determined, and finally after using the weighted priorities, this problem becomes an ordinary linear programming problem with a single objective, and finally this problem is solved.

Multi-objective planning is characterised by multi-objectivity, mutual conflict, and participation of decision makers. When dealing with MOLP problems, commonly used methods include linear weighting method, main objective method, hierarchical analysis method [7] and gradient descent method. These methods transform multi-objective problems into single-objective problems or search for non-inferior solutions directly in the multi-objective space in different ways.

Multi-objective planning model [8] as a kind of optimisation means that can be flexibly regulated according to the needs of the decision-making objectives, after decades of continuous development and improvement, has formed a set of more mature model construction framework system. [9] MOLP has a wide range of applications, the solution process is relatively easy, and the generality is strong, including [10] Raw material management, resource allocation, portfolio management and environmental protection and so on. By using the MOLP technique, decision makers can systematically evaluate the trade-offs between different objectives and find an optimal solution to achieve the best combination of all objectives.

3. Experimental procedure

The aim of this experiment is to solve the optimal crop planting strategy in conjunction with a multi-objective linear programming model. The overall idea is shown in Figure 1.

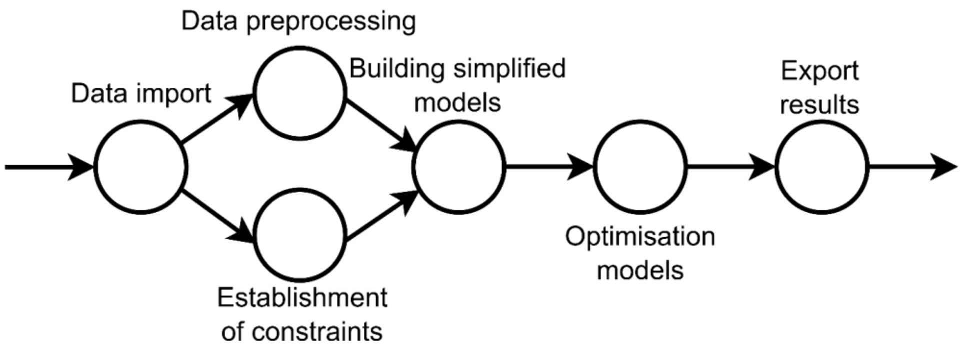

Figure 1. Overall Idea Map

3.1. Multi-objective linear programming modelling

In order to reach the optimal planting plan, we take profit maximisation as the main goal, according to the growth pattern of crops, and each crop has requirements for different planting plots and seasons, the planting plan needs to consider that the planting plots for each crop in each season need to be consecutive, and the planting area in a single plot cannot be too small.

Through the above description can be obtained multi-objective linear planning model, the establishment of the constraints are: the same crop in the same plot cannot be re-cropped; each plot at least once in three years to plant legumes; each crop quarter planting plots cannot be too dispersed; each crop in a single planting plot area cannot be too small; each crop planted in different seasons of the plots have restrictions.

Corresponding to the relevant constraints to establish the corresponding formulae:

$$\begin{cases} b_{i,j,k,t} + b_{i,j,k,t+1} \leq 1, i \in [17,34] \\ b_{i,j,k,t} + b_{i,j,k+1,t} \leq 1, i \in [1,16] \end{cases} \tag{2}$$

$$\sum_{t=T}^{t+2} \sum_{i \in D_2 \cup D_4} b_{i,j,k,t} \geq 1, T \in \{2024,2025,2026,2027,2028,2029,2030\} \tag{3}$$

$$\min \mathrm{s} = \sum_{\mathrm{i}=1}^{41} \sqrt{\frac{1}{\mathrm{Jnum}} \sum_{\mathrm{j} \in \mathrm{J}} \left(\mathrm{j} - \bar{\mathrm{j}}\right)^2} \tag{4}$$

$$a_{i,j,k,t} \geq \frac{1}{2} S_j \tag{5}$$

$$a_{i,j,k,t} \leq S_j, i \in [1,15], j \in T_1 \cup T_2 \cup T_3 \tag{6}$$

$$a_{i,j,k,t} \leq S_j, i \in [17,37], j \in T_4 \tag{7}$$

$$a_{i,j,k,t} \leq S_j, i \in [17,34], j \in T_5 \tag{8}$$

$$a_{i,j,k,t} \leq S_j, i \in [17,34] \cup [38,41], j \in T_6 \tag{9}$$

$$\begin{cases} a_{i,j,k,t} \leq S_j, i \in [17,34], j \in T_4, k = 1 \\ a_{i,j,k,t} \leq S_j, i \in [35,37], j \in T_4, k = 2 \end{cases} \tag{10}$$

$$a_{i,j,k,t} \leq S_j, i \in [38,41], j \in T_5 \tag{11}$$

Where $b_{i,j,k,t}$ is a judgement on whether crop i is to be planted in the jth plot in the kth season of the tth year, taking only the values 0 and 1, where crops with i∈ [17,34] are able to be planted in the first and second seasons, and crops with i ∈ [1,16] can only be planted in a single season.

For the dispersion of planting plots, this paper uses the standard deviation of the plot numbers of the plots planted with i crops to make a judgement. Where Jnum denotes the number of plots planted by crop i, J denotes the set of plot numbers planted by crop i, and $\hat{\mathrm{J}}$ denotes the mean of the plot numbers planted by crop i. Here, in order to ensure that the plots planted by crops in each season cannot be too scattered, it is necessary to keep the standard deviation s at a minimum. i∈ [1,15] denotes that grain crops other than rice are planted in a single season, $j \in T_1 \cup T_2 \cup T_3$ denotes that the land belongs to the flat and dry land, terraced land, and hillside land, and the planting area of i crop in j land does not exceed the area of j land. i∈ [17,37] denotes one quarter i∈[17,37] denotes one quarter of rice and two quarters of vegetable crops, and $j \in T_4$ denotes that the land belongs to watered land. i∈ [17,34] denotes the first quarter of each year of vegetable crops except cabbage, carrots and white radishes, and $j \in T_5$ denotes that the land belongs to a normal greenhouse. i∈ [17,34] ∪ [38,41] denotes two quarters of vegetable crops except cabbage, carrots and white radish, and $j \in T_6$ denotes that the site belongs to a smart greenhouse. k = 1 denotes the first quarter, and k = 2 denotes the second quarter. i ∈ [38,41] denotes the crop of edible mushrooms.

3.2. Multi-objective linear programming models

(1) For waste in excess of slow-moving parts

Objective function:

$$\max \pi = \sum_{t=2024}^{2030} \sum_{k=0}^{2} \sum_{i=1}^{41} \left(ZR_{i,k,t} - ZC_{i,k,t}\right) \tag{12}$$

$$\max \pi = \sum_{t=2024}^{2030} \sum_{k=0}^{2} \sum_{i=1}^{41} \left(\sum_{j=1}^{54} \left(w_i * min\left(GM_{i,j} * a_{i,j,k,t}, EX_i\right) - a_{i,j,k,t} * H_{i,j}\right) \right) \tag{13}$$

Where π is the total profit under optimal planning from 2024 to 2030, and $ZR_{i,k,t}$ is the total revenue generated from the sale of the ith crop in the kth season of the tth year, which is calculated by the equation $ZR_{i,k,t} = \sum_{j=1}^{54} \left(w_i * min\left(GM_{i,j} * a_{i,j,k,t}, EX_i\right)\right)$, Where $G_{i,j}$ denotes the production of the ith crop in the jth plot, and EX_i is the expected sales of the ith crop, i.e., the actual production in 2023. $ZC_{i,k,t}$ is the total planting cost of the ith crop in the kth season of the tth year, which is calculated as $ZC_{i,k,t} = \sum_{j=1}^{54}\left(a_{i,j,k,t} * H_{i,j}\right)$, where $H_{i,j}$ is the planting cost of the ith crop in the jth plot.

(2) In response to the sale of the portion in excess of demurrage at 50 per cent of the sales price in 2023

Objective function:

$$\max \pi = \sum_{t=2024}^{2030} \sum_{k=0}^{2} \sum_{i=1}^{41} \left(ZR_{i,k,t} - ZC_{i,k,t}\right) \tag{14}$$

$$\max \pi = \sum_{t=2024}^{2030} \sum_{k=0}^{2} \sum_{i=1}^{41} \left(\sum_{j=1}^{54} \left(w_i * \left(min\left(GM_{i,j} * a_{i,j,k,t}, EX_i\right) + max\left(0, GM_{i,j} * a_{i,j,k,t} - EX_i\right) * 0.5\right) - a_{i,j,k,t} * H_{i,j}\right) \right) \tag{15}$$

The basic objective function is basically the same as that of the first question, but due to the different treatment of the part that exceeds the stagnant sales, the corresponding calculation of$ZR_{i,k,t}$, i.e., the total income from sales, will be different, and it is necessary to sell the part that exceeds the expected production at half-price, and its calculation formula is:

$$ZR_{i,k,t} = \sum_{j=1}^{54} \left(w_i * \left(min\left(GM_{i,j} * a_{i,j,k,t}, EX_i\right) + max\left(0, GM_{i,j} * a_{i,j,k,t} - EX_i\right) * 0.5\right)\right) \tag{16}$$

After the above experiments, the optimal crop planting scheme for the two cases is derived, as shown in the following table.

4. Results

In this paper, after establishing a basic simplified model and setting up constraints by combining different factors, the model is iterated for many times, and finally the results are obtained through a multi-objective linear programming model.

For the sake of tabular simplicity, we numbered each crop with an English letter, as shown in Table 1 below:

Table 1. Crop numbers

crops	serial number
sorghum	A
common sorghum	B
broomcorn	C
Pumpkin	D
Sweet potato	E
Black Bean	F
Wheat	G
Red beans	H
Crawler beans	I
Cereals	J
Cucumber	K

Table 1 numbers each crop and is applied to Tables 2 and 3.

Table 2 addresses the case of wasteful treatment of more than the stagnant portion of the crop, and the model, after several iterations, resulted in an optimal planting plan for the crop with a total profit of $116,996,139.5, and the results are shown in Table 2 below:

Table 2. Number of acres of crops planted in the top 25 plots in Scenario 1, 2024

Plot number	Crops	Acres planted
A1	ABCDE	16
A2	ABDEFG	9.17
A3	ACDEG	7
A4	DF	36
A5	EHI	11
A6	ABEFGH	8.57
B1	ACDEFIJ	5.75
B2	ABCDEG	6.67
B3	EFG	9.33
B4	CDEFG	5
B5	ABDEFGH	12.29
B6	ABDFG	11
B7	ABCFG	7.33
B8	ADEGH	8.33
B9	ABDEFGH	3.57
B10	BCDFHK	8.57
B11	ABCDF	9
B12	ABCEFG	5.83
B13	ABCDEFH	3.33
B14	ABCFG	3
C1	ABCFG	3
C2	ABCDEFG	2.17
C3	ABCDE	3
C4	BDEGIJ	2.57
C5	ABDEG	5.4

Table 3 For the case of selling at a reduced price of 50% for the portion that exceeds the stagnant portion, the model, after several iterations, yields an optimal planting plan for the crop with a total profit of $22466472.17, and the results are shown in Table 3 below:

Table 3. Number of acres of crops planted in the top 25 plots in Case 2, 2024

Plot number	Crops	Acres planted
A1	ABDEG	16
A2	ABDEG	11
A3	ABDEG	7
A4	ABDEG	14.4
A5	ABDEG	13.6
A6	ABDEG	11
B1	ABDEG	12
B2	ABDEG	9.2
B3	ABDEG	8
B4	ABDEG	5.6
B5	ABDEG	5
B6	ABDEG	17.2
B7	ABDEG	11
B8	ABDEG	8.8
B9	ABDEG	10
B10	ABDEG	5
B11	ABDEG	12
B12	ABDEG	9
B13	ABDEG	7
B14	ABDEG	4
C1	ABDEG	3
C2	ABDEG	2.6
C3	ABDEG	3
C4	ABDEG	3.6
C5	ABDEG	5.4

From the above study, we have arrived at the optimal crop cultivation programme for the two scenarios and have derived the total profit for each of them. The final result of the table is the optimal planting solution for the two different cases.

5. Conclusions

In this paper, we establish a multi-objective linear planning model for crop planting planning problem and derive the crop planting scheme and its corresponding total profit in each quarter, which verifies the reliability of the model in solving the crop planting problem. In the future, we expect that this research can integrate more related technologies to optimise the accuracy of the model, improve the utilisation of the land and the total profit, and provide a relevant basis for the sustainable development of agriculture.

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