

An fuzzy multi-objective model on paddy circular economy system *

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Abstract. Circular economy is environment-friendly and resources saving. The theory of circular economy has widely spread and accepted by governments all over the world recently. Coordinated development for economy and ecology is more and more important and the concept of circular economy has been applied to solve many different problems. This paper builds a fuzzy multi-objective programming model, and then uses lexicographic method and genetic algorithm to study on paddy circular economy system. In the end, this paper gives some useful advice for arrangement of paddy planting patterns.

Keywords: multi-objective programming, paddy planting pattern, lexicographic method

1 Introduction

With dramatic increase of the globe population, problems about the shortage of all kinds of resources and environmental pollution are becoming more and more serious. In the past several decades, the concept of “circular economy system” was put forward and well accepted by most governments. In China, developing circular economy is the need of carrying out the outlook on scientific development, realizing sustainable development, and building harmonious socialist society^[19].

In the past two decades, the theory of circular economy has been widely spread and used in many areas, including agriculture, industry, logistics and so on. The concept of circular economy is used in the transformation of Zhejiang industry clusters and its ultimate goal is zero emission and zero pollution^[3]. Based on the circular economy theory and value-chain theory of industry, Li Yingde and Xing Zhiliang analyze the significance and features of the integrated development model in mines, set up the technology system, and design the program and flow chart under the condition of high technology^[11]. The concept of circular economy is also used in supply chain management. Li Jingfang analyzes stimulation-response behavior in closed-loop supply chain and identifies the stage of behavioral assumption to analyze it^[10]. Li Bingxiu examines the problem of the sustainable development ability assessment of green supply chain based on circular economy^[9]. Besides these, researching on agriculture circular economy also developed very fast^[1, 16, 17, 21]. Wang Yuhong introduces the concept of agricultural circular economy, summarizes the main difficult problems which the development of agricultural circular economy is facing at present, and proposes a series of policy suggestions to develop agricultural circular economy further^[17]. Tu Guoping analyzes the ecological effect of the agriculture energy circular economy system by using system dynamics^[16].

Although researches on circular economy in various areas have got some achievements in the past several years, there is still a lot of work in the future. Based on the above discussion, this paper researches on agriculture circular economy according to the situation of Sichuan Basin and builds a fuzzy multi-objective model to analyze it.

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The paper is organized as follows: section 2 describes the problem, and then builds a fuzzy multi-objective model about the arrangement of planting areas. Section 3 uses the genetic algorithm and the lexicographic method to analyze the problem and gives some advice. Finally, section 4 give the conclusions.

2 Modeling

Under the direction of the principle of circular economy, this section builds a fuzzy multi-objective programming model to describe the condition of paddy planting and finds the results by using the lexicographic method and genetic algorithm.

2.1 Description of the problem

Paddy planting pattern is based on rice planting system. Its goal is integrative use of agriculture resources. Paddy planting pattern's core technique is ecological planting with high-efficiency, while its accessorial technique is reusing of castoff and extending of the chain of agriculture industry. At present, most of the researches on paddy planting pattern with optimal model mainly focus on some aspect of the planting practice or few crops. This paper builds an optimal planting model which based on six paddy planting patterns and dominating elements that affect the results of planting. This model is used as a decision method for planting plan. This plan includes what planting pattern should be chose and what management of planting is more rational. Based on the above points, the paper builds an optimal multi-objective programming model about paddy planting patterns. According to the fundamental of circular economy, three objectives are mentioned and used for comparing benefit of various planting patterns. These objectives are production value of planting, grain crop yield of planting and ecological benefit of straw in each planting pattern.

According to the condition of agriculture in Sichuan Basin, five types of crops in paddy planting practice are discussed and analyzed , which are rice, wheat, rape, potato and vegetable. So these crops are elements of paddy planting patterns. There are six planting patterns which consist of these crops are feasible and reasonable. They are: "rice – wheat" pattern, "rice – rape" pattern, "rice – wheat – vegetable" pattern, "vegetable – rice – vegetable" pattern, "rape/potato – rice" pattern and "potato – rice – potato" pattern. Tab. 1 shows the sowing (planting) and harvesting date of various crops in these patterns.

2.2 Mathematical model

The mathematical model is based on the paddy planting in Sichuan Basin and these crops have all been planted widely in Sichuan province. In order to make the discussion more clear, this section argues that the type of vegetable is fixed in "wheat – rice – vegetable" pattern and "rice – vegetable – vegetable" pattern. This means that only one type of vegetable is chosen in each planting pattern.

Objective functions

According to the description of the problem, this multi-objective model have three objectives, and they are raising the income of farmers, making sure the grain crops yield is enough and protecting environment. So production value maximization, grain crops yield maximization and ecological benefit of straw maximization should be considered. In order to clarify the problem and get reasonable results at the end of discussion, this model only consider rice, wheat and potato when calculate the grain crops yield, and the straw of rice and wheat when calculate the ecological benefit of straw. Production value maximization:

$$\max E[f_1(\mathbf{x})] = \sum_{i=1}^6 E[\tilde{r}_i]x_i, \quad (1)$$

where $x_i (i = 1, 2, \dots, 6)$ is the area that covered by the i th planting pattern; $\mathbf{x} = (x_1, x_2, \dots, x_6)^T$; \tilde{r}_i is the income of the i th pattern.

Table 1. Sowing (planting) and harvesting date of various crops in each planting patterns

Planting patterns	Rice	Wheat	Rape	Potato (s)	Potato (a)	Vegetable (s)	Vegetable (a)
“wheat–rice”	5.20~8.30	11.5~5.15					
“rape–rice”	5.20~8.30		10.15~5.5				
“wheat–rice–vegetable”	5.25~8.25	11.5~5.15					9.5~11.3
“vegetable–rice–vegetable”	5.30~8.30					1.20~5.25	9.5~20.30
“rape/potato–rice”	5.20~8.30		10.20~5.5		9.5~12.20		
“potato–rice–potato”	4.25~8.25			12.10~4.20	9.1~11.30		

Price and yield are the key elements to determine the incomes of these planting patterns. They may change year by year, so the incomes are also not fixed and should be fuzzy variables. Expected value model technique is a very useful method to solve problems with fuzzy variables and fit for this topic, so this model uses expected value model to deal with fuzzy variables.

Grain crops yield maximization:

$$\max E[f_2(\mathbf{x})] = \sum_{i=1}^6 \sum_{j=1}^3 E[\tilde{c}_{ij}]x_i, \tag{2}$$

where \tilde{c}_{ij} is the output per a unit of area of the j th ($j = 1, 2, \dots, 5$) crops in the i th planting pattern. The crops types include rice, wheat and rape. The weather influences grain crops yield, so the outputs of rice, wheat and rape are also fuzzy variables and should be solved by using expected value model.

Ecological benefit of straw maximization:

$$\max E[f_3(\mathbf{x})] = \sum_{i=1}^6 s_i x_i, \tag{3}$$

where s_i is the ecological benefit of the i th pattern.

Relationship of variables

For the relationship of variables, this model can find the income of each pattern by using the price and output of each type of crop. When finding the ecological benefit of straw, the model only consider the cost of pollution control and the value of fertilization. $\tilde{r}_i = \sum_{j=1}^5 p_j \tilde{c}_{ij}$, $s_i = \sum_{j=1}^2 l_{ij} h_{ij} (a_j + g_j)$, $g_j = \sum_{k=1}^3 n \cdot m_{jk} / q_k$, where p_j is the price of the j th crops; \tilde{c}_{ij} is denoted as the output per a unit of area of the j th crops in the i th planting pattern; h_{ij} is the amount of straw of the j th crop produced in the i th pattern; l_{ij} is the proportion of returning part of the straw of the j th crop in the i th pattern. k is the type of contamination, which including NO_x , SO_2 and soot; m_{jk} is the amount of the k th contamination produced by burning of the straw of the j th crop; q_k is the polluting index of the k th contamination; n is the average cost of contamination; g_j is the cost of pollution control per unit amount of the straw of the j th crop caused by burning; a_j is the value of fertilization per unit amount of straw produced by the straw of the j th crop.

Constraints

When making paddy planting plan, several factors should be considered: the total area which is used can not exceed the planting area that we have, which is called “constraint of planting area resource” ; for the six paddy planting patterns, each of them has some advantages in different aspects, so all of them should be planted and none can be abandoned, which is called “constraint of planting scale” ; for paddy planting patterns in Sichuan Basin, new multiple cropping systems are more efficient and should spread from now on, so the “rape/potato – rice” pattern and the “potato – rice – potato” pattern should be encouraged to plant in larger scale, which is called “constraint of spreading for multiple cropping system” . These constraints are showed as: $\sum_{i=1}^6 x_i \leq S$, $x_i \geq S/10$, $x_1 + x_2 \leq S/3$. So we can build an fuzzy multi-objective programming model as follows:

$$(P) \begin{cases} \max E[f_1(\mathbf{x})] = \sum_{i=1}^6 E[\tilde{r}_i]x_i \\ \max E[f_2(\mathbf{x})] = \sum_{i=1}^6 \sum_{j=1}^3 E[\tilde{c}_{ij}]x_i \\ \max E[f_3(\mathbf{x})] = \sum_{i=1}^6 s_i x_i \\ \text{s.t.} \begin{cases} \sum_{i=1}^6 x_i \leq S \\ x_i \geq \frac{S}{10} \\ x_1 + x_2 \leq \frac{S}{3} \end{cases} \end{cases} \quad (4)$$

3 Analysis

This section analyzes the multi-objective model through a series of experimental data which bases on the planting practice in Sichuan Basin, then uses model (4) to find the best results.

3.1 Experimental data

According to the multi-objective model (4), the following three parts data are necessary: crop yield, production value and the index about ecological benefit. So before we calculate this model, the fuzzy variables: the output of crops and the income of planting patterns should be converted to their expected values by using expected value model technique. For these planting patterns, the grain crops yield of rice, wheat and potato, and their production values are not fixed year by year. So in this model, both \tilde{c}_{ij} and \tilde{r}_i are triangular fuzzy variable. Through years' experiment^[14, 15], we can get their values as showing in Tab. 2. The values of index about ecological benefit^[12] are showed in Tab. 3.

Table 2. Grain crops yield of rice, wheat and potato and production value of each planting pattern

Planting patterns	Rice (kg)	Wheat (kg)	Potato (kg)	Production value (yuan)
“wheat–rice”	(530, 550, 570)	(330, 350, 370)		(1450, 1500, 1530)
“rape–rice”	(520, 555, 570)			(1700, 1735, 1770)
“wheat–rice–vegetable”	(480, 490, 540)	(290, 325, 340)		(2850, 2862, 2874)
“vegetable–rice–vegetable”	(470, 505, 520)			(5800, 5850, 5900)
“rape/potato–rice”	(475, 500, 525)		(750, 810, 830)	(2360, 2400, 2440)
“potato–rice–potato”	(630, 655, 660)		(3000, 3300, 3600)	(3688, 3702.4, 3716.8)

Table 3. The index of ecological benefit

	Rice straw	Wheat straw	Experimental data
The amount of NO _x (gram per kilogram)	13.9	13.5	
The amount of SO ₂ (gram per kilogram)	3.6	2.2	
The amount of soot (gram per kilogram)	8.2	19.0	
The value of straw fertilization (yuan per kilogram)	0.02	0.025	
The polluting index of NO _x			0.95
The polluting index of SO ₂			0.95
The polluting index of soot			2.18
The average cost of contamination (yuan per gram)			0.12

3.2 The algorithm

According to the the type of this multi-objective problem, the genetic algorithm and the lexicographic method are chosen and adopted to find out the best result. Genetic algorithm is a stochastic search method for optimization problems based on the mechanics of natural selection and natural genetics. GA has demonstrated considerable success in providing good solutions to many complex optimization problems and received more and more attentions during the past three decades. Lexicographic method is a very useful method to deal with multi-objective model. At first, all the objectives are reordered according to their degree of importance. Then

we treat the multi-objective model as a single objective model, and get the best solution of the first objective. Then this method goes on to find out the best solution of the next objective based on the above best solution until all the solution of each objectives are found. So the last best solution is the final best solution of the whole multi-objective model.

So we combine genetic algorithm and lexicographic method together, and found the process as follows:

Procedure The GA algorithm of planning of paddy planting pattern

- Step 1.** Planting areas of every planting patterns are represented as a N dimensional vector Ch_r , which includes six genes and each gene stand for one planting pattern;
- Step 2.** Set the generation counter to zero, $n = 0$;
- Step 3.** Using uniform distribution, generate initial population $gen(0)$ of trial vectors Ch_r for $r = 1, 2, \dots, N$ from a feasible range in each dimension, so we can get $x_i = 10$ ($i = 1, 2, \dots, 6$) as the initial population;
- Step 4.** Evaluate fitness of each individual of current population by using lexicographic method as the fitness subroutine and the process is divided into three stages, as showing in section 3.3;
- Step 5.** Increase the generation counter by one, $n = n + 1$;
- Step 6.** Apply GA to produce $gen(n + 1)$: preserve the elite chromosomes, select 20 parents from population of trial vectors using tournament selection, recombine them using crossover and mutation operators to produce 20 child vectors;
- Step 7.** Evaluate fitness (the value of the three objectives) of each chromosome of current population by using lexicographic method as the fitness subroutine and store the solution corresponding to the best fit chromosome;
- Step 8.** Apply the replacement operator and diversity mechanism to the current population;
- Step 9.** Check for the convergence criterion: if current generation number n is equal to 400, stop and print the results corresponding to the best plan of paddy planting. Otherwise, go to step 6;
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3.3 Numerical analysis

By using expected value model technique, the data of grain crops yield and production value in Tab. 2 can transform from fuzzy variables into certain variables. In order to discuss this problem clearly, the area of planting is confirmed to 100 units of area. Then put the data from Tab. 3 into this multi-objective model (4), the model can be changed into the following form:

$$(P) \begin{cases} \max E[f_1(\mathbf{x})] = 1495x_1 + 1735x_2 + 2862x_3 + 5850x_4 + 2400x_5 + 3702.4x_6 \\ \max E[f_2(\mathbf{x})] = 1015.5x_1 + 1041.2x_2 + 1050.6x_3 + 1550x_4 + 1176.5x_5 + 1557x_6 \\ \max E[f_3(\mathbf{x})] = 24.82x_1 + 13.62x_2 + 22.29x_3 + 12.49x_4 + 12.49x_5 + 14.75x_6 \\ \text{s.t.} \begin{cases} \sum_{i=1}^6 x_i \leq 100 \\ x_i \geq 10 \\ x_1 + x_2 \leq \frac{100}{3} \end{cases} \end{cases} \quad (5)$$

In this model, the multi-objective model can transform into the single objective model by using lexicographic method. According to the situation of paddy planting in Sichuan Basin, the importance degree of the three objectives can be confirmed as following: production value maximization > grain crops yield maximization > ecological benefit of straw maximization. So in the first stage, the multi-objective model can transform into:

$$(1) \text{ Objective function: } \max f(x) = 1495x_1 + 1735x_2 + 2862x_3 + 5850x_4 + 2400x_5 + 3702.4x_6. \quad (6)$$

$$(2) \text{ Constraints: } \sum_{i=1}^6 x_i \leq 100; \quad x_i \geq 10; \quad x_1 + x_2 \leq \frac{100}{3}. \quad (7)$$

From the single objective model, the best solution of the first objective is 41444 yuan when $x_1 = 10, x_2 = 10, x_3 = 10, x_4 = 50, x_5 = 10, x_6 = 10$. Then we should find the best solution of the second objective based

on the above result. So the first objective turn into a new constraint. Thus the transform index of the first objective is $k_1 = 0.9$, and then add a new constraint to the model as: $1495x_1 + 1735x_2 + 2862x_3 + 5850x_4 + 2400x_5 + 3702.4x_6 \geq 41444 \times 0.9$.

Based on above discussion, the best solution of the second objective is 136043.1 kilogram when $x_1 = 10, x_2 = 10, x_3 = 10, x_4 = 30.702, x_5 = 10, x_6 = 29.298$. Then the transform index of the second objective is $k_2 = 0.9$, and then the best solution of the third objective is 1640.129 yuan when $x_1 = 10, x_2 = 10, x_3 = 23.87, x_4 = 36.13, x_5 = 10, x_6 = 10$. $1015.5x_1 + 1041.2x_2 + 1050.6x_3 + 1550x_4 + 1176.5x_5 + 1557x_6 \geq 136043.1 \times 0.9$.

So when $x_1 = 10, x_2 = 10, x_3 = 23.87, x_4 = 36.13, x_5 = 10, x_6 = 10$, we can get the final best solution: $f_1(x) = 373000.4, f_2(x) = 128981.3, f_3(x) = 1640.129$. From Tab. 4, the results show that “rice

Table 4. The results when $k_1=0.9$ and $k_2=0.9$

Planting patterns	Planting area (units of area)	Planting patterns	Planting area (units of area)
“wheat–rice”	10.00	“vegetable–rice–vegetable”	36.13
“rice–rape”	10.00	“rape/potato–rice”	10.00
“rice–wheat–vegetable”	23.87	“potato–rice–potato”	10.00
Objectives	Value		
production value	373000.4 yuan		
grain crop yield	128981.3 kilogram		
ecological benefit of straw	1640.129 yuan		

Table 5. The comparison results with various transform indices

(k_1, k_2)	$(x_1, x_2, x_3, x_4, x_5, x_6)$	$(f_1(x), f_2(x), f_3(x))$
(0.5, 0.5)	(23.33, 10, 36.67, 10, 10, 10)	(276701.9, 115464.1, 1929.933)
(0.75, 0.75)	(10, 10, 44.68, 15.32, 10, 10)	(310820.2, 118588.8, 1844.022)
(0.95, 0.95)	(10, 10, 16.94, 43.06, 10, 10)	(393707.3, 132442.2, 1572.164)

– wheat – vegetable” pattern and “vegetable – rice – vegetable” pattern have the best integrated benefit, and they should spread in the future. So the government should make some policies to encourage farmers to adopt these planting patterns. By using different transform index of the first and second objective, we can get different results of the decision variable and the final solution shown in Tab. 5. From the Tab. 5, the results show that when k_1 and k_2 rise from 0.5 to 0.95, the most important objective, the production value maximization increases by 117005.4 yuan, while the objective of grain crops yield maximization increases by 16978.1 kilogram and the objective of ecological decreases by 357.769 yuan. On the other hand, when k_1 and k_2 rise from 0.5 to 0.95, the planting area of “rice – wheat” pattern decreases from 23.33 units of area to 10 units of area, while the planting area of “rape/potato – rice” pattern increases from 10 units of area to 43.06 units of area. Based on the above discussion, when using this model to design the paddy planting patterns, we should also pay attention to the following two problems: (1) In different areas, the importance degree of the three objectives (production value maximization, grain crops yield maximization and ecological benefit of straw maximization) may be different. So they should be reordered when using the genetic algorithm and the lexicographic method to find the best solution of the model; (2) When finding the transform index of the first and the second objectives, we should consider both the condition of the area which the model practise on and the attitude of decision maker to the three objectives. So we can confirm the index more reasonable.

For the above problems, we should build a more proper model basing on the specific planting condition, we can find a best solution and arrange the planting areas about each paddy planting patterns more rationally. So the agriculture production would be more efficient.

4 Conclusions

In this paper, we set up a multi-objective mathematical model of paddy planting pattern based on the situation of Sichuan Basin. By using the genetic algorithm and the lexicographic method, the best solution of this model is found and the different solutions with different transform index is discussed. Then we get useful advice about the arrangement of paddy planting patterns. In the future, the similar problem can be extended as follows:

(1) Different areas have different conditions, so we should adjust the multi-objective programming model when using it in different areas. The main differences is types of crops and planting patterns, so the number of objective and the form of constrains may be different.

(2) In the programming model, we considered that the type of vegetables is only one, but the real situation sometimes is not like that. So if the type of vegetable is more than one, the model would be more complex and need to be analyzed in the future.

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