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Evaluation on the Development of Circular Agriculture in Guizhou Province Based on Entropy Method

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Abstract Vigorously developing agricultural circular economy is an effective way to achieve sustainable agricultural development, and a strategic measure to ease the pressure on agricultural resources, protect ecological and clean resources, and promote sustainable agricultural and rural economic development. From the theoretical perspective of circular agriculture, this paper builds the evaluation indicator system for circular agriculture, and uses entropy method to carry out the comprehensive evaluation of the development level of agricultural circular economy in Guizhou Province from 2003 to 2012. At the same time, this paper analyzes the obstacles to the development of agricultural circular economy in Guizhou Province in 2012, and sets forth the relevant recommendations based on these limitations, in order to improve the development level of circular agriculture in Guizhou Province.

Key words Guizhou Province, Circular agriculture, Comprehensive evaluation, Obstacle analysis

1 Introduction

Circular agriculture is a new agricultural development model which combines the theory of circular economy and sustainable development, and a new way to achieve agricultural economic growth while coordinating the population and resources & environment[1]. Chinese scholars' studies of circular agriculture are mainly focused on the definition of circular agriculture (Xuan Ya'nan *et al.*, 2005; Guo Tiemin *et al.*, 2004; Zhou Zhenfeng *et al.*, 2004)[2-4]; the necessity of developing circular agriculture in China (Zhou Zhenfeng *et al.*, 2004; Li Rongsheng, 2005; Ma Jiang, 2005)[4-6]; analysis of development model of circular agriculture (Yin Xundun *et al.*, 2005)[7]. The evaluation of the development of circular agriculture is mostly the comprehensive evaluation of the development of circular agriculture in a country or region, and few studies are performed on the evaluation of agricultural industry model of businesses and farms. In this paper, based on numerous evaluation methods, we select the entropy method to rationally determine the indicator weight and draw on the indicator evaluation system built by predecessors for the comprehensive evaluation and obstacle diagnosis of circular agriculture in Guizhou Province. Guizhou Province is a traditional agricultural province, and agriculture has a large share in the industrial structure. In the context of carrying out the construction of circular agriculture nationwide, Guizhou Province should rely on these favorable conditions to improve the sustainable development of agricultural system and social, economic and ecological benefits in Guizhou Province. By selecting Guizhou Province as the object of empirical research, this paper builds the indicator system for the comprehensive evaluation of circular agriculture, and analyzes the obstacles to the development of circular agriculture, in order to provide a reference for the further development of circular agriculture in Guizhou Province.

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2 The basic content of comprehensive evaluation indicator system for the development of circular agriculture in Guizhou Province

2.1 Design of comprehensive evaluation indicator system for the development of agricultural circular economy In building the evaluation indicator system for the development of agricultural circular economy, this paper draws on the BPEIR conceptual model of Ma Qifang *et al.*, namely "Behavior - Pressure - Effects - Impact - Response" model. The evaluation indicators include four aspects: economic and social development indicators; resources reduction input indicators; resources recycling evaluation indicators; resources and environment safety evaluation indicators[8]. In this paper, based on the actual situation of agricultural development in Guizhou Province and principle of circular agricultural development, we select 15 factors as the evaluation indicators, to build the comprehensive evaluation indicator system for the development of circular agriculture in Guizhou Province.

2.2 Establishment of comprehensive evaluation indicator system for the development of circular agriculture

2.2.1 Data sources. The economic data are mainly from *Guizhou Statistical Yearbook* (2003 - 2012), *China Statistical Yearbook* (2003 - 2012), *Guizhou Provincial Economic and Social Development Statistics Bulletin* (2003 - 2012). The relevant resources data are mainly from *Guizhou Provincial Land and Resources Bulletin* (2003 - 2012) and the relevant government websites.

2.2.2 The basic principles and calculation steps of entropy method. In information theory, there is a function relationship $H(x) = -\Sigma f(X_K)\ln f(X_K)$, where $H(x)$ is information entropy and $-\Sigma f(X_K)\ln f(X_K)$ is information, with opposite signs but

same absolute value. Entropy is a measure of uncertainty. The larger the amount of information, the smaller the uncertainty, and the smaller the entropy; the smaller the amount of information, the greater the uncertainty, and the greater the entropy. Assuming there are m years and n indicators, it can form an original data matrix $X = (X_{ij})mn$. According to the characteristics of entropy, we can use the entropy value to judge the degree of dispersion of indicator X_j. If there is greater difference in the indicator value X_{ij}, then the degree of dispersion of X_j will be higher, and $H(x)$ will be smaller, that is, the amount of information provided will be larger and the weight will also be greater. Therefore, based on the degree of dispersion of indicators, we can use the relationship between the raw data to determine the indicator weight.

(i) There are positive and negative indicators in the evaluation indicator system for the development of circular agriculture. The greater the value of positive indicators, the better the development of circular agriculture; if the value of negative indicators is smaller, it will be more conducive to the development of circular agriculture. So it is necessary to adopt different algorithm for the standardization of positive and negative indicators:

$$\text{Positive indicator } X'_{ij} = \frac{X_{ij} - \min\{X_j\}}{\max\{X_j\} - \min\{X_j\}}$$

$$\text{Negative indicator } X'_{ij} = \frac{\max\{X_j\} - X_{ij}}{\max\{X_j\} - \min\{X_j\}}$$

where X_{ij} is the value of evaluation indicator j in year i; $\max\{X_j\}$ and $\min\{X_j\}$ are the maximum and minimum values of evaluation indicator j in all years, respectively; m is the number of evaluation years; n is the number of evaluation indicators.

(ii) Calculate the proportion of value of indicator j in year i:

$$Y_{ij} = \frac{X'_{ij}}{\sum_{i=1}^{m} X'_{ij}}$$

(iii) Information entropy is an indicator to measure uncertainty. In the multi-attribute decision making, various column vectors of normalized decision-making matrix $X[(X_{1j}, X_{2j}, \cdots, X_{mj})^T, (j = 1, 2, \cdots, n)]$ are seen as the distribution of amount of information to calculate the entropy of indicator property X_j as follows:

$$e_j = -k\sum_{i=1}^{m}(Y_{ij} \times \ln Y_{ij})$$

where $k > \frac{1}{\ln m} < 0$.

(iv) Calculate the coefficient of variation of indicator j, namely the discrimination degree for the evaluation degree (d_j):

$$d_j = 1 - e_j,\ 1 \leqslant j \leqslant n$$

(v) Calculate the weight of each property X_j, and the higher the coefficient of variation, the greater the weight W_j:

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j},\ j = 1, 2, \cdots, n$$

2.2.3 Indicator weight determining. Therefore, according to the basic principles and calculation steps of the above entropy method, we get the comprehensive evaluation indicator system for the development of circular agriculture in Guizhou Province as well as indicator weight (Table 1).

Table 1 Comprehensive evaluation indicator system for the development of circular agriculture in Guizhou Province

Classification indicator (B)	Indicator weight	Individual indicator C	Indicator weight	Indicator interpretation
Economic and social development indicator(B_1)	0.406	Agricultural GDP per unit area (C_1//yuan/ha)	0.076	Agricultural GDP/crop acreage
		Rural per capita net income (C_2//yuan)	0.090	Per capita total income of farmers - per capita expenditure of farmers
		Per capita food production (C_3//kg)	0.035	Total food production/total population
		Grain yield (C_4//kg/ha)	0.027	Food production/arable land area
		Unit livestock and poultry rate (C_5//yuan/t)	0.060	Livestock output value/meat production
		Total power of agricultural machinery (C_6 // 10^4kW)	0.067	Power of farming machinery + power of forestry machinery + power of animal husbandry and fishery
		Commodity rate of farming, forestry, animal husbandry and fishery (C_7//%)	0.051	Commodity value of farming, forestry, animal husbandry and fishery/total output value of farming, forestry, animal husbandry and fishery
Resource reduction input indicator (B_2)	0.207	Chemical fertilizer application rate (C_8//kg/ha)	0.080	Pure volume of chemical fertilizer/crop acreage
		The level of pesticide use (C_9//kg/ha)	0.078	The use of pesticides/crop acreage
		The level of plastic sheeting use (C_{10}//kg/ha)	0.049	The use of plastic sheeting / crop acreage
Resource recycling indicator (B_3)	0.151	Effective utilization coefficient of chemical fertilizer (C_{11}//yuan/kg)	0.079	Farming output/pure volume of chemical fertilizer
		Multiple cropping index (C_{12}//%)	0.072	Crop area/arable land area
Resources and environment safety indicator(B_4)	0.236	Forest coverage rate (C_{13}//%)	0.096	Woodland area/total land area
		Effective irrigation coefficient (C_{14})	0.089	Effective irrigation area/arable land area
		Per capita arable land area (C_{15}//ha)	0.051	Arable land area/total population

3 Empirical analysis

3.1 Comprehensive evaluation results The evaluation score of single indicator is calculated as follows:

$$S_{ij} = W_j \times X'_{ij}$$

Since the evaluation of development of agricultural circular economy is comprehensive evaluation, the weighted function method is used to calculate the composite score of circular agriculture in a year:

$$S = \sum_{j=1}^{n} S_{ij} = \sum_{j=1}^{n} W_j \times X'_{ij}$$

where W_j is the weight of various indicators; X'_{ij} is the normalized value for each evaluation indicator; S is the comprehensive evaluation score of development of circular agriculture.

The comprehensive evaluation results of circular agriculture in Guizhou Province can be calculated as shown in Fig. 1. According to Fig. 1, the development process of circular agriculture in Guizhou Province during 2003 – 2012 can be divided into three phases. (i) The phase of slow ascension (2003 – 2005). During this phase, the evaluation value of circular agriculture was higher than in 2003, the comprehensive evaluation value was in (0.27, 0.37), and the average annual growth rate of comprehensive evaluation value of circular agriculture reached 18.5%. (ii) The phase of small decline (2005 – 2006). The comprehensive evaluation value of circular agriculture was 0.376 in 2005 and 0.3 in 2006, decreasing by approximately 19%. (iii) The phase of rapid development (2006 – 2012). Compared with 2003, the development level of circular agriculture was rapidly enhanced, and it increased from 0.3 in 2006 to 0.767 in 2012, an increase of about 26%.

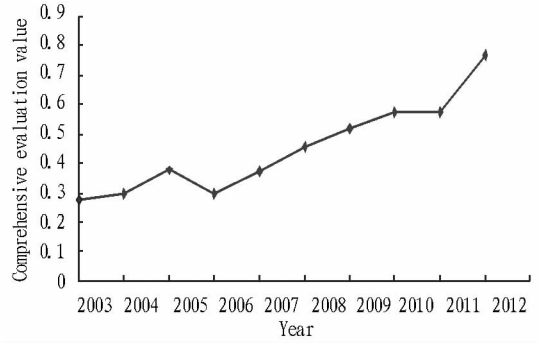

Fig. 1 The comprehensive evaluation results of development of circular agriculture in Guizhou Province from 2003 to 2012

The changes in the evaluation index of various classification indicators concerning the development of circular agriculture in Guizhou Province during 2003 – 2012 can be shown in Fig. 2. In terms of the annual average index value of various classification indicators concerning the development of circular agriculture, it is in the descending order as follows: economic and social development indicator (1.452), resource and environment safety indicator (0.327), resource reduction input indicator (0.299), and resource recycling indicator (0.117). (i) From the analysis, it is found that the evaluation index of economic and social development indicator showed an overall upward trend, and the economic and social development indicators are positive indicators, indicating that the economic and social development factors have played an important role in enhancing the overall development level of circular agriculture in Guizhou Province since 2003. But there was great volatility in the evaluation index of economic and social development indicator, undergoing two phases of decline in 2003 and 2012, suggesting that the economic and social development in the two phases has become the obstacle to the development of circular agriculture in Guizhou Province. (ii) After 2003, the evaluation index of resource reduction input indicator showed an overall downward trend. During 2003 – 2008, the resource reduction input index declined ceaselessly, indicating that the main limiting factor was resource reduction input. During 2008 – 2010, the resource reduction input index climbed, indicating that the constraint of resource reduction input on circular agriculture was eased. During 2010 – 2012, the resource reduction input index showed a downward trend again, indicating that there was a phenomenon of high resource input in the development of circular agriculture. (iii) The resource recycling index after 2003 was higher than in 2003 except 2006, and the resource recycling index from 2003 to 2012 showed a rising overall trend. The resource recycling levels in Guizhou Province have made important contribution to the development of circular agriculture. (iv) The evaluation index of resources and environment safety indicators after 2003 showed an upward trend overall. During 2003 – 2012, the index of resources and environment safety indicators showed a rising trend except 2004, indicating that the development of agriculture in Guizhou Province during this period focused on the environmental protection and resource conservation, in favor of development of circular agriculture.

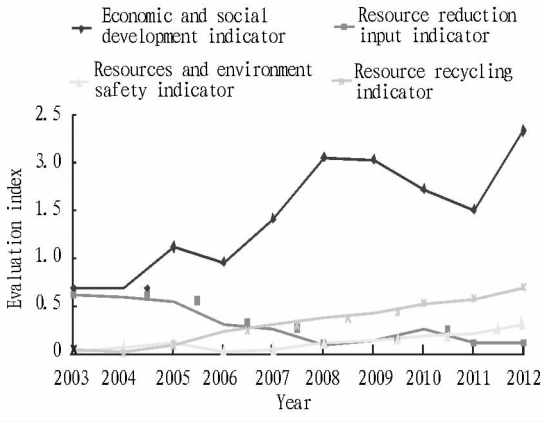

Fig. 2 The evaluation index of various classification indicators concerning the development of circular agriculture in Guizhou Province during 2003 – 2012

3.2 Obstacles to the development of circular agriculture

We can use three indicators (factor contribution degree, indicator deviation degree and obstacle degree) to judge the constraints on the development of circular agriculture. The factor contribution degree U_j is the weight of various indicators in the comprehensive evaluation indicator system, as shown in Table 1. The indicator deviation degree V_j represents the gap between the individual indicators and development goals of circular agriculture, denoted by the difference between normalized value of single indicators and

100%. The obstacle degree W_j signifies the value of influence of individual indicators and classification indicators on the overall level of circular agriculture, and this indicator is the result and goal of obstacle diagnosis of circular agriculture. The indicator principle and calculation method are as follows[9]:

$$V_j = 1 - X_j$$

where X_j is the normalized value of individual indicators, and the value is derived using the extreme value normalization.

$$M_j = V_j \times \frac{U_j}{\sum_{j=1}^{15}(V_j \times U_j)} \times 100\%$$

Through the ranking of obstacle degree (M_j) of individual indicators, we can determine the degree of influence of various obstacles to the development of circular agriculture. We perform the individual indicator obstacle degree test on the development level of circular agriculture in Guizhou Province in 2012 and sequence the major obstacles, as shown in Table 2.

The major obstacles to the development of circular agriculture in Guizhou Province in 2012 are sequenced in descending order in terms of the individual indicator obstacle degree as follows: application rate of chemical fertilizer > pesticide use levels > plastic sheeting use levels > commodity rate of farming, forestry, animal husbandry and fishery > grain yield > per capita food output > per capita arable land area. It can be found that the major obstacles to the development of circular agriculture are focused on the resource reduction input indicators and economic and social development indicators. In order to more clearly determine the obstacles to the development of circular agriculture, we calculate the obstacle degree of four classification indicators for the evaluation on development of circular agriculture, respectively, and the specific results are shown in Fig. 3. It is found that the obstacles to the development of circular agriculture in Guizhou Province in 2012 are resource reduction input indicator (77.74%), economic and social development indicator (21.23%), and resources and environment safety indicator (1.03%). And the obstacle degree of resource recycling indicator is 0, indicating that the development of circular agriculture is not restricted in terms of resource recycling. Therefore, under the current conditions for agricultural development, how to improve the efficiency of resources input becomes a prominent issue in Guizhou Province.

Table 2 Ranking of major obstacles to the development of circular agriculture in Guizhou Province in 2012

Order	1	2	3	4	5	6	7
Obstacles	C_8	C_9	C_{10}	C_7	C_7	C_4	C_3
Obstacle degree//%	34.31	30.14	13.30	12.74	4.54	3.95	1.03

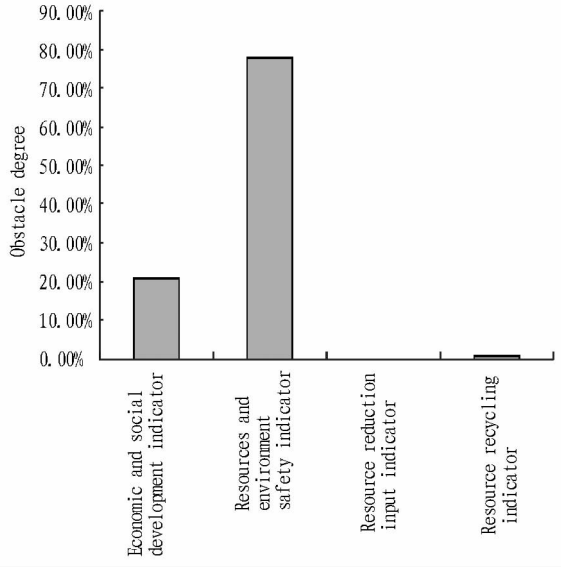

Fig. 3 The obstacle degree of classification indicators for the development of circular agriculture in Guizhou Province in 2012

4 Conclusions and policy recommendations

4.1 Conclusions Vigorously developing agricultural circular economy is an effective way to achieve sustainable agricultural development, and a strategic measure to ease the pressure on agricultural resources, protect ecological and clean resources, and promote sustainable agricultural and rural economic development. By analyzing the obstacles of various indicators and four classification indicators in 2012, it is found that the resource reduction input has become the biggest obstacle to the development of circular agriculture, followed by the level of economic and social development. The application rate of chemical fertilizers, pesticide use levels and plastic sheeting use levels are the major obstacles. Three economic and social development indicators (commodity rate of farming, forestry, animal husbandry and fishery, grain yield and per capita food production) also severely limit the development of circular agriculture, indicating that the agricultural output is low and the commodity rate of agricultural products is also low in Guizhou Province. Meanwhile, the per capita arable land area also affects the safety of resources and environment to some extent. Therefore, in the future development of circular agriculture, it is necessary to take appropriate measures to focus on improving the resource input efficiency and socio-economic development.

4.2 Policy recommendations

4.2.1 Reducing the material inputs per unit area and improving the resource utilization rate. At present, the resource reduction input has become a major factor limiting the development of circular agriculture in Guizhou Province, so it is necessary to solve some problems during agricultural production, such as excessive use of chemical fertilizers, pesticides and plastic sheeting as well as pollution caused by the use of these resources. First, it is necessary to use scientific methods to allocate fertilizers and pesticides in accordance with the scientific proportion, and try to use low toxicity

and residue pesticides and organic fertilizers to improve the efficient use of fertilizers and pesticides. Second, it is necessary to solve the problem of land pollution caused by plastic sheeting and improve the reuse of plastic sheeting to reduce waste and pollution of plastic sheeting.

4.2.2 Promoting the agricultural industrialization and improving the commodity rate of farming, forestry, animal husbandry and fishery. The commodity rate of farming, forestry, animal husbandry and fishery in Guizhou Province limits the development of circular agriculture, so it is necessary to actively promote the agricultural industrialization, extend the industrial chain of agricultural production, and focus on the development of agro-processing industries. Guizhou Province should seize the opportunity to play its own comparative advantages to develop cash crops and livestock industries; develop new circular agriculture and three-dimensional agriculture, extend the industrial chain and increase multiple cropping index[10]; actively foster the leading enterprises, strengthen ties with farmers, and establish agricultural cooperatives to raise the level of agricultural industrialization.

4.2.3 Strengthening the science and technology input and developing new varieties. Guizhou is a traditional agricultural province, but it has no good arable land resources for agricultural production, so the food production is not high, serious impeding the development of circular agriculture. Therefore, it is necessary to strengthen science and technology input, promote agricultural production technology, actively cultivate new varieties, and convert the scientific and technological achievements into the actual agricultural production. It is necessary to introduce improved varieties of major food crops, increase improved variety coverage, build the high-quality crop variety demonstration area, and build the improved variety breeding base of major food crops.

4.2.4 Strengthening the protection of farmland and achieving the food supply and demand balance. Due to limited arable land resources in Guizhou Province, the government should take various measures to implement the most stringent farmland protection system to protect arable land and stabilize the basic farmland area, in order to achieve sustainable use of farmland resources. Meanwhile, in order to alleviate the reduction of arable land and ease the contradiction between human and land, it is necessary to strictly control unlawful appropriation of arable land, actively promote the balance of occupation and compensation of arable land, and steadily increase arable land area to increase food production in Guizhou Province.

4.2.5 Strengthening the macro-control and developing the regional development planning of circular agriculture. Government should strengthen macro-control, to provide policy support for the development of circular agriculture. For example, the government can reward the companies and individuals for making contribution to the construction of circular agriculture and collect related fees and taxes due to excessive application of fertilizers or pesticides to guide farmers to develop circular economy[11]. Meanwhile, in order to better carry out the construction of circular agriculture, the government should develop regional development planning of circular agriculture to make comprehensive and accurate deployment for the development of circular agriculture.

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