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Construction of the evaluation system of regional agricultural circular economy and TOPSIS application

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ABSTRACT

In order to compare the effectiveness of inter-region agricultural circular economy (ACE, similarly hereinafter) development, this paper established the index system of regional ACE evaluation, and conducted a descriptive-comparative analysis with the agricultural circular data of respective Heilongjiang Reclamation Area, Heilongjiang Province and the whole nation. Then, TOPSIS was used to evaluate the achievements of ACE. The results show that in terms of the development efficiency of ACE, Heilongjiang Reclamation Area ＞ the nation ＞ Heilongjiang Province. The methods and conclusions in this paper can guide the research work in areas with good ACE development.

Keywords: Regional ACE, Index System, TOPSIS.

1. INTRODUCTION

A necessary part of ACE development is to establish a comprehensive evaluation index system and a corresponding statistic data collection system under the constraints of sustainable development and the ACE principles. With scientific method of comprehensive evaluation, the development situation of ACE is assessed comprehensively to identify the development levels of agricultural circular economic systems, determine the main system constraints, clarify the direction and focus of development, and propose corresponding policy measures according to local conditions.

At present, the domestic research on the quantitative evaluation system of circular economy is still in the exploratory stage. Some scholars have constructed the evaluation index system of circular economy and evaluated them methodologically.

Under the psychology of ecological efficiency, Zhou Guomei (2003) established a preliminary evaluation index system of circular economy [1]; based on the "3R" principle of circular economy, Li Jian (2004) constructed a three-layer evaluation system (target layer, criterion layer and base layer) and an AHP-based company-performance-oriented fuzzy comprehensive evaluation model that reflects the fuzzy theory [2]; Zhang Bo (2005) proposed the index system of circular economy from the perspectives of resource input reduction, pollutant discharge reduction, resource recycling and reutilization, socio-economic development and ecological environment quality, performing grey relational analysis and empirical evaluation of the circular economy of Nantong city, Jiangsu province [3]; Ma Qifang (2005) used BPEIR concept model (i.e. Behavior-Pressure- Effect-Impact-Reflection model) and Delphi method to select the evaluation index system of regional ACE, and applied AHP method to comprehensively assess the development level of the ACE in Jiangsu province [4]; Sun Jianwei (2007) used the gray relational analysis method to establish an evaluation model of regional ACE development, with which the development level of the ACE in Nanjing city was evaluated by using data sequences of the optimal value of ACE indices over the years [5]; Yang Wen and Li Shiping (2008) established an ACE evaluation system to conduct an AHP-based quantitative evaluation on the development levels and the obstacles of Ningxia ACE [6]. Zhu Jiande et al. (2008) evaluated the economic benefit of the architecture industry in China’s 31 provinces, municipalities and autonomous regions on the TOPSIS basis, providing references for the implementation of the macro regulation of the industry [7]; through TOPSIS analysis, Wu Xiaoqing et al. (2008) conducted a comprehensive evaluation on the circular economy of Suzhou Hi-tech Industrial Development Zone, Suzhou Industrial Park Ecological Industry Park and Wuxi New Area National Ecological Industry Demonstration Zone, identifying their deficiencies and putting forward targeted improvements and development ways [8].

Based on the characteristics of ACE, this paper devised the index system of regional ACE evaluation, and evaluated the effectiveness of regional ACE by using TOPSIS method.

2. EVALUATION METHOD

2.1 The concept of TOPSIS analytical method

TOPSIS is the abbreviation for Technique for Order Preference by Similarity to Ideal Solution. Its basic thought is to determine the optimal and worst schemes of the normalized raw data matrix and identify a scheme's closeness to the optimal scheme by calculating the distance of each scheme from the respective optimal scheme and worst scheme as the evaluation basis of scheme quality . TOPSIS has such advantages as convenience, reasonability, high comprehensibility, simple calculation, the ability to express scheme alternatives in the mathematic format, and the access to objective weight. Therefore, it has been promoted and applied in a variety of fields.

Assuming that there are m objects and each object has n attributes, the mathematical description of the multi-attribute decision-making problem is shown in equation (1):

$$Z=\max / \min\{ z_{ij} \mid i=1,2,\ldots m, j=1,2,\ldots.n\} \tag{1}$$

2.2 The general application procedures of TOPSIS

① Establish multi-attribute decision-making matrix D . If there are m schemes and each of them has n attributes, the decision-making matrix of the to-be-decided multi-attribute problem becomes:

$$D = \begin{matrix} & x_1 & x_2 & \cdots & x_n \\ A^1 & x_{11} & x_{12} & \cdots & x_{1n} \\ A^2 & x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ A^m & x_{m1} & x_{m2} & \vdots & x_{mn} \end{matrix} \tag{2}$$

where x_{ij} is the value of the scheme A^i 's attribute X_j , such as the quality loss L_{ij} (i =1,2,.., m , j =1,2, $\cdots$, n).

② Let x_j^* be the maximum value of the j th attribute, and the standardized version of the matrix D is:

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ p_{m1} & p_{m2} & \vdots & p_{mn} \end{bmatrix} \tag{3}$$

in which $p_{ij} = \frac{x_{ij}}{x_j^*}$ (i =1,2, $\cdots$, m , j =1,2, $\cdots$, n).

③ Calculate the weighed matrix of P .

$$WP = \begin{bmatrix} w_1 p_{11} & w_2 p_{12} & \cdots & w_n p_{1n} \\ w_1 p_{21} & w_2 p_{22} & \cdots & w_n p_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ w_1 p_{m1} & w_2 p_{m1} & \vdots & w_n p_{mn} \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \vdots & r_{mn} \end{bmatrix} \tag{4}$$

where w_j is the weight of the jth attribute, and $\sum_{j=1}^{n} w_j = 1$.

④ To determine the positive ideal solution and negative ideal solution.

The positive ideal solution: for benefit indices, the positive ideal solution has the maximum value among all values in the attribute alternatives, or the set of all maximum values in the columns of the decision-making matrix; for cost indices, the positive ideal solution has the minimum value among all values in the attribute alternatives, or the set of all minimum values in the columns of the decision-making matrix.

$$r^+ = \left\{ \left(\max \ r_{ij} \middle| j \in J \right), \left(\min \ r_{ij} \middle| j \in J' \right) \middle| i = 1,2,\cdots,m \right\} = \left\{ r_1^+, r_2^+, \cdots, r_j^+, \cdots, r_n^+ \right\} \tag{5}$$

The negative ideal solution: for benefit indices, the negative ideal solution has the minimum value among all values in the attribute alternatives, or the set of all minimum values in the columns of the decision-making matrix; for cost indices, the negative ideal solution has the maximum value among all values in the attribute alternatives, or the set of all maximum values in the columns of the decision-making matrix.

$$r^+ = \left\{ \left(\min \ r_{ij} \middle| j \in J \right), \left(\max \ r_{ij} \middle| j \in J' \right) \middle| i = 1,2,\cdots,m \right\} = \left\{ r_1^-, r_2^-, \cdots, r_j^-, \cdots, r_n^- \right\} \tag{6}$$

In equation (5) and (6),

$$J = \left\{ j = 1,2,\cdots,n \middle| j \ \ related \ \ to \ \ the \ \ benefit \ \ indicators \right\}$$

$$J' = \left\{ j = 1,2,\cdots,n \middle| j \ \ related \ \ to \ \ the \ \ \cos t \ \ indicators \right\}$$

⑤By calculating the n-dimension Euclidean distance, we obtain the distance of different schemes from positive ideal solution and negative ideal solution. The distance between an alternative and the positive ideal solution is:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (r_{ij} - r_j^+)^2} \quad (i =1,2,\cdots, m) \tag{7}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} (r_{ij} - r_j^-)^2} \quad (i =1,2,\cdots, m) \tag{8}$$

⑥ calculate the relative closeness of each alternative to the ideal solution.

$$C_j^* = \frac{d_i^-}{d_i^+ + d_i^-} \quad (i =1,2,\cdots, m) \qquad 0 \le C_j^* \le 1 \tag{9}$$

where C_j^* measures the ratio of the distance between schemes and negative ideal solution to the distance between negative ideal solution and positive ideal solution. Therefore, the larger C_j^* is, the farther the scheme is from the negative ideal solution, and the nearer the scheme is from the positive ideal solution.

⑦ arrange C_j^* in ascending or descending orders, and determine the priority of alternatives, among which the largest value of C_j^* is the optimal solution because it is the farthest from positive ideal solution and the nearest from negative ideal solution.

3. THE CONSTRUCTION OF REGIONAL AGRICULTURAL CIRCULAR ECONOMY EVALUATION INDEX SYSTEM AND ITS CONNOTATIONS

In selecting indices, based on the current research findings of ACE, we integrated the "3R" principle of circular economy with our evaluation system, and obtained the following indices:

3.1 Evaluation index of resource reduction input

The principle of reduction is an important principle of agricultural circular economy. It requires that in the production process, with technological and managerial improvements, resources can be saved and used more efficiently, and the amount of pollutants discharged can be reduced and even eliminated, which helps in realizing sustainable and ecologically compatible economic growth. The development focus of ACE is the transformation of agricultural growth mode into a low-consumption, less-polluted, and sustainable version, focusing on improving resource utility rate and saving land, water, fertilizer, pesticide and energy.

① Fertilizer application intensity (kg/hm2): It refers to the ratio of the fertilizer amount used in agricultural production (including nitrogen fertilizer, phosphate fertilizer, potash fertilizer and compound fertilizer) to the total arable area. Fertilizer use should be converted into pure volume, which means that the amount of nitrogen fertilizer, phosphate fertilizer, and potash fertilizer should be the reduced mass of nitrogen, phosphorus pentoxide and potassium oxide and that the amount of compound fertilizer should be the reduced mass of the major components. The smaller, the better.

② agricultural energy consumption index (standard coal) (t/10,000 yuan): It refers to the amount of standard coal consumed to gain certain output value in agriculture, forestry, animal husbandry, fishery, and forestry. The corresponding formula is: agricultural energy consumption index = the energy consumption volume of agriculture, forestry, animal husbandry, fishery, and forestry/the output value of agriculture, forestry, animal husbandry, fishery, and forestry. The smaller, the better.

③ virtual agricultural water coefficient (kg/hm^2): it refers to the amount of water consumed in every arable area to maintain the normal growth of crops. The formula is: the virtual agricultural water coefficient = (the virtual water consumption amount per unit × agricultural output value)/crop acreage. The smaller, the better.

④ pesticide use level (t/hm^2): it refers to the reduced mass of fertilizer use per unit area. The formula is: pesticide use level = the reduced mass of fertilizer use/the total crop acreage. The smaller, the better.

⑤ plastic film use level (t/hm^2): it refers to the usage amount of plastic films over all crops. The formula is: the plastic film use level = the usage amount of plastic films/crop acreage. The smaller, the better.

3.2 Recycling of resources

The recycling and efficient use of resources is the fundamental difference between agricultural circular economy and other industrial circular economy. Therefore, the mode, efficiency and benefit of resource allocation have become an important index to measure the circular economy of agriculture. The goal of resource recycling is to increase the utilization rate of resources, and to employ economic resources as repeatedly and variously as possible. The industry of waste recycling should be developed actively, so that improving the capacity of sustainable resource utilization and the efficiency and benefit of resource utilization. In this way, the resource consumption volume per unit output value will gradually decrease, and thus the pollution is controlled radically.

① fertilizer effective use coefficient (yuan/t): it is the agricultural output value generated from a certain amount of fertilizer use. To improve fertilizer utilization rate is an important measure to achieve agricultural growth. The formula is: fertilizers effective utilization coefficient = total agricultural output value/the reduced amount of fertilizer use.

② Comprehensive utilization rate of crop straw (%): it refers to the annual ratio of comprehensive utilization amount of crop straw to total crop yield. The comprehensive utilization of straw includes returning chopped straws into the field, returning quickly decomposed straws into the field, straw return after livestock digestion, straw fuel, straw gasification, building materials, edible fungus production, and weaving materials. Open air burning, field stacking or temporary storage are excluded from comprehensive straw utilization.

③ Comprehensive utilization rate of feces (%): it refers to the ratio of the comprehensive utilization amount of feces to the overall quantity of feces in the intensive livestock and poultry farms. Relative criteria should comply with GB18596-2001 "livestock and poultry breeding industry pollutant discharge standards" and "livestock and poultry breeding pollution control management approach". The comprehensive utilization of livestock and poultry manure mainly includes direct use as fertilizer, raw material of organic fertilizer, compost, and recycling energy (including biogas).

④ Multiple cropping index (%): It refers to the annual ratio of the total crop-seeded area to the common arable area, which is an indicator of the degree to which the arable land is developed. The formula is: multiple cropping index = crop acreage/cultivated area × 100%.

3.3 Resources and Environment Safety Indicators

By taking rational use of natural resources and developing the economy within the environmental limits, not only can funds be accumulated while technologies be improved, but the environment can be further protected. Environmental quality enhancement is both the target and content of circular economy construction. The development of circular economy should not only pay attention to economic efficiency, but also attach importance to environmental benefits.

① effective irrigation coefficient (%): it refers to ratio of irrigable arable area to the common arable area in normal harvest years with basically-equipped irrigation devices, a certain amount of water resource and flat land. The formula is: effective irrigation coefficient = effective irrigated area/cultivated area × 100%.

② per capita arable land (hm^2 /head): it refers to the common area of cultivated land per capita. The formula is: per capita arable land = cultivated land area/total population.

4. THE COMPARISON OF DESCRIPTIVE EVALUATION OF REGIONAL ACE DEVELOPMENT OF HEILONGJIANG RECLAMATION AREA, HEILONGJIANG PROVINCE AND THE COUNTRY

Using the above indicators, according to the 2009 Statistical Yearbooks of respective China, Heilongjiang Reclamation Area and Heilongjiang Province, we obtained the corresponding data, calculated the regional ACE evaluation indicators, and displayed the results in Table 1.

Table 1. The comparison of descriptive evaluation of regional ACE development of Heilongjiang reclamation area, Heilongjiang province and the country

The year of 2008		Heilongjiang reclamation area	Heilongjiang province	the country
Resource reduction input	①Fertilizer application intensity(kg/ha.)	157.77	147.37	335.26
	②agricultural energy consumption index(ton/10,000 yuan)	0.54	0.07	0.14
	③virtual agricultural water coefficient(kg/ha.)	6154.78	5085.93	3667.60
	④pesticide use level(ton/ha,)	0.004	0.005	0.011
	⑤plastic film use level(ton/ha,)	0.006	0.005	0.013
Resource recycling	①fertilizer effective use coefficient(yuan/ton)	80856.10	58344.73	53529.36
	②Comprehensive utilization rate of crop straw	0.91	0.37	0.35
	③Comprehensive utilization rate of feces	0.85	0.50	0.29
	④Multiple cropping index	0.91	0.93	0.88
Resource environment safety	①effective irrigation coefficient	0.494	0.182	0.480
	②per capita arable land (ha./head)	1.528	0.254	0.092

From Table 1, we draw the following conclusions:

According to the resource reduction input in Heilongjiang Province, the use of chemical fertilizers, energy consumption, pesticides and agricultural film are much lower than the national average. Only the agricultural virtual water use level is higher than the national level, which is mainly related to the position of Heilongjiang province as China’s largest producing area of japonica rice. In terms of resource security, the effective irrigation coefficient reflects the low water use efficiency of Heilongjiang province and the better performance of per capita arable land than the country’s; from the use of resources, fertilizer effective utilization coefficient, comprehensive utilization rate of straw, livestock and poultry manure recycling rate and multiple cropping index are better than the whole country. All in all, except for water utilization, Heilongjiang Province has better ACE overall conditions than the whole country, and that it is effective to take Heilongjiang as the demonstrative research sample area.

As can be seen from the indexes of Heilongjiang reclamation area, the fertilizer and energy consumption are higher than those in Heilongjiang Province and the whole country. Nevertheless, the effective utilization coefficient of chemical fertilizers is the highest among the three geological ranges, and the per capita arable land is respective 6 and 16 times of Heilongjiang Province and the whole country. The agricultural virtual water use level is higher than Heilongjiang Province and the whole country, yet the effective irrigation coefficient is also the highest, which means that the utilization rate of fertilizer, water and excess energy are higher and resource-safer. The use of pesticides and plastic films is quite below the national level yet near Heilongjiang level; the average utilization rate of straw and the livestock and poultry manure recycling rate are much higher than that of the whole country and Heilongjiang province. The multiple cropping index is better than that of the whole country and similar to that of Heilongjiang. It shows that the agricultural circular economy conditions in Heilongjiang reclamation area are better than those over the country and the overall situation of Heilongjiang province.

5. COMPARISON OF TOPSIS PERFORMANCE IN EVALUATING THE REGIONAL DEVELOPMENT OF AGRICULTURAL CIRCULAR ECONOMY IN HEILONGJIANG RECLAMATION AREA, HEILONGJIANG PROVINCE AND CHINA

Table 2. TOPSIS evaluation results of the regional development of agricultural circular economy in Heilongjiang reclamation area, Heilongjiang province and China

Order	Ci	Region
1	0.345	Heilongjiang reclamation area
2	0.314	China
3	0.178	Heilongjiang province

Based on the brief introduction of TOPSIS, we used SPSS 16.0 program editing function to evaluate the development situation of agricultural circular economy in the above three regions, and obtained the following results:

The results show that in terms of the development efficiency of ACE, Heilongjiang Reclamation Area ＞ the nation＞Heilongjiang Province, which basically complies with the descriptive results obtained before.

6. CONCLUDING REMARKS

In view of its position as China's most important commodity grain base, Heilongjiang reclamation area is the most advanced representative of grain productivity. With an arable area equal to 1.29 times of Zhejiang Province counterparts, Heilongjiang reclamation area has become the largest grain safety/manufacturing/processing base, with the total grain output of 10.265 billion kilograms and the grain processing and production capacity of 13.91 billion kilograms. Its grain logistics level is also in the forefront of the country. The grain supply chain whose place of origin is in Heilongjiang reclamation area is one of the few Chinese typifications of grain supply chain, presenting the progressiveness of supply chain. It can be deducted that the modernized agricultural productivity is more conducive to the development of agricultural circular economy, and that it is more demonstrative to take Heilongjiang as the research sample area of agricultural circular economy.

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