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Research on the coupling and coordinated development of agricultural economy and ecological environment system in Chongqing municipality

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Abstract: Investigating the level and characteristics of coordinated coupling development between the agricultural economy and agricultural ecological environment systems in Chongqing Municipality is of great significance for the sustainable development of agriculture in Chongqing. Based on the statistical yearbook data of Chongqing Municipality from 2000 to 2022, this article constructs a comprehensive evaluation index system for the agricultural economy and agricultural ecology of Chongqing Municipality. The entropy method and comprehensive development evaluation model are used to calculate the comprehensive development level of the two systems, and a coupling coordination degree model is applied to systematically analyze the level of coordinated development between the two systems. The comprehensive development level of the agricultural economy in Chongqing Municipality shows a fluctuating upward trend, with significant fluctuations in the comprehensive evaluation index of the agricultural economy from 2000 to 2008, followed by a steady upward trend after 2008. The comprehensive development level of the agricultural ecological environment fluctuates significantly, with an overall fluctuating upward trend from 2000 to 2012, followed by a sharp downward trend after 2012. The coupling coordination degree has experienced a transition from moderate coordination to basic coordination, then to high coordination, and finally maintained a stable state of basic coordination. It is necessary to develop ecological agriculture from the perspective of economic development and prioritize ecological protection. Strengthening agricultural ecological environment protection from the perspective of protecting the ecological environment can promote economic development. In the process of economic development, it is essential to protect the ecological environment from destruction and promote economic development through ecology, interaction, and mutual influence, achieving benign development.

1. Introduction

System coupling is widely used in agricultural systems, and the optimized coupling of the

agricultural economy and ecological environment system is the most suitable solution for the mutual restriction of the agricultural economy and agricultural ecological environment systems, making the entire agricultural system develop more harmoniously and orderly. Studying coupling processes helps clarify the coupling process and evolution laws of the agricultural economy and ecological environment systems, achieving consistency between agricultural industries and resources, which is of great practical significance for building stable, sustainable, and efficient agricultural economic ecological systems. On the one hand, the premise and foundation of the development of the agricultural economy system are the material and development space provided by the agricultural ecological environment system, which is also influenced by the agricultural ecological environment system. On the other hand, the agricultural economy system will also act on the agricultural ecological environment system. Rational agricultural production promotes the balance of the agricultural ecological environment system, while irrational practices lead to imbalances in the agricultural ecological environment system. Therefore, only by continuously promoting the coordinated development of the agricultural economy and ecological environment systems can the positive effects and coordinated effects between them be exerted, thereby promoting the efficient utilization and coordinated development of the entire agricultural economic ecological system.

In recent years, the issue of coordinated coupling between agricultural economy and ecological environment has attracted widespread attention in the academic community. At the theoretical level, Ren Jizhou [1] proposed the theory of large agricultural system coupling, laying the theoretical foundation for research. At the empirical level, Gao Jing [2] and others pointed out that the degree of coupling coordination of China's agricultural ecological economic system has evolved from moderate coordination to extreme coordination with an increasing trend year by year. Zheng Bofu [3] and others found that the agricultural ecological system and the agricultural economic system in the hilly areas of southern Jiangxi have evolved into highly coordinated coupling, with a distribution pattern of low in the central part and high in the north and south. Wang Jing [4] and others found that the construction of gully land engineering can promote the transformation of the agricultural ecological and economic relationship in the Loess Plateau of Yan'an into mutual coordination. Fan Zuhong [5] and others used a dynamic-static combined coupling degree model to explore the coupling coordination of the agricultural ecological economic system in the karst areas of Guizhou Province, finding that this situation is closely related to the short board effect of ecological system development. In addition, Zou Yadong [6], Huang Liying [7], Li Aijie [8], respectively, based on the degree of coupling coordination and evolutionary trends of agricultural economy and ecological environment in different provinces. These studies provide a reference for the ideas and methods of this research. Chongqing is located in the southwestern inland of China, in the upstream area of the Yangtze River, with rich and diverse terrain, including high hills, low hills, mountains, plateaus, mid-hills, gentle hills, plains, and low mountains. Ninety-eight percent of it is mountainous, with a total cultivated area of 28.0525 million mu, but with many sloping lands and land fragmentation, which have adverse effects on agricultural production. The "14th Five-Year Plan" for promoting agricultural and rural modernization in Chongqing Municipality emphasizes the construction of a modern, efficient, and characteristic agricultural belt in Chongqing and the optimization of industrial layout, laying a foundation for high-quality development. However, there are still prominent problems such as poor agricultural production conditions and fragile ecological environment. The work of agricultural pollution prevention and control needs to be improved. Therefore, exploring the coordinated relationship between the agricultural economy and ecological environment in Chongqing Municipality will be beneficial to the healthy development of agriculture and of great significance for the sustainable development of the agricultural economy and ecological environment in Chongqing Municipality. This study uses a coupling coordination degree

model to analyze relevant indicators of Chongqing Municipality from 2000 to 2022 and explore the coordinated development of agriculture and ecological environment in Chongqing Municipality.[9]

2. Research Design

2.1 Data Source and Construction of Indicator System

Table 1: Evaluation Index System of Coupling and Coordinated Development of Agricultural Economy and Ecosystem in Chongqing

destination layer	subsystem	serial number	index	unit	Index attribute	weight
Agricultural economy -Agroecological environment system evaluation system	agricultural economy	1	per capita output of grain	kg/person	+	0.0201
		2	per capita agricultural output value	RMB/person	+	0.0204
		3	Per capita disposable income of rural residents	RMB/person	+	0.0592
		4	Total power of agricultural machinery per capita	Million kW	+	0.0101
		5	The proportion of agricultural output value to the output value of agriculture, forestry, animal husbandry and fishery	%	+	0.0236
		6	agricultural labor productivity	%	+	0.0745
		7	electricity for rural use	BillionkW ħ	+	0.1489
		8	Rural Engel coefficient	%	-	0.0674
	agroecological environment	9	Per capita planted area of crops	hm2	+	0.0139
		10	Pesticide application rate	t	-	0.0528
		11	Amount of agricultural chemical fertilizer applied	ten thousand t	-	0.0853
		12	forest coverage rate	%	+	0.0158
		13	Crop affected area	103hm2	-	0.0152
		14	Crop disaster area	103hm2	-	0.0496
		15	Soil erosion control area	103hm2	+	0.0381
		16	Irrigated area of cultivated land	103hm2	+	0.1031

The agricultural economic and ecological environmental data involved in this study mainly come from the "Chongqing Statistical Yearbook" from 2000 to 2022. When selecting indicators, reliability, accessibility, and operability principles were followed. Drawing on the research results of relevant scholars, indicators for the coordinated development of agricultural economy and ecological environment were comprehensively selected according to local conditions. Combined with the actual situation in Chongqing Municipality, an evaluation indicator system for the agricultural economy and ecological environment system of Chongqing Municipality, consisting of 16 indicators such as per capita grain production and per capita agricultural output value, was

constructed. The evaluation indicator system is shown in Table 1.

2.2 Data Standardization and Weight Calculation

2.2.1 Data Standardization

Since the selected indicators have different dimensions and attributes, the data indicators were standardized using the range method. The formulas are as follows:

For positive indicators:
$$x'_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}} \tag{1}$$

For negative indicators:
$$x'_{ij} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}} \tag{2}$$

In formulas (5) to (6), x_{ij} represents the original indicator value, x'_{ij} represents the standardized value of the indicator data, $x_{\min}$ represents the minimum value in the indicator data, and $x_{\max}$ represents the maximum value in the indicator data.

To avoid bias caused by subjective weighting, this study adopted the entropy method for objective weighting to determine the indicator weights of the agricultural economy and ecological environment in Chongqing Municipality.[10]

2.2.2 Indicator Weight Calculation

The premise of using the coupling coordination model is to quantify the comprehensive evaluation levels of the two subsystems. It is essential to assign weights to various indicators in the two systems. Common methods for determining different indicator weights include the Delphi expert consultation method, the Analytic Hierarchy Process (AHP), and the entropy method. Compared with the former two methods, the entropy method can eliminate subjective interference and make the results more objective and reasonable. Therefore, after standardizing the data, this study used the entropy method to calculate the weights of each indicator (see Table 1). The specific formulas are as follows:

Step 1: To rationalize the values, shift the standardized values by 0.0001 units to ensure they are not zero, as shown in formula

$$U_{ij} = x'_{ij} + \alpha \tag{3}$$

Where, U_{ij} is the value after translation, α is the translation amplitude, here α = 0.0001.

Step 2: Calculate the proportion of the \(j^{th}\) indicator in the sample interval for the \(i^{th}\) system, as shown in formula (4):

$$P_{ij} = x'_{ij} / \sum_{i=1}^{n} x'_{ij}, \quad i = 1,2,\cdots, \ n, \ \ j = 1,2,\cdots, \ m \tag{4}$$

where n is the number of indicator systems, and m is the number of indicators.

Step 3: Calculate the entropy value and coefficient of variation for the j indicator, as shown in formulas (5) and (6):

$$e_j = -\frac{1}{\ln(n)}\sum_{i=1}^{n} P_{ij} \ln P_{ij} \tag{5}$$

$$d_j = 1 - e_j \tag{6}$$

In the formula, e_j is the entropy value of the j-th index, and $e_j \geq 0$, $k = \frac{1}{\ln(n)} > 0$, d_j are the difference coefficients of the j-th index.

Step 4: Calculate the weight of the \(j^{th}\) indicator, as shown in formula (7):

$$w_{ij} = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{7}$$

where w_{ij} represents the weight of the j indicator in the system. Using the entropy method can adjust the weights of various indicators quantitatively and objectively, reflecting the superiority of information entropy and obtaining effective weights.

2.3 Model Construction

The coupling coordination model is used to evaluate the degree of coupling coordination between systems. Coupling refers to the dynamic relationship between elements in two or more systems, where they interact and influence each other to achieve coordinated development among systems. Coordination refers to the degree of benign coupling in the interaction relationship, reflecting the quality of coordination. By establishing relevant indicator systems for the agricultural economy system and the agricultural ecological environment system, constructing comprehensive development evaluation models and coupling coordination models, the coupling relationship between the two systems and its changing trend can be analyzed.[11]

2.3.1 Construction of Comprehensive Development Evaluation Model

Before calculating the coupling coordination degree of the two systems, it is necessary to calculate the comprehensive development level of each system separately, obtaining the comprehensive evaluation index for different years of the two systems. The calculation formula is as follows:

$$U_i = \sum_{j=1}^{m} w_{ij} U_{ij}, \sum_{j=1}^{m} w_j = 1 \tag{8}$$

Where: U_i is the comprehensive evaluation index value of the i-th system; U_{ij} is the efficiency coefficient, indicating the contribution degree of item j in the i system to the system.

2.3.2 Construction of Coupling Coordination Model

Drawing on the coupling coefficient model in physics, a coupling model for the agricultural economy and ecological environment system is constructed, with the calculation formula as follows:

$$C = 2\sqrt{\frac{U_1 \times U_2}{(U_1+U_2)^2}} \tag{9}$$

where C represents the coupling degree of the two systems, $C \in [0,1]$.

The above model measures the magnitude of the interaction between systems or elements. However, it may not fully reflect the synergistic effects and overall efficiency between different systems. Therefore, to further analyze the coordinated development of the agricultural economy and ecological environment system in Chongqing Municipality, it is necessary to introduce a coupling coordination model. The calculation formulas are as follows:

$$T = \alpha U_1 + \beta U_2 \tag{10}$$

$$D = \sqrt{C \times T} \tag{11}$$

Where D is the degree of coupling coordination, $D \in [0,1]$; C is for coupling degree, $C \in [0,1]$; T is the comprehensive evaluation index of agricultural economy and ecological environment; α, β are undetermined coefficients. This study assumes that industrial economy and ecological environment have the same important impact on the sustainable development of agriculture, so the values of α, β are 0.5.

The degree of coupling development of agricultural economy and ecological environment system can be divided into different coupling, degree of coupling coordination and degree of coordination development according to the coupling coordination standard in Table 2.

Table 2: The types and classification criteria of coupling coordinated development

coupling degree C	Coupling phase	coordination degree D	Coordinated development type
$0 < C \le 0.1$	Extremely uncoupled	$0 < D \le 0.1$	Incongruous coupling
$0.1 < C \le 0.3$	Low coupling	$0.1 < D \le 0.3$	Low coordination coupling
$0.3 < C \le 0.5$	Moderate coupling	$0.3 < D \le 0.5$	Moderately coordinated coupling
$0.5 < C \le 0.7$	Basic coordination coupling	$0.5 < D \le 0.7$	Basic coordination coupling
$0.7 < C \le 0.9$	highly coupled	$0.7 < D \le 0.9$	Highly coordinated coupling
$0.9 < C \le 1$	Extreme coupling	$0.9 < D \le 1$	Extremely coordinated coupling

3. Empirical analysis

3.1 Comprehensive and evaluation index analysis

The weights of each index of Chongqing's agricultural economy and ecological environment system were obtained by entropy method, and the comprehensive evaluation indexes of U1 and U2 were calculated according to the weights obtained. Then, the obtained values are substituted into the coupling coordination degree model, and the coupling degree C, comprehensive evaluation index T and coupling coordination degree D of the two systems are calculated. The results are shown in Table 3. According to the results of Table 3, the change trend chart of the comprehensive development level of agricultural economy and ecological environment in Qing City can be drawn, as shown in Figure 1.

Table 3: Result of Coupling and Coordinated Development Level of Agricultural Economy and Ecological Environment System in Chongqing from 2000 to 2022

year	Agricultural economic system comprehensive evaluation index U1	Agroecological environment system comprehensive evaluation index U2	Two systems comprehensive evaluation index T	Coupling degree C	Coupling degree D	Coupling coordination type
2000	0.2166	0.2466	0.2294	0.9972	0.4783	Moderately coordinated coupling
2001	0.1637	0.4762	0.3199	0.8727	0.5284	Basic coordination coupling
2002	0.1422	0.4353	0.2888	0.8617	0.4988	Moderately coordinated coupling
2003	0.0842	0.2741	0.1782	0.8430	0.3876	Moderately coordinated coupling
2004	0.4015	0.3303	0.3659	0.9952	0.6035	Basic coordination coupling
2005	0.3520	0.3164	0.3342	0.9986	0.5777	Basic coordination coupling
2006	0.1663	0.4305	0.2984	0.8967	0.5173	Basic coordination coupling
2007	0.2852	0.4898	0.3875	0.9645	0.6113	Basic coordination coupling
2008	0.1307	0.4428	0.2867	0.8390	0.4905	Moderately coordinated coupling
2009	0.3079	0.6532	0.4806	0.9332	0.6697	Basic coordination coupling
2010	0.4246	0.5423	0.4834	0.9926	0.6927	Basic coordination coupling
2011	0.4194	0.6346	0.5270	0.9789	0.7183	Highly coordinated coupling
2012	0.4443	0.6631	0.5537	0.9803	0.7367	Highly coordinated coupling
2013	0.5101	0.4685	0.4893	0.9991	0.6992	Basic coordination coupling
2014	0.5899	0.3789	0.4844	0.9760	0.6876	Basic coordination coupling
2015	0.5812	0.1478	0.3645	0.8041	0.5414	Basic coordination coupling
2016	0.5708	0.3070	0.4389	0.9538	0.6470	Basic coordination coupling
2017	0.5581	0.2842	0.4212	0.9457	0.6311	Basic coordination coupling
2018	0.4901	0.3396	0.4148	0.9834	0.6387	Basic coordination coupling
2019	0.5387	0.2285	0.3836	0.9146	0.5924	Basic coordination coupling
2020	0.7160	0.2380	0.4770	0.8654	0.6425	Basic coordination coupling
2021	0.8483	0.0854	0.4669	0.5766	0.5188	Basic coordination coupling
2022	0.8193	0.1838	0.5016	0.7737	0.6230	Basic coordination coupling

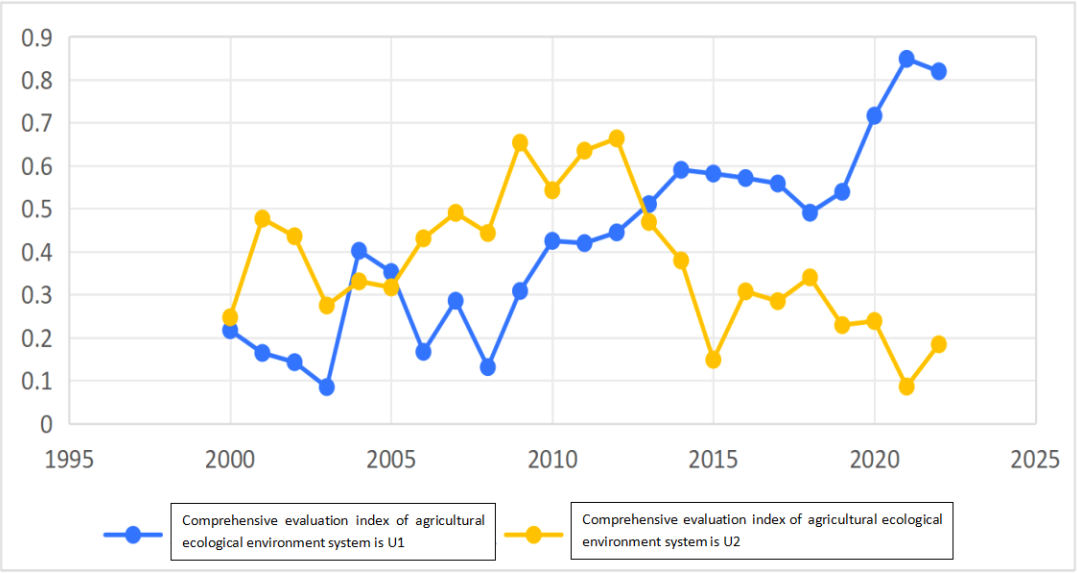

Figure 1: Comprehensive development level of agricultural economy and ecological environment in Chongqing from 2000 to 2022

The comprehensive development level of Chongqing's agricultural economy has shown a fluctuating upward trend over the past few years. It initially decreased, then rose, followed by another decrease, but overall maintained an upward trend, indicating the fluctuating nature of agricultural economic development. In recent years, there has been a trend towards improvement. The changing trend can be divided into three stages:

From 2000 to 2008, the comprehensive evaluation index of the agricultural economy fluctuated significantly. It decreased from 0.2166 to 0.0842 between 2000 and 2003, possibly due to the decreasing proportion of agricultural output in the overall output of agriculture, forestry, animal husbandry, and fishery industries, which decreased from 59.3% to 55.3%. From 2003 to 2004, it increased from 0.0842 to 0.4015, possibly due to increases in various economic indicators such as per capita grain production, per capita agricultural output value, and per capita disposable income of rural residents. From 2004 to 2008, the comprehensive evaluation index fluctuated, possibly due to the constraints of the geographical environment, making it difficult to scale up agricultural planting and investment in mountainous areas, resulting in slow agricultural economic development.[12]

From 2008 to 2018, the comprehensive evaluation index of the agricultural economy showed a steady upward trend, increasing from 0.1307 to 0.4901. During this period, the level of agricultural economic development in Chongqing Municipality significantly improved, possibly due to increasing agricultural investment, improving agricultural infrastructure, significant improvement in agricultural mechanization levels, and a significant increase in total agricultural power and per capita agricultural output value.[13]

From 2018 to 2022, the comprehensive evaluation index of the agricultural economy showed a rapid upward trend, increasing from 0.4901 to 0.8193, reaching a peak of 0.8483 in 2021. The rapid development of the agricultural economy may be attributed to the government's efforts to consolidate the success of poverty alleviation by increasing agricultural subsidy funds and policy measures.

The comprehensive development level of the agricultural ecological environment in Chongqing has fluctuated significantly. From 2000 to 2022, the changing trend of the comprehensive development level of the ecological environment in Chongqing Municipality can be roughly divided into two stages:

From 2000 to 2012, the comprehensive evaluation index of the agricultural ecological

environment showed an overall upward trend, increasing rapidly from 0.2466 to 0.6631, indicating significant achievements in ecological environment construction and demonstrating strong development momentum. The reduction in disaster-affected areas of crops, soil erosion control area, and increase in forest coverage were important factors contributing to the rise in the comprehensive evaluation index of the agricultural ecological environment system. Additionally, the increasing attention from the government and society to the agricultural ecological environment also contributed to the stable increase in the comprehensive evaluation index.[14]

From 2012 to 2022, the comprehensive evaluation index of the agricultural ecological environment showed a significant downward trend, decreasing from 0.6631 to 0.1838, with a minimum value of 0.0854 in 2021. During this period, the level of agricultural economic development far exceeded that of agricultural ecological environment comprehensive development, indicating degradation of the agricultural ecological system and increased environmental pressure.

The trend of overall development of the two systems can be divided into two stages. Before 2012, the overall trend was upward, with the agricultural economic development lagging behind that of the ecological environment, indicating significant achievements in ecological environment governance and a positive trend. After 2012, agricultural economic development continued to rise, while the comprehensive development level of the agricultural ecological environment showed a downward trend, with a development level lower than that of agricultural economic development, indicating rapid agricultural economic development, possibly at the expense of ecological environment resources or due to frequent occurrences of severe disasters such as seasonal droughts and floods, leading to asynchronous development of agricultural economic development and agricultural ecological environment.[15]

3.2 Coupling coordination analysis

The average coupling degree between the agricultural economy and agricultural ecological system in Chongqing Municipality over the past 22 years is 0.91, indicating a strong correlation between them. At the same time, the coupling coordination degree between the agricultural economy and agricultural ecological system has shown a steady upward trend overall. Chongqing has experienced a general change from moderate coordination and coupling to basic coordination and coupling, and then to highly coordinated coupling, gradually stabilizing. The change in coupling coordination is generally increasing first and then decreasing to stabilize, which is similar to the changing trend of the comprehensive evaluation index of the two systems. Specifically, it can be divided into the following two stages:

From 2000 to 2012, the coupling coordination degree showed a continuous upward trend, evolving from moderate coordination coupling to basic coordination coupling, and then to highly coordinated coupling. During this period, Chongqing's agricultural economic development was still in its initial stage. The agricultural production process was extensive, leading to large energy consumption and increased emissions of agricultural waste. In addition, pollution control measures were not comprehensive, resulting in frequent entry of pollutants into soil and water environments. However, from 2005 to 2012, Chongqing showed a gradual increase in the degree of coordination in agricultural economic development and ecological environment, indicating that while pursuing agricultural economic development, Chongqing continuously deepened its focus on environmental protection, promoted ecological civilization construction, and made significant achievements.[16]

From 2013 to 2022, the coupling coordination degree remained stable, indicating that with continuous investment in agricultural economic development and ecological environment construction, both were in a state of continuous development. However, during this period, agricultural economic development and ecological environment development remained at a basic

coordination level for a long time, indicating the emergence of new problems in the process of agricultural economic development and environmental protection. It may not be possible to achieve highly coordinated development of the two systems solely by increasing investment. Further measures are needed to strengthen the coordination between agricultural economic development and ecological environment protection, such as adjusting the industrial structure, innovating agricultural production and environmental protection technologies, and providing policy support.

3.3 Policy recommendations

Based on the above analysis, it can be seen that the comprehensive development level of the agricultural economy and the ecological environment system fluctuates, and the coupling coordination level of the two systems is currently maintained at a basic coordination level. In order to gradually improve the coupling coordination of the two systems, this study proposes suggestions from two aspects: agricultural economy and agricultural ecological environment systems.

Develop ecological agriculture and emphasize ecological protection. On the one hand, vigorously develop characteristic agriculture in mountainous areas of Chongqing, such as citrus, pickled vegetables, fisheries, tea, etc., while focusing on protection. For example, relying on large and medium-sized reservoirs to create ecological reservoir fisheries bases. In the process of developing ecological fisheries, we should refrain from baiting, fertilizing, and using medicine. This can optimize the agricultural industrial structure and promote the green development of Chongqing's agricultural economy. On the other hand, Chongqing, with its long history and abundant tourism resources, has a leading tourism industry. It can integrate agriculture and tourism, using tourism development to drive agriculture. By relying on characteristic agricultural bases, natural ecology, and other rural tourism resources, create natural scenic areas with ecological features, promote the development of agricultural economy, and avoid environmental damage.

Strengthen the protection of agricultural ecological environment and promote economic development. As the agricultural ecological system is the premise of agricultural economic development, only by strengthening the protection of the ecological environment can economic development be promoted. Firstly, strengthen the concept of ecological environment protection, increase media publicity, and conduct relevant knowledge lectures in rural areas to raise public awareness of the importance of protecting the ecological environment. Secondly, strictly implement various ecological protection policies, improve the ecological environment supervision mechanism with clear rewards and punishments, and protect the ecology under various policies and mechanisms. Finally, continue to promote the reduction of chemical fertilizers and pesticides, replace chemical fertilizers with organic fertilizers, use efficient and low-risk pesticides to reduce pollution.[17]

4. Conclusion

In this study, entropy method, comprehensive development evaluation model and coupling coordination degree model were used to analyze and evaluate the coupling coordination between agricultural economy and ecological environment system in Chongqing from 2000 to 2022, and the following two conclusions were drawn:

From the change trend of the comprehensive evaluation index, it can be concluded that the comprehensive development level of Chongqing's agricultural economy is on the rise in general, and the fluctuation is obvious. On the whole, the comprehensive development level of agro-ecological environment showed a trend of first increasing and then decreasing, and the fluctuation was also obvious. Before 2013, the development level of agricultural ecological environment steadily exceeded the development level of agricultural economy, and after 2013, the

development level of agricultural ecological environment lagged behind the development level of agricultural economy.

The coupling coordination degree of Chongqing's agricultural economic system and agro-ecological environment system can be divided into two stages: first, the coupling coordination degree presents a rapid improvement state, which shows a moderate coordination coupling from 2000 to 2003, and the coupling coordination degree changes from a moderate coordination coupling to a basic coordination coupling from 2003 to 2010. From 2010 to 2012, the coupling coordination degree changed from basic coordination coupling to high coordination coupling. Second, from 2012 to 2022, the coupling coordination degree changed from highly coordinated coupling to basic coordinated coupling, and showed a stable state. On the whole, the coupling degree of Chongqing's agricultural economic system and agro-ecological environment system is kept in a stable state of basic coordination and coupling.

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