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Original Research

What Drives the Fluctuations of "Green" Development in China's Agricultural Sector? An Entropy Method Approach

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Abstract

The sustainable and coordinated development of agriculture directly associated with the national economy and social development, and the agriculture development is closely affected by several societal, economic and environmental effects. Based on the panel data of agricultural production from 2004 to 2015 in China, 21 indicators were selected to construct a five-dimensional index system of sustainable agricultural green development, including population, society, economy, environment and resources perspective. Using entropy method and coordination degree method, the spatial-temporal dynamics and coordination degree of agricultural green development index (AGDI) are explored. The results show that: sustainable agricultural green development is mostly affected by the sustainability of population system, followed by the sustainability of environmental system, resource system, economic system and societal system. In terms of the spatial dimension, it has large differences between different regions. In terms of the coordination degree of AGDI between the five dimensions, it shows a trend of "continuous decline and then rising fluctuation" from 2004 to 2015. From the spatial distribution of the coordination degree between these subsystems, the number of provinces with "coordination" and "comparative coordination" between the sustainability of each subsystem is increasing, at the same time, the provinces belong "coordination" and "comparative coordination" are mainly distributed in the central and eastern regions of China. This paper analyses the spatial-temporal dynamics and coordination degree of AGDI based on the evidence collected in China, it furthered explores the great significance of the five-dimensional systems in improving the level of agricultural sustainable development.

Keywords: agricultural sustainable development, coordination degree, dynamic evaluation, evolutionary analysis, entropy method

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Introduction

Agriculture is the basis of national economic development. The green development of agricultural is closely associated with population, society, economy, resources, environment and other factors. From the perspective of standardization and comparative research, agriculture is generally divided into traditional agriculture and modern agriculture. In the construction of modern agriculture, there are many modes, such as ecological agriculture, circular agriculture, organic agriculture and green agriculture. Green agriculture has become the main mode of modern agriculture and an important mode of sustainable development of agriculture. Whether the development of agriculture can be sustainable and coordinated directly affects the development of the whole national economy and social stability. However, with the rapid development of the economy, a series of problems such as excessive population growth, imperfect social infrastructure, lack of resources, and serious environmental pollution have intensified the contradiction between agricultural development and ecological environment. A great number of measures have been taken to address the sustainable development of agriculture (hereafter ASD). For example, promoting green production mode, strengthening the coordination between different factors, and making some initiatives for adaptation to agricultural development. The green development index of agricultural (AGDI) is mainly reflected in two aspects: agricultural production efficiency and production factors, which constitute agricultural green production efficiency. The framework of AGDI of different regions is the basic premise of testing the agricultural green development theory, which must include motivation mechanisms for promoting green agricultural productivity, meanwhile, index construction and measurement data of relevant variables selecting were also important. AGDI, as the key to the construction of ecological civilizations, has become a key issue for sustainable agricultural development. It is necessary to analysis and identity the need to strengthen spatio-temporal dynamic of AGDI and to improve the quality and efficiency of the agricultural supply system. Therefore, understanding the temporal and spatial dynamics and coordination degree of AGDI will have important practical guiding significance for further promoting the sustainable development of agriculture.

As an important component of green development indicator system, evaluation/assessment of AGDI is always one of the focus of green development study, it attracts widespread attention from relevant scholars. In recent years, agricultural green development has become more and more important. Some scholars have studied the model and evaluation of ASD [1-4]. The assessment objectives of agricultural green development included different levels, such as the whole units, specific agriculture production systems and so on [5-9]. The evaluation at macro level is mostly used in policy evaluation, at the micro level, the academic research has begun to tilt towards guiding production decisions in recent years [10, 11]. Some organizations include FAO, UN, OECD and scholars have built different indicator systems to reflect the level of agriculture sustainable development [12, 13]. Some scholars build three-dimensional indicator system which contains economy, environment and society based on the component of green development [14-16], some others extended the meaning of green development and listed population, resources, technology as the separate dimension to construct the four-dimensional or five-dimensional indicator system [17, 18]. Meanwhile, as the concept of green development covers a wide range, there are some differences between different research institutions and scholars in the selection of specific indicators, one of the main reasons for the differences is the selection of evaluation regions [19, 20]. Generally speaking, in terms of the evaluation system of developed countries, the indicator selection is more inclined to ecology and environment [21, 22], while for developing countries, it is more inclined to economic development and poverty reduction [23,24]. In terms of research methods and theories, geographic detector method [25], system dynamics theory [26], dissipative structure theory [27, 28], energy theory [29-31], the ecological footprint theory [32, 33] and life cycle assessment (LCA) [34] haven been used to explore the evaluation of agricultural sustainable development level. The researchers put forward different models of evaluation index system, including “Pressure – State – Response” (PSR) model and “Drive force – State – Response” (DSR) model. In terms of indicator calculation mainly relates to analytic hierarchy process (AHP), principal component analysis, factor analysis, cluster analysis method, entropy method, grey correlation method, the space distance method [35-43] and so on.

In summary, the existing research uses different methods to explore the sustainable development of agriculture from different perspectives, which lays a solid theoretical and practical foundation for this study. However, the existing literature are somewhat flawed due to the following reasons. First, most of the research are concentrated in developed countries, while little attention has been paid to the sustainable development of agriculture in developing countries such as China. Moreover, the existing literature lack of an in-depth analysis of the coordination degree of ASD from the temporal and spatial dimension. Last but not least, the dataset of existing research usually focuses on a single or a few of regions, the study contains different regions and the study of the regional integration of agricultural sustainable dynamics development are relatively scarce. On the whole, the studies on the green development of agriculture stressed the theoretical analysis and the construction of evaluation index system. In the existing studies, some measurement methods were largely adopted to construct the indicator system of the green development of agriculture and conduct spatial difference analysis, whereas the strong external spillover effect of the green development of agriculture has been rarely explored.

Accordingly, this paper uses entropy method, coordination degree calculation and regional correlation network method to conduct empirical analysis on the green development of agriculture index of each province. Furthermore, the important nodes are identified by employing the complex network, also the potential propagation path of the green development of agriculture is presented intuitively. Therefore, this research aims to fill the abovementioned research gaps by using the panel data of agricultural production collected in China from 2004 to 2015. Firstly, through the existing research and the current situation of ASD, this study constructs the AGDI system of China; secondly, the entropy method is used to calculate the indicators of ASD, and its dynamic changes are analyzed from the time and space dimensions to further explore the reasons for its changes; thirdly, the coordination degree formula is used to calculate the coordination degree of ASD in provinces (cities and autonomous regions), which further reflects the level; finally, the regional correlation network is used to empirically analyze the AGDI. The complex network is used to identify important nodes and intuitively give the potential transmission path of ASD.

Material and Methods

Materials

In order to accurately evaluate the spatial-temporal dynamic change and the coordination degree of ASD

Table 1. Agricultural green development system, evaluation indicators and information entropy.

First-level indicator name	Second-level indicator name	Unit	Attribute information entropy	
Population system 0.0992	Rural education population	%	Positive	0.9420
	Natural population growth rate	%	Reverse	0.9341
	Regional population density	%	Reverse	0.8236
Social system 0.2349	Per capita electricity consumption in rural areas	KW·h/person	Positive	0.8713
	Per capita housing area of villagers	Square meter/person	Positive	0.8683
	Engel Coefficient of Rural Residents	%	Reverse	0.8108
Economic system 0.2820	Per capita agricultural production	Yuan/person	Positive	0.8596
	Per capita net income of rural residents	Yuan/person	Positive	0.8548
	Agricultural fixed assets investment	Billion	Positive	0.8601
	Agricultural output value per unit of planting area	Yuan/ha	Positive	0.7987
Resource system 0.1729	Per capita cultivated area	Mu/person	Positive	0.9237
	Agricultural land productivity	kg/hm^2	Positive	0.8640
	Total mechanical power per unit of cultivated land	Kw/hm^2	Positive	0.7194
	Agricultural water consumption	100 million cubic meters	Positive	0.9091
	Effective irrigation rate	%	Positive	0.8937
Environmental system 0.2110	Fertilizer using intensity	kg/hm^2	Reverse	0.8916
	Pesticide using intensity	kg/hm^2	Reverse	0.8686
	Film using strength	kg/hm^2	Reverse	0.8661
	Soil erosion control area	1000 hectares	Positive	0.8359
	Forest cover rate	%	Positive	0.7120
	Agricultural disaster rate	%	Reverse	0.9559

(Note: The proportion of rural educated population = 1 - the proportion of illiterate population in rural areas in the population aged 15 years and over; rural per capita electricity consumption = rural electricity consumption / rural population; per capita gross agricultural production value = total output value of agriculture, forestry, animal husbandry and fishery / rural population; per capita cultivated land area = cultivated land area / population; land productivity = total grain output / cultivated land area; total mechanical power per unit cultivated land area = total power of agricultural machinery / cultivated land area; fertilizer use intensity = fertilizer use amount / cultivated land area; pesticide use intensity = pesticide use / cultivated land area; plastic film use intensity = agricultural plastic film use / cultivated land area.)

in China, a hierarchical structure model for the evaluation of China's ASD level is constructed based on the datasets and the evaluation index system of sustainable development capability. The specific structural model includes five-dimensional indicators, namely, population system sustainability, social system sustainability, economic system sustainability, resource system sustainability and environmental system sustainability. Each first-level indicator is composed of several second-level indicators, as shown in Table 1. Some of the indicators are obtained by calculation.

The research datasets mainly come from the "Reform and Open 30 Years of Rural Data Collection", "China Statistical Yearbook" (2005-2016) and "China Rural Statistical Yearbook" (2005-2016). Part of the datasets is calculated based on the yearbook data, and the spatial data used is derived from the 1:3 million vector data provided by the National Basic Geographic Information Data Center.

Methods

The agricultural green development index is composed of many elements. This study divides the effects of AGDI into five dimensions: population system indicators, social system indicators, economic system indicators, resource system indicators and environment system indicators. In order to find out the characteristics of the temporal and spatial evolution of AGDI, and to analyze the factors that affect the sustainable development of agriculture in different regions, this study discussed the temporal and spatial dimension of the AGDI comprehensive score index, the spatial and temporal changes of the sustainable capacity of five subsystems (population, society, economy, resources and environment), and the evolution of the coordination degree of AGDI. Fig. 1 is the theoretical framework for the AGDI system.

Entropy Method

Entropy method is a mathematical method that explore the discrete degree of an index. The greater the degree of dispersion, the greater the impact on the comprehensive evaluation score. Using the entropy method to calculate comprehensive evaluation score of ASD avoids subjective factors to a certain extent. Firstly, the dynamic weights of the second-level indicators are determined by using the entropy method. Secondly, the comprehensive weighted calculation of each second-level indicator is used to obtain the dynamic weights of first-level indicators. Finally, the comprehensive evaluation scores of ASD are calculated [44].

The detailed calculation steps are as follows:

(1) Standardization of each indicator

In order to eliminate the dimensional relationship between each indicator and make the data comparable, the indicators a_{ij} are dimensionless and isotropic, so that the numerical size is between [0, 1]. The method is as below:

Positive indicator:

$$x_{ij} = \frac{a_{ij} - \min(a_{ij})}{\max(a_{ij}) - \min(a_{ij})} \quad (1)$$

Negative indicator:

$$x_{ij} = \frac{\max(a_{ij}) - a_{ij}}{\max(a_{ij}) - \min(a_{ij})} \quad (2)$$

Where a_{ij} is the original value of index j of area i, x_{ij} is the standardized value of index j of area i.

(2) Calculating the proportion of x_{ij} in the total standard value of each region

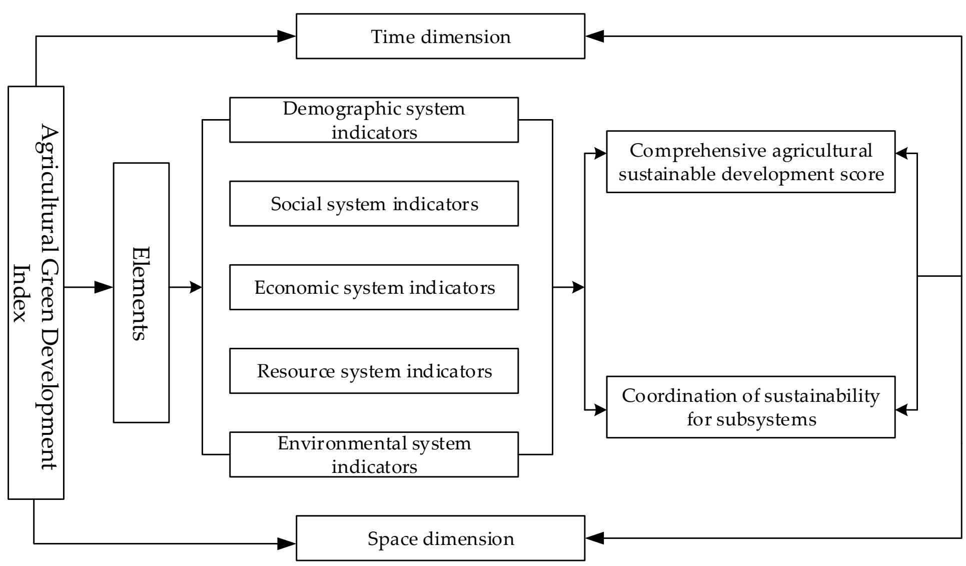

Fig. 1. Structure of agricultural green development index system.

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{3}$$

(3) Computing information entropy of item j

$$E_j = -\frac{\sum_{i=1}^{m} P_{ij} lnP_{ij}}{lnm} \text{ (j=1,2,3,…,n)} \tag{4}$$

Where m is the number of regions, when P_{ij} = 0, P_{ij} lnP_{ij}.

(4) Calculating the dynamic weight of each indicator

$$W_j = \frac{1-E_j}{n-\sum_{j=1}^{n} E_j} \tag{5}$$

Where j is the number of indicators, and the weight of each indicator is calculated by the entropy method. The essence is to make full use of the value coefficient for each indicator information. The higher the value coefficient, the greater the impact on the comprehensive evaluation of ASDC.

(5) Calculate the sustainability of each subsystem

The weights of the indicators in each subsystem are standardized, and the formula is:

$$W_{kj}^{*} = \frac{W_j}{\sum_{j=1}^{r} W_j} \tag{6}$$

The formula for the sustainability of each system is:

$$S_{ki} = \sum_{j=1}^{r} W_{kj}^{*} x_{ij} \tag{7}$$

In the formula, when j = 1,2,3,4,5, S_{ki} represents population system sustainability, social system sustainability, economic system sustainability, resource system sustainability, and environmental system sustainability in region i. r is the number of indicators in each subsystem.

(6) Calculating the comprehensive evaluation score of ASDC

The weight of each subsystem's sustainability is:

$$W_k = \sum_{j=1}^{r} W_j \tag{8}$$

The comprehensive evaluation score of ASDC is:

$$S_i = \sum_{j=1}^{5} W_k S_{ki} \tag{9}$$

Where S_i is the comprehensive evaluation score of ASDC in region i. The range of S_i is [0,1]. The bigger S_i is, the stronger the comprehensive ability of ASDC is.

Coefficient of Variation Method

Comparing the discrete degree of the two datasets, if the measurement scale of the two datasets is different, or the dimensions of datasets is different, it is not appropriate to use the standard deviation directly. The effects of measurement scales and dimensions should be eliminated, and the coefficient of variation (CV) is the ratio of the standard deviation of the original data to the average of the original data. CV is an effective method to eliminate this effect. In fact, it can be considered that the CV, like the range, standard deviation and variance, are all absolute values reflecting the degree of data dispersion. The data is not only affected by the dispersion of variable values, but also affected by the average level of variable values. The CV is a common index to measure the relative difference of a certain element in a region. The larger the value, the greater the gap between regions, otherwise, the smaller the gap. This study uses the CV coefficient to measure the evolutionary characteristics of the comprehensive score of ASDC, and the relative differences in the sustainability of each subsystem (population, economy, society, resources, environment) for the time series. The formula is as follows [45]:

$$S_t = \sqrt{\sum_{i=1}^{n}(Y_{it} - \bar{Y}_t)^2/n},\ V_t = S_t/\bar{Y}_t \tag{10}$$

Where S_t is the standard deviation, $\bar{Y}_t$ is the comprehensive score index for ASDC in t years, n is the numbers of provinces. Y_{it} is comprehensive ASDC score of t year in the i province. Y_t is the coefficient of variation (CV).

Coordination Degree Calculations

The coordination degree is to measure the degree of harmony and consistency between the elements of the system or the system in the process of development, which reflects the trend of the system from disorder to order, and it is a quantitative indicator of the degree of coordination. The sustainable ability of each subsystem is the guarantee of the ASD. In order to understand the state and evolution rules of ASD more clearly, the concept of coordination degree was introduced, definition of coordination degree is $C = 1 - \frac{S}{M}$.

Where M is the mean value of the sustainability of each subsystem in a certain year, and S is the standard deviation. The greater the C, the better the coordination degree between the subsystems, and vice versa [46].

Construction of Regional Association Network

In this paper, China's provinces and regions act as the network nodes. The edges between nodes represent the relevance of each province or the radiance of green development of agriculture. On that basis, this paper constructs the related network of regional green development of agriculture. The construction primarily consists of the steps below. First, a certain time range is selected, the correlation coefficient of regional green development of agriculture is calculated. Second, on the basis of the first step, the correlation coefficient matrix is transformed into a distance matrix. Third, the minimal spanning tree (MST) method is employed to construct the complex network. To start with, given the value of the green development of agriculture, the correlation coefficient of the regional green development of agriculture is determined [47], as expressed below:

$$\rho_{ij} = \frac{E[r_i r_j] - E[r_i]E[r_j]}{\sqrt{(E[r_i^2] - E[r_i]^2)(E[r_j^2] - E[r_j]^2)}} \quad (11)$$

Where r_i and r_j are the green development of agriculture index of region I and j, respectively, ρ_{ij} is normalized to [-1,1]. Given the correlation coefficient calculated in the formula, the correlation coefficient matrix ρ can be obtained. The elements in the matrix ρ are denoted as ρ_{ij}, which represents the correlation coefficient between region I and j. It can be therefore suggested that the correlation coefficient matrix ρ is a symmetric matrix, in which the diagonal elements are all 1. After the correlation coefficient matrix is obtained, the measured distance between regions is defined, and the correlation coefficient matrix is transformed into the distance matrix D. The element d_{ij} in the distance matrix D is expressed as:

$$d_{ij} = \sqrt{2(1 - \rho_{ij})} \quad (12)$$

As revealed from the formula, the larger the correlation coefficient between regions, the smaller the measured distance will be between them. On that basis, matrix D is suggested as a symmetric matrix. The distance matrix D is taken as the adjacency matrix to generate the distance network graph and the initial network graph. Moreover, to remove the verbose edges in the network graph and highlight the important information in the network, this paper adopts the minimum spanning tree (MST) to denoise the network.

For the constructed association network, Degree centrality and Betweenness centrality, two topological indexes, are adopted to determine the importance of nodes. Degree centrality further falls to Node centrality and Graph centrality. This paper primarily applies Node centrality. Essentially, such a property refers to the number of edges of a node that is connected. The more edges there are, the more important the node will be in the network. The degree centrality is specifically expressed as:

$$C_D(i) = k_i/(N-1) \quad (13)$$

Where $C_D(i)$ represents the degree centrality of node i, k_i represents the degree of node i, and N-1 represents the maximum possible degree. The Betweenness centrality of node i is the normalized intermediate number of node i, which refers to the rate of the number of shortest paths through node I between node j and node k to the number of all shortest paths between node j and node k.

Betweenness centrality in a network measures the ability of a node to control resources. Therefore, in China's green development of agriculture network, the nodes with higher Betweenness centrality are more able to control other nodes. In other words, the nodes with high Betweenness centrality are bound to be important nodes and act as a "bridge" in the whole network diagram. The specific expression of Betweenness centrality is written as:

$$C_B(i) = 2B_i/[(N-1)(N-2)] \quad (14)$$

Where $C_B(i)$ represents Betweenness centrality of node i, and B_i represents the intermediate number of node i.

Results and Discussion

Analysis of AGDI Based on Temporal Dimension

Based on the entropy method, this study constructs AGDI from five aspects of population, economy, society, resources and environment. The specific analysis is as follows: In general, the AGDI indicator is low at 0.3515, indicating that the comprehensive capacity of AGDI needs to be improved. The comprehensive evaluation score of AGDI is the result of the combination of population system sustainability, social system sustainability, economic system sustainability, resource system sustainability, environmental system sustainability and the respective weights. The weight of each indicator is relatively stable, so the sustainability of each subsystem is the main impact on the comprehensive evaluation of AGDI. As shown in Table 2, the population system has the strongest sustainability, with an annual average of 0.6024, the second is the environmental system sustainability, with an annual average of 0.4567, the social sustainability is the weakest, with an annual average of 0.2382. The sustainability of each subsystem varies greatly and development is not coordinated. It is necessary to promote the coordinated development of each subsystem's sustainability, so as to improve the comprehensive ability of agricultural green development in China.

Fig. 2 visually reflects the evolution of ASD from 2004 to 2015 in China. From the perspective of change trend, the ASD index fluctuates first and then continues to rise and then continues to decline, and the change range is small, ranging from 0.3200 to 0.3700. It further illustrates that the level of ASD is low, and the potential for sustainable development of each subsystem is relatively large. To improve the sustainable development ability of agriculture, we need to improve the sustainability of subsystems, especially the sustainability of social system and resource system.

Table 2. Scores of agricultural sustainable development level (2004-2015).

Years	Population system	Social system	Economic system	Resource system	Environmental system	ASDC indicator
2004	0.5938	0.2259	0.3136	0.3398	0.4364	0.3454
2005	0.6255	0.2307	0.2971	0.3412	0.4521	0.3477
2006	0.6495	0.1995	0.3020	0.3379	0.4378	0.3292
2007	0.6291	0.2374	0.3270	0.3364	0.4494	0.3513
2008	0.6262	0.2115	0.3380	0.3428	0.4613	0.3428
2009	0.5790	0.2073	0.3288	0.3548	0.4658	0.3478
2010	0.5702	0.2436	0.3340	0.3359	0.4720	0.3538
2011	0.5754	0.2436	0.3545	0.3399	0.4576	0.3582
2012	0.5775	0.2476	0.3662	0.3324	0.4644	0.3614
2013	0.5948	0.2597	0.3698	0.3224	0.4731	0.3652
2014	0.6048	0.2781	0.3444	0.3309	0.4459	0.3633
2015	0.6035	0.2730	0.3099	0.3267	0.4643	0.3521
Mean	0.6024	0.2382	0.3321	0.3367	0.4567	0.3515

The sustainability of the population system rises first, then decreases, and then continues to rise. Among them, the population system sustainability is 0.6024 per year, and the average annual growth rate is 0.136%. The reason is that although the natural population growth rate has dropped from 5.45% in 2004 to 5.17% in 2015, the regional population density has continued to decline to 3.46% per year, but the rural education level increased from 81.10% in 2004 to 94.65% in 2015.It shows that the quality education of rural population in China is constantly improving, but due to the large population base and the increasing role of natural growth rate year by year, to a certain extent, the sustainable development of population system is slowing down.

The sustainability of social system fluctuation falls at first, then fluctuation rises. Among them, the sustainability of social system is 0.2382 per year, and the average annual growth rate is 1.74 per cent. This shows that the level of sustainability of China's rural social system is low. Statistical data show that in 2004-2015, the per capita electricity consumption in rural areas increased steadily except in 2007, with an average annual growth rate of 16.68%; while the Engel coefficient decreased steadily except in 2008, with an average annual decline rate of 2.36%; and the per capita housing area of rural residents shows an increasing trend as a whole. With the continuous deepening of rural reform and construction, rural infrastructure construction is gradually improving, which provides a good foundation for the sustainable development of rural social systems. However, there is a big gap in rural infrastructure construction between different regions. The rural infrastructure construction in the eastern and central regions is generally better than that in the western regions. This is mainly due to the slow development of the sustainable capacity of the overall social system in China.

The sustainability of the economic system generally shows a trend of rising first, then declining, and then rising fluctuations. Among them, the annual sustainability of economic system is 0.3321. Through the analysis of raw data, it is found that the average annual growth rates of agricultural fixed asset investment, per capita agricultural production, per capita net income of rural residents, and agricultural output value per planted area are 75.68%, 23.84%, 22.97%, and 13.21%, respectively. It shows that the growth of sustainable capacity of China's agricultural economic system is driven by the input of production factors to a certain extent. However, due to the great differences in the level of agricultural economic development in different regions of China, the sustainability of the regional economic system shows a fluctuating trend.

The sustainability of resource systems is generally fluctuating. Among them, the resource system sustainability is 0.3367 per year. Agriculture is highly dependent on resources, and resource system sustainability is an important guarantee for sustainable agricultural development. From the statistical analysis of raw data, the average annual growth rate of mechanical total power, per capita arable land area, agricultural water consumption, agricultural land productivity, and effective irrigation rate per unit of cultivated land area is 2.47%, 2.17%, 0.62%, -0.64% and -0.67%, respectively. These factors have a positive impact on the sustainability of resource system, but on the whole, the average annual growth rate of agricultural land productivity and effective irrigation rate has decreased, which weakens the sustainability of resources.

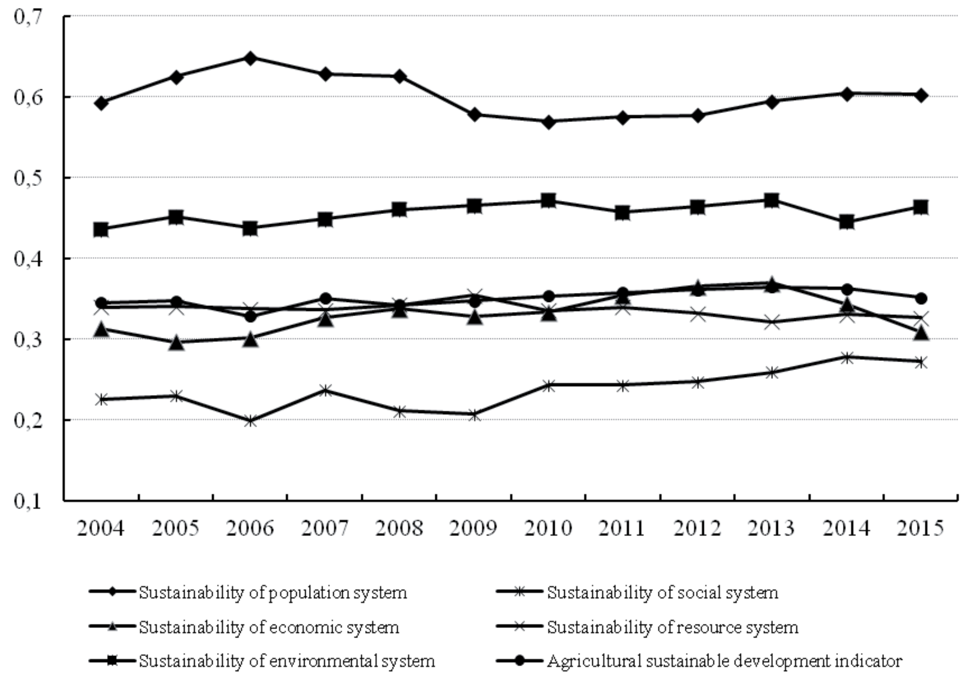

Fig. 2. The evolution trend of various indicators of ASDC in China (2004-2015).

The sustainability of the environmental system is generally "smooth". Among them, the environmental system sustainability is 0.4567 per year, and the average annual growth rate is 0.53%. From the indicators that affect the sustainability of environmental systems, the annual average growth rates of agricultural disaster rate, soil erosion control area, forest coverage, plastic film use intensity, pesticide use intensity and fertilizer use intensity were 2.42%, 2.13%, 1.92%, 0.56%, -0.04% and -0.19%, respectively. China's agriculture is located in three disaster-prone zones, with frequent floods and seasonal droughts, and the problem of agricultural non-point source pollution is becoming more and more prominent, which seriously hinders the improvement of the sustainability of the environmental system. In recent years, the state and local governments have increased their investment in rural environmental protection, making the sustainable development of China's environmental system more stable. However, its development level is still at a low level, and needs to be improved.

As shown in Table 3, in general, the comprehensive score of ASD changed between 0.32~0.37 from 2004 to 2015, and the average annual average score of ASD was 0.3515. In terms of the CV value of ASD, it changed between 0.22~0.28 from 2004 to 2015, and the average annual CV was 0.2543. In 2009, the CV value was the highest 0.2795, followed by 2006, 0.2759, while in 2014, the CV vale was the lowest, 0.2298, followed by 2013, 0.2366. According to the range of the ASDC value, except in 2006, the comprehensive score of provinces is basically concentrated at 0.35, which indicates that the difference of comprehensive score of ASD is not obvious among interannual. According to the CV value of ASD, the value is less than 0.28, it belongs to the lower variation, which is consistent with the small difference of the comprehensive score of ASD, but the low comprehensive score of ASD value shows that the overall level of agricultural sustainable development in China has a great room for improvement.

As shown in Fig. 3, it intuitively reflects the evolution of ASD and CV value from 2004 to 2015. The comprehensive score of ASD shows the trend of fluctuation first, then continues to rise and then

Table 3. Evolution of the ASD Score Index (2004-2015).

Year	Composite score index	Coefficient of variation
2004	0.3454	0.2637
2005	0.3477	0.2496
2006	0.3292	0.2759
2007	0.3513	0.2412
2008	0.3428	0.2524
2009	0.3478	0.2795
2010	0.3538	0.2692
2011	0.3582	0.2644
2012	0.3614	0.2489
2013	0.3652	0.2366
2014	0.3633	0.2298
2015	0.3521	0.2399
Mean	0.3515	0.2543

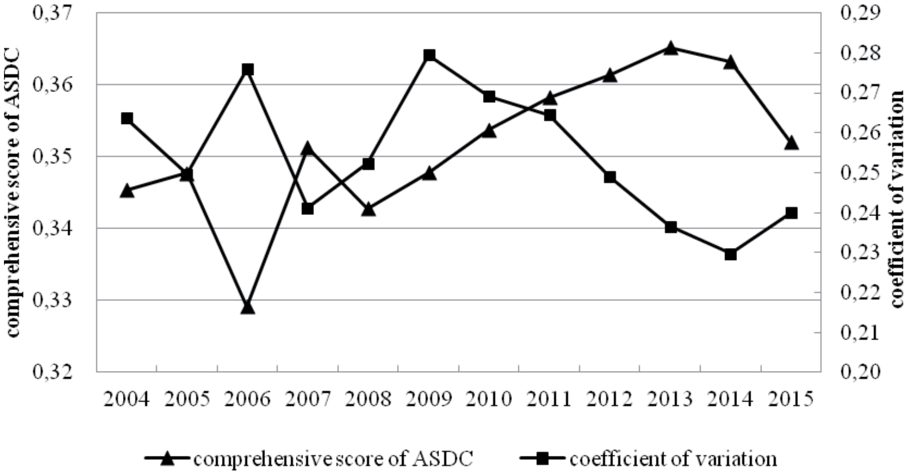

Fig. 3. Evolution of the ASD score index and the CV value (2004-2015).

continues to decline. The average annual growth rate of ASD score is 0.0609. According to the comprehensive score the CV value of ASD, the coefficient of variation increases first, then decreases continuously, and then increases. The average annual growth rate of the CV is -0.2164. From the variation trend of the CV value, it can be seen that the comprehensive score of ASD in provinces fluctuates first, then fluctuates, which is consistent with the evolution trend of the comprehensive score of ASD from 2004 to 2015.

Analysis of ASD Based on Spatial Dimension

In order to find out the evolution process of ASD in various provinces in China. According to the ASD index of different provinces, this study makes full use of the current research results and divides it into four types, namely [0, 0.25], [0.25, 0.50], [0.50, 0.75] and [0.75, 1.00]. On this basis, this study selects the four-year ASD index in 2004, 2008, 2012, 2015. In order to more intuitively display the spatial dynamic evolution of ASD indices in various provinces in China, Arcgis10.6 spatial measurement tools was used to map the spatial distribution of agricultural sustainable development indices in different provinces (Fig. 4).

As shown in Fig. 4 from 2004-2015, the number of ASD index in [0, 0.25] and [0.50, 0.75] types in different provinces are relatively small. The provinces with the ASD index in the [0, 0.25] type is distributed in the western part of China, and the provinces with the ASD index in the [0.50, 0.75] type are distributed in eastern part of China. The number of provinces with ASD index in the [0.25, 0.50] type is the largest and remains basically stable. There is no province of ASD index in the [0.75, 1.00] type. From the perspective of its spatial differentiation, this may be due to the relatively low overall population, society, economy, resources and environment systems in Western China and the relatively high overall level in eastern China. It shows that in recent years, the ASD index in China's provinces is relatively low, that is, the ability of comprehensive and coordinated development among subsystems needs to be improved. So what is the coordination degree between the sustainability of China's subsystems. According to the formula of coordination degree of AGDI, coordination degree is to measure the degree of harmony and consistency between population, economy, society, resources and environment in the process of development, therefore, we will further explore the coordination degree analysis of the ASD value in China.

In general, the level of ASD in different regions is prominent, which is determined by the sustainability of population, society, economy, resources, environment and other systems. The ultimate goal of sustainable development of agriculture is population and social system, which makes people and society develop healthily. Economic sustainability is the foundation and necessary premise of ASD. The sustainable ability of resources and environment is the fundamental guarantee to realize the sustainable development of agriculture. Therefore, this study explores the ASD in China from the perspective of population, society, economy, resources and environment.

In terms of the sustainability of the population system, from 2004 to 2015 the proportion of rural education in the eastern, central and western regions of China was 91.55%, 91.96% and 85.83%, respectively. It can be seen that the level of rural education in the central region is better than that in the western region, while the natural population growth rate is the highest in the western region, with an average annual average of 6.81%, followed by the eastern region (4.47%) and the central region (4.68%). The higher level of rural education and the relatively low rate of natural population growth in the central and eastern regions, which have contributed to the continuous improvement of the sustainability of the population system, but over the past few years, the higher population density in the central and western regions (62.49%) and the lower population density in the western region (60.57%)

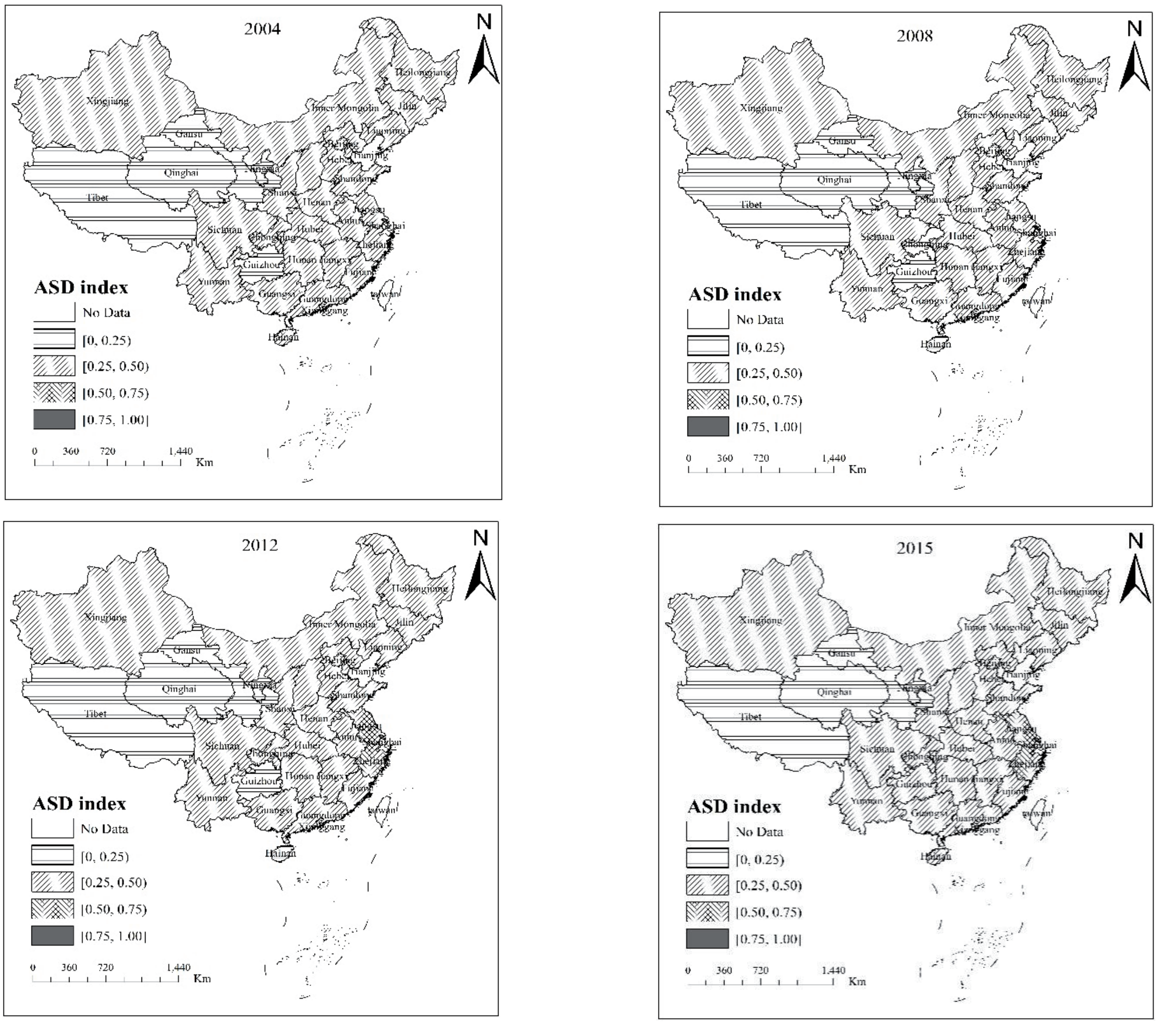

Fig. 4. Spatial differentiation of ASD index by province in China (2004-2015).

has led to the largest increase in the population sustainability in the eastern region, followed by the central region (62.49%) and the western region (60.57%).

In terms of the sustainability of social systems, the annual average of rural electricity consumption in eastern China is the highest, 2425.18 KW•h/ persons, then followed by the central region (KW•h/335.61) and the western region (KW•h/289.21). This is because the rural community infrastructure construction and urbanization level in the eastern and central regions are generally higher than in the western regions, the agricultural market exchange, circulation channels are more perfect, reducing production and transaction costs to ensure the relative stability of agricultural production. In terms of the living standards of rural residents, the highest per capita housing area for rural residents in the eastern region, 39.03 square meters per person, then followed by the central region (33.44 m^2/person) and the western region (27.85 m^2/person). The engel coefficient of rural residents in the western region is the highest, 43.26%, followed by the central region (40.27%) and the eastern region (39.91%). Overall, the living standard of rural residents in the eastern and central regions is higher than that in the western regions, which provides a stable guarantee for villagers engaged in agricultural production in the eastern and central regions. To a large extent, this promotes sustainable agricultural development and improve the ability of social sustainable development.

In terms of the sustainable ability of the economic system, it can be seen that in the areas with higher sustainable development of agriculture, the level of rural residents is higher, and the investment intensity of agricultural production is also higher. For example, from 2004 to 2015, the per capita net income of rural residents in the eastern region was the highest, 9285.91 yuan per person, followed by the central region (6060.07 yuan per person) and the western region (4474.69 yuan per person), while the agricultural fixed assets were the highest in the central region, 35.299 billion yuan, followed by the eastern region (21.55 billion yuan) and the western region (19.824 billion yuan). Because the income level in the western region is relatively low and the willingness to pursue short-term profits is stronger than that in the eastern and central regions, farmers pursue the supply of short-term economic products and ignore the long-term environmental protection, which widening the gap between the eastern and central regions.

The development of non-agricultural industries has greatly improved the production efficiency of agricultural factor input to a certain extent, and has promoted the sustainable development of agriculture. The highest agricultural land productivity in the central region, which is 0.5493 kg/hm^2, followed by the eastern region (0.4783 kg/hm^2) and the western region (0.3337 kg/hm^2), and the highest agricultural effective irrigation rate in the eastern region, which is 68.2%, then followed by the central region (52.60%) and the western region (41.15%). At the same time, the areas with low ASDC, land resources investment and predatory management are increased through traditional extensive patterns, this resulting in a serious decline in land quality. Land desertification also hinders and reduces the comprehensive score of ASD.

From the perspective of the sustainability of the environmental system, the massive use of chemical fertilizers has brought huge damage to the environment. The degree of environmental pollution in the eastern and central regions is much higher than that in the western regions. For example, the intensity of fertilizer use in the eastern region is the highest at 630.77 kg/hm^2, followed by the central region (493.27 kg/hm^2) and the western region (326.31 kg/hm^2). Similarly, the intensity of pesticide use and mulching film use are the highest in the eastern region, however, from the perspective of areas with higher levels of ASDC value, the central region has the highest forest coverage rate at 34.52%, followed by the eastern region (32.29%) and the western region (24.48%). From the perspective of regional water storage capacity, the central region has the lowest agricultural disaster rate at 48.15%, followed by the eastern region (48.23%) and the western region (49.84%). The natural and agricultural disasters caused by this effect are lower in the eastern and central regions than in the western regions.

Identification of Important Nodes in Green Agriculture Network

According to the index of the provincial green development of agriculture, the provinces are selected as nodes to calculate the correlation coefficient among nodes. Subsequently, the correlation coefficient matrix is constructed and transformed into the distance matrix, which is adopted as the adjacency matrix. On that basis, the initial green agriculture adjacency matrix network diagram of each province is constructed (Fig. 5).

To be specific, the square is the network node, and the thickness of the connecting edge is determined according to the distance between two nodes. The larger the element value, the thicker the line will be; otherwise, the thinner the line will be. According to the definition of distance matrix, the thicker the lines between two nodes, the larger the element value will be, the longer the distance will be, and the smaller the correlation coefficient will be, i.e., the smaller the correlation between the two nodes will be.

In Fig. 5, all the connecting edge lines connected with the node of Beijing are noticeably thin, thereby indicating that the node of Beijing has a relatively close correlation with the nodes connected to it. The practical significance of the mentioned result is that there exists a close correlation between Beijing and its adjacent provinces in terms of the green development

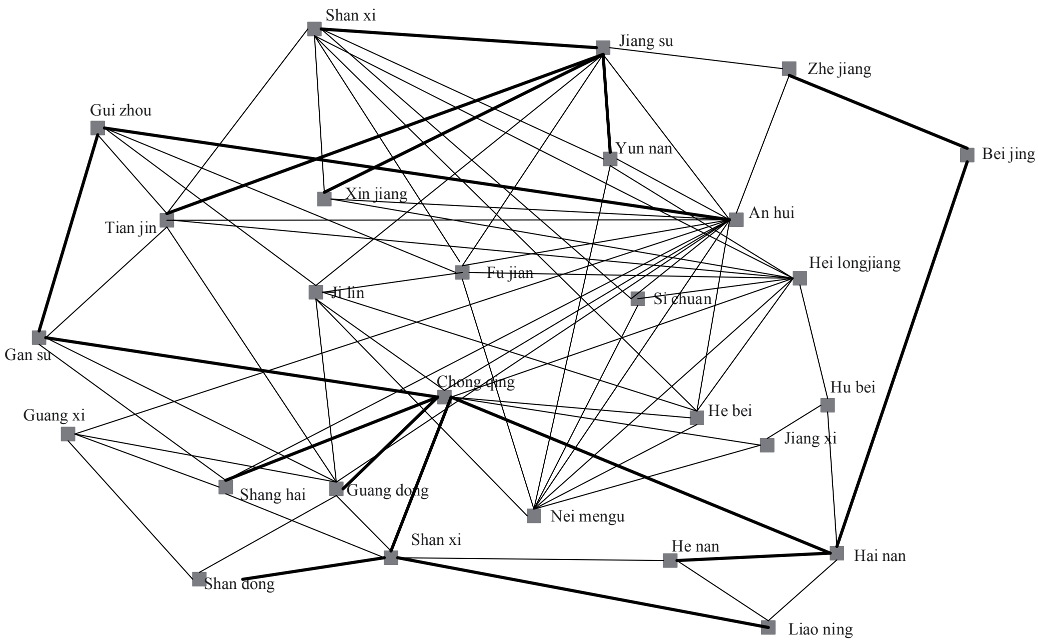

Fig. 5. Agricultural Green Network.

Table 4. The Degree centrality and Betweenness centrality of agricultural green network.

Order	Province	Degree centrality	Order	Province	Betweenness centrality
1	Jiangsu	18.503	1	Shanxi	115.875
2	Chongqing	16.480	2	Guangdong	110.750
3	Guizhou	11.038	3	Chongqing	90.286
4	Anhui	10.067	4	Jilin	81.092
5	Jilin	9.875	5	Anhui	65.875
6	Fujian	8.306	6	Tianjin	57.790
7	Tianjin	7.987	7	Hainan	50.450
8	Xinjiang	7.605	8	Heilongjiang	43.632
9	Shanxi	6.876	9	Gansu	35.731
10	Neimenggu	6.085	10	Neimenggu	28.835

of agriculture, and a significant external spillover effect is exerted by the green development of agriculture.

It is difficult to intuitively judge the systemic importance of each province in the green development of agriculture from Fig. 5. For this reason, Degree centrality and Betweenness centrality are used in this paper to determine the systemically important provinces in the green development of agriculture network.

The Degree centrality and Betweenness centrality of each node are calculated and sorted. Subsequently, the top 10 provinces in terms of the Degree centrality and the Betweenness centrality are selected, as listed in Table 4. As the table shows, Chongqing is the most systemically important province, followed by Jilin, Anhui, Tianjin, Shanxi and Inner Mongolia. The above results demonstrate that the first priority should be paid to the systemically important provinces (e.g., Chongqing) in the process of green development of agriculture, since they exert a strong external spillover effect and can drive the green development of agriculture of the provinces connected with them.

Study on the Extension Path of the Green Development of Agriculture

In Fig. 6, there are excessive connections in the initial adjacency matrix network diagram of the green development of agriculture of each province, which makes it unlikely to intuitively judge the infection of the green development of agriculture of each province. For this reason, this paper constructs MST by complying with the initial adjacency matrix D (Fig. 6). The square represents the province, and the thickness of the edge is determined according to the value of the adjacent matrix element. The larger the element value, the thicker the line will be; otherwise, the thinner the line will be.

Fig. 6. Agricultural Green Development Network.

As shown in Fig. 6, if there is an impact from outside the network (e.g., increased investment in agricultural factors), there will be a positive development trend for the green agriculture. The resulting green development trend of agriculture will be extended to the whole network along the MST path, thereby boosting the overall development. besides, if the internal nodes of the network take corresponding measures to foster green development, the development of other provinces can be also stimulated at the fastest speed along the MST path. In network MST, as impacted by the excessive Betweenness centrality of some nodes, i.e., the greater the Betweenness centrality of nodes in the network, the shorter the longest path length of MST will be, and the faster the propagation speed of the green development of agriculture in the network will be. Based on this, the nodes located in the center of the network will be more systemically important than the nodes located in the edge of the network, and they face greater opportunities for green development of agriculture.

Analysis of the Coordination Evolution of ASD Based on Temporal Dimension

The trend of the coordination evolution of ASD in China from 2004 to 2015 is shown in Fig. 7. In general, the coordination evolution of ASD showed a trend of "continuous decline in 2004-2006 and then rising fluctuation from 2006 to 2015, in which the coordination degree reached the highest in 2014, 0.5617, and the lowest in 2006, 0.4795. According to the classification of coordination degree, the coordination degree of ASD is in "disharmony" from 2004 to 2015, which indicates that the coordination level of agricultural sustainable capacity of various subsystems in China is not high. This is because the economic is regarded as the main development priority. At the same time, due to the large differences in resource endowments and external natural and literati factors, the sustainable development of agriculture in various regions is not balanced.

Specifically, there is two phases. The first phase is 2004-2006, China's sustainable development coordination has a "continuous decline" trend. This is mainly due to the great differences in resources endowment and external natural and literary factors among provinces (cities and autonomous regions) in China. The second phase is from 2006-2015, the coordination degree of ASD is on the rise in general. The main reason is that in recent years, governments have attached great importance to environmental protection and given great support to agriculture, which has led to rapid development of agriculture and a great improvement in the coordination degree of sustainable agricultural development.

Generally speaking, the coordination degree of ASD is "uncoordinated". It shows that the task of coordinating development among subsystems of ASD is arduous and long-term, and needs to be guided and strengthened by continuous and perfect policies.

Analysis of the Coordination Degree Based on Spatial Dimension

As can be seen from Table 4, from the ranking of coordination degree of subsystems, in terms of top 10 provinces, the eastern region accounted for 7, they are Zhejiang, Guangdong, Fujian, Hebei, Shandong, Beijing and Jiangsu respectively, the central region accounted for 3, they are Hunan, Henan and Jiangxi respectively. and autonomous regions, and no provinces (cities and autonomous regions) in the west ,1 in the east, Hainan and 2 in the central regions, 7 in Shanxi, Jilin and 7 in the western regions, they are Shaanxi Province, Chongqing, Tibet Autonomous Region, Qinghai Province, Yunnan Province, Gansu Province and Guizhou Province. From the overall ranking of the coordination degree between the subsystems, the eastern region is larger than the central region,

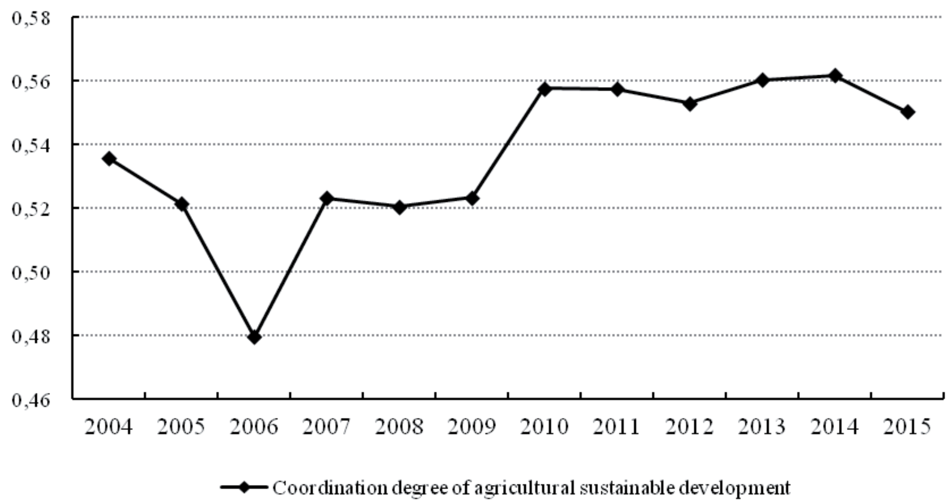

Fig. 7. Evolution trend of the coordination evolution of ASD in China (2004-2015).

Table 5. Coordination degree and ranking of ASD of eastern, central and western regions (2004-2015).

Eastern regions			Central regions			Western regions		
Province	Value	Rank	Province	Value	Rank	Province	Value	Rank
Zhejiang	0.8472	1	Hunan	0.6845	7	Guangxi	0.5627	13
Guangdong	0.8427	2	Henan	0.6818	8	Sichuan	0.5239	15
Fujian	0.8365	3	Jiangxi	0.6194	10	Xinjiang	0.5123	16
Hebei	0.7604	4	Anhui	0.6119	11	Neimenggu	0.4761	18
Shandong	0.7278	5	Hubei	0.6092	12	Ningxia	0.4714	20
Beijing	0.6877	6	Heilongjiang	0.4697	21	Shanxi	0.4209	23
Jiangsu	0.6774	9	Shanxi	0.3719	26	Chongqing	0.3920	24
Tianjin	0.5406	14	Jilin	0.3671	28	Xizang	0.3729	25
liaoning	0.5025	17				Qinghai	0.3710	27
Shanghai	0.4726	19				Yunnan	0.3106	29
Hainan	0.4304	22				Gansu	0.2570	30
						Guizhou	0.2343	31

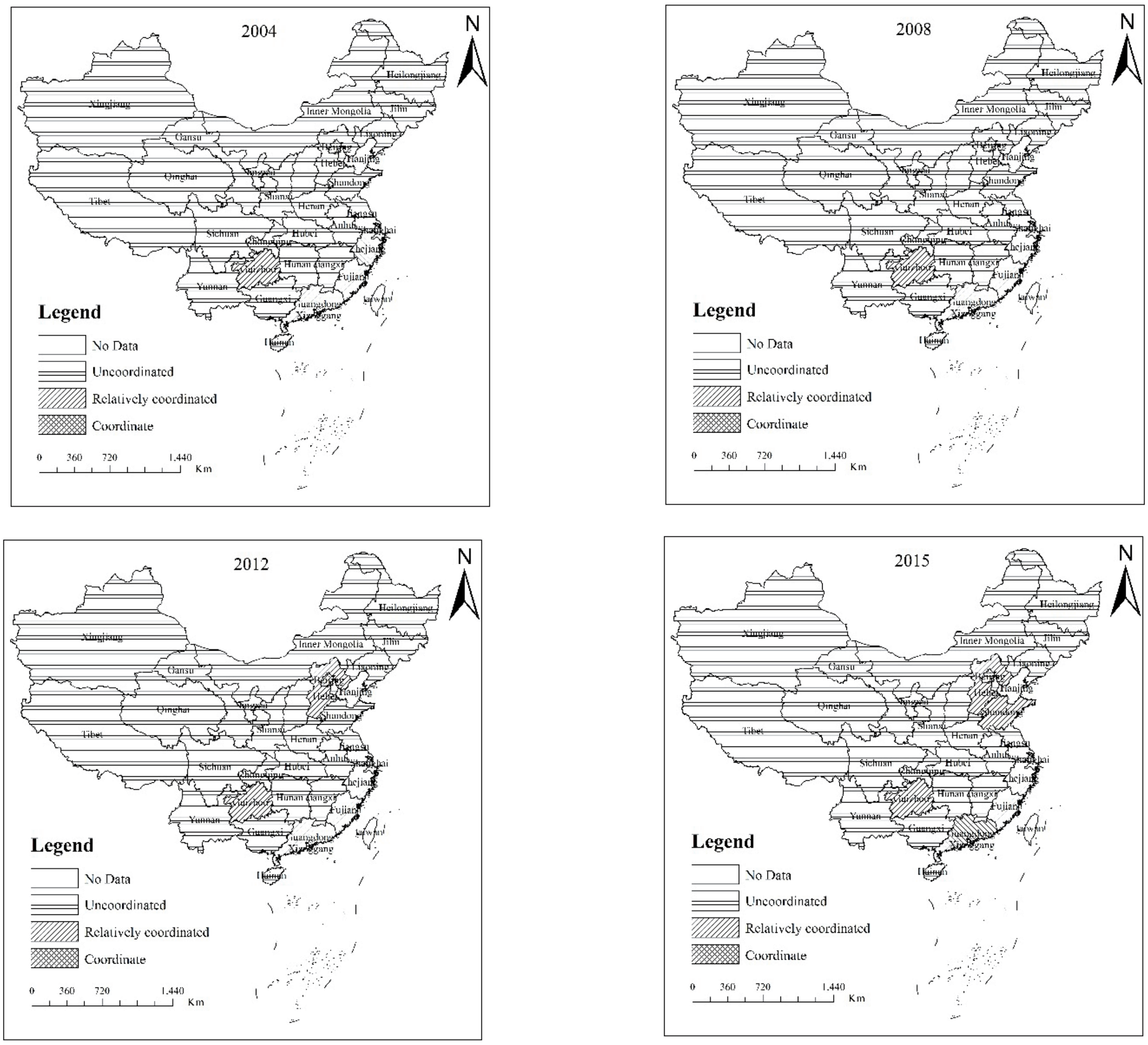

Fig. 8. Evolution of the coordination evolution of ASD for difference provinces (2004-2015).

and the central region is larger than the western region. For the last 10 ranking of coordination degree, one in the east, namely Hainan, two in the middle, Shanxi and Jilin, seven in the west, Shaanxi, Chongqing, Tibet, Qinghai, Yunnan, Gansu and Guizhou. From the overall ranking of the coordination degree among subsystems, the eastern region is larger than the central region, and the central region is larger than the western region.

In general, the level of coordination degree among subsystems in different regions is highlighted. which is determined by the sustainability of population, society, economy, resources, environment and some other systems. The improvement of coordination degree between each subsystem will inevitably require the improvement of each subsystem's sustainable ability and the coordinated development between subsystems. The coordination degree ha great differences among the subsystems in the east, central and western regions, so it is important to solve the unbalanced development of the subsystems between the regions.

In order to show the evolution of the coordination degree more intuitively, this study uses the isometric method to make a specific analysis. According to the calculation results of coordination degree formula, the value of coordination degree is classified according to the research results of existing literature [37]. The result is defined as [0, 0.75] as "uncoordinated" between subsystems, [0.75, 0.90] as "comparative coordination", and [0.90, 1.00] as "coordination" (Fig. 6). Taking 2004 as the base period, the relevant years are extracted at intervals every four years. Finally, the spatial distribution of the coordination relationship in 2004, 2008, 2012 and 2015 is obtained. In 2004, the coordination degree among subsystems was „coordinated" only in Zhejiang province, and in „comparative coordination" were Fujian and Guangdong provinces, while the remaining 28 provinces were „uncoordinated". In 2008, Zhejiang, Fujian and Guangdong provinces were in „comparative coordination". In 2012, Beijing, Hebei, Zhejiang, Fujian, Guangdong, Guangdong, Hunan were in „comparative coordination". In 2015, Guangdong is in the „coordination" level, Hebei, Zhejiang, Fujian, Shandong, Hunan were in „comparative coordination" level, while the remaining 25 provinces are in the „uncoordinated" (Fig. 8). Overall, the number of provinces with „coordination" and „comparative coordination" among the subsystems in 2004-2015 is increasing. At the same time, due to the vast region and regional differences, development should be adapted to local conditions and the actual situation. For different regions, different elements and infrastructure should be invested.

Conclusions

Based on the data collection from China, this paper analyzes the spatial and temporal dynamic and coordination degree of ASD from 2004 to 2015 based on the entropy, coefficient of variation and coordination degree methods.

From the temporal dimension, the ASD index firstly shows a trend of fluctuation it has a continuous rise trend and then a process of continuous decline. From the spatial dimension, the agricultural sustainable development indexes of various provinces are mainly in the [0.25, 0.50]. In terms of the trend of coordination degree of ASD, it showed a trend of "first continuous decline and then fluctuation rise". This study considers five aspects: population, society, economy, environment and resources. And helps to improve the coordinated development of the sustainability of each subsystem and improve the comprehensive level of sustainable agricultural green development.

Based on an analysis of AGDI performance evaluation, the regional association network was constructed to represent the relevance of each province or the radiance of green development of agriculture. The setting of the indicator (Degree centrality and Betweenness centrality) of agricultural green network can better reveal the relationship between the human economic and social activities, the resources and the environment.

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Conflict of Interest

The authors declare no conflict of interest.

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