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Study on the influence mechanism and level measurement of agricultural green development—A case study of China

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Taking China as an example, this paper analyzes the impact mechanism of agricultural green development and constructs a measurement system of agricultural green development level. The system includes seven subsystems (ensuring food security, optimizing agricultural structure, improving market mechanism, innovation-driven development, building ecological civilization, inheriting traditional culture, and benefiting the people) and 55 measurement indicators. Empirical research was carried out using entropy method and gray correlation to measure the level of green development of China's agriculture, analyze its spatial distribution law, and divide it into three levels according to the development level, then analyze the regional characteristics of each grade. The research shows that the overall level of agricultural green development in China is relatively low, and the constraints are obvious. It is easy to ignore the value of agricultural green development, and the phenomenon of non-green development still exists. Therefore, we must attach great importance to the green development of agriculture, change agricultural production from the pursuit of quantity to the pursuit of quality in the past, formulate an effective path to promote the comprehensive level of agricultural green development in the whole ecological chain, and build a collaborative research institution and information monitoring platform for agricultural green development.

KEYWORDS

green development of agriculture, influence mechanism, entropy method, gray correlation analysis, China

1 Introduction

Agricultural development is an important foundation for the stable and healthy operation of the national economy. The essence of agricultural green development is to promote agriculture from increasing production to improving quality, improve the utilization ratio of cultivated land and natural ecological resources, and actively deal with the prominent problems of agricultural ecological environment.

Agricultural green development is the core connotation of the Rural Revitalization Strategy. At present, China's agricultural non-point source pollution is still serious, and China is the world's largest producer and consumer of chemical fertilizers and pesticides (Sun S. et al., 2019; Sun Y. et al., 2019). Yu et al. (2019) believe that farmers abuse production factors to cause agricultural environmental pollution. Li (2020) states that China's agricultural environmental pollution is the result of multi-layer superposition of mainstream discourse and policy guidance under the dual constraints of China's national conditions and China's agricultural conditions. It is closely related to the problems of China being abundant in population but poor in cultivated land and prominent food security status. Under the guidance of this historical development logic, the agricultural production mode of small farmers has formed a solidified path dependence (Li, 2020). Based on the analysis of world development experience, in Transforming Traditional Agriculture, Schultz believes that in the process of the transformation of any economy in the world from an agricultural society to an industrial society, there will be environmental pollution problems that agriculture cannot solve by itself (Schultz, 1999).

Economic growth theory posits that total factor productivity (TFP) is the core index to measure economic development, and its growth difference is the fundamental reason for the economic differences between different countries and regions (Hall and Jones, 1999). To a large extent, agricultural modernization is the process of continuous improvement of the contribution of TFP to agricultural economic growth (Coelli and Rao, 2005). However, traditional agricultural TFP accounting is based on factor input and expected output. While improving agricultural output, with the continuous increase in the use of modern agricultural means of production such as pesticides, agricultural films, fertilizers, agricultural machinery, and so on, the total amount of agricultural carbon emissions is also increasing, resulting in "high carbon" agriculture (Hailu and Veeman, 2000). Methods to measure the level of agricultural modernization include simple linear summation (Cloke, 1977), semi-structured interviews (Barbara, 2002), etc. The Intergovernmental Panel on Climate Change of the United Nations believes that it is reasonable to use carbon emissions as the unexpected output of agricultural production, and can accurately give various carbon sources and their emission coefficients in agricultural production (IPCC, 2007). In order to overcome the defects of the simple linear summation method, non-radial and non-angular directional distance functions based on relaxation variables are introduced in the study (Cooper et al., 2006). The Luenberger index is decomposed into pure technical efficiency, pure technical progress, scale efficiency, and technology scale (Grosskopf, 2003) and introduced into the measurement (Tone, 2001; Rashidi and Saen, 2015). Since the non-angle directional distance function based on relaxation variables allows the input or output variables to change in different proportions, and there is no need to make the angle selection based on input or output, it can reflect resource saving. The comprehensive realization of multiple targets such as pollution reduction and economic growth is more in line with the requirements of green development. Data envelopment analysis (DEA) is widely used to evaluate the technical efficiency of panel data (Mandal, 2010). Because the DEA method has advantages in evaluating the relative efficiency of similar decision-making units with multi-input and multi-output indicators, it is widely used in the study of ecological environment efficiency. For example, Korhonen and Luptacik (2004) used the DEA method to measure the ecological environment efficiency of 24 power enterprises in Europe. Aldanondo-Ochoa and Casasnovas-Oliva (2014) measured the technical efficiency and ecological environment efficiency of organic agriculture in Navarre, Spain, using the DEA method, and concluded that organic agriculture is more effective than traditional agriculture. Zhou et al. (2008) evaluated and compared the eco-environmental efficiency of eight regions in the world based on different DEA models. However, compared with the traditional DEA (Charnes et al., 1978), the slack-based measure model proposed by Tone (2004) not only considers the impact of the unexpected output on the production process, but also eliminates the impact of the relaxation variable on the measurement value by directly incorporating the relaxation variable of each input–output into the objective function, so that the measurement value conforms to the reality and is more accurate (Sun et al., 2014). In terms of evaluation index system research, HÖh et al. (2002) took the ecological environment efficiency of land, energy, raw materials, water, greenhouse gas, acid gas, labor, capital, and other input factors as the macro-level evaluation index in the design of a German ecological environment economic account. In the research of ecological environment efficiency measurement methods, there are mainly life cycle assessment (Lozano et al., 2009), multiple criteria decision making (Montanari, 2004; Gómez-López et al., 2009), stochastic frontier analysis (Reinhard et al., 2000), distance function (Wang et al., 2010), etc.

Therefore, there are problems such as agricultural soil eutrophication and heavy metal pollutants, water source and groundwater pollution, pesticide residues of agricultural products, and so on, which lead to an increase in the risk of drinking water source and food safety, which is contrary to the strategic goal of the Rural Vitalization Strategy. This paper holds that in the process of China's rural agricultural development, in the past, attention has always been focused on solving the problem of feeding a large population, focusing on improving agricultural income and farmers' enthusiasm for growing grains, and balancing the urban–rural duality and the differences between workers and farmers to promote the process of rapid urbanization and rapid industrialization, which inevitably bears the weight that rural agriculture should not bear. However, as China's urbanization and industrialization have reached a certain level, an all-round well-off society and a per capita GDP of more than USD 10,000 have entered the middle-income stage. It is urgent to pay attention to the problems of rural agricultural ecological environment and change from the original extensive traditional agricultural development mode to green development.

The goal of agricultural green development is to pursue the synergy of agricultural ecology, economic and social benefits, sustainable agricultural development, and intergenerational equity (Duan, 2016). When China's per capita cultivated land is $<$40% of the world's per capita and agricultural resources are relatively deficient, we should not only meet the food security of 1.4 billion people, but also achieve three pillars of sustainable agricultural development: production sustainability, economic sustainability, and ecological sustainability (China Modernization Strategy Research Group, 2004). Cui (2008) research asserts that the key to China's sustainable agricultural development is to develop and utilize natural resources reasonably, improve the scientific and technological contribution rate and agricultural production efficiency of agricultural production, and focus on the coordinated development of agricultural production, agricultural economy, agricultural ecological resources, and rural areas. Xu Xiaoli, Zhao Junya, and other researchers believe that China's agriculture should replace the production mode that consumed a lot of resources in the past with a healthy production mode, so as to realize the sustainable growth of ecological, economic, and social benefits of agricultural development. They believe that China's agricultural modernization should be the integration of agricultural social modernization and agricultural ecological modernization (Zhao, 2017; Xu et al., 2019; Di and Hu, 2020).

Zhu Lingwei and other researchers believe that China's agricultural green development should focus on improving the utilization efficiency of agricultural means of production and agricultural energy, adjusting the structure of planting and breeding industry appropriately, emphasizing the need to reduce the impact of industrial pollution sources on agricultural ecological environment, reduce carbon emissions, and improve industrial energy utilization efficiency and industrial energy price (Rong et al., 2015; Zhu et al., 2019; Wang et al., 2020). Sun et al. (2020) believe that we should pay attention to rural agriculture, maintain the ecological environment of water resources, improve the utilization efficiency of water resources, and reduce the discharge of industrial and agricultural wastewater. Liu Hongying and other researchers believe that we should increase investment in scientific and technological innovation and the promotion and application of innovative achievements in rural agriculture, improve production efficacy and efficiency, reduce human cost, promote supply-side reform in agriculture, improve the openness of major agricultural provinces in the central and western regions, and realize green agricultural development (Huang, 2018; Liu et al., 2022). Xu et al. (2021) believe that China's national conditions and agricultural conditions lead to uneven economic and social development levels and large differences in natural resource endowments and ecological environment, and that there is an urgent need for collaborative cooperation among provinces (municipalities directly under the central government and autonomous regions) to further promote the development of green economy.

To summarize, the research on the level of agricultural green development in the existing literature focuses on three aspects, namely specific industries, economic belts, and regional levels, and there is a lack of systematic research on the level of agricultural green economic development and its influencing factors from the perspective of provinces (municipalities directly under the central government and autonomous regions) and taking the whole country as the research object. Based on this, combined with the Rural Revitalization Strategy and the main problems of agricultural high quality, this paper constructs a measurement system suitable for the level of agricultural green development in the new era, and measures and evaluates China's agricultural green development from the perspective of Rural Revitalization. Based on 2019 data, gray correlation and entropy weight methods are used to quantify and empirically study the level of green agricultural development in 30 provinces of China (municipalities directly under the central government and autonomous regions; Hong Kong, Macao, Taiwan, and Tibet are not empirically analyzed due to the difficulty in obtaining data). According to the empirical results, policy suggestions are put forward to provide reference for provinces (municipalities directly under the central government and autonomous regions) to formulate corresponding measures. At the same time, this work has theoretical and practical reference significance for the construction of a national green economic system, the healthy development of the national economic system, and the realization of green, coordinated, and sustainable goals.

2 Theory and mechanism analysis

The development of traditional agriculture has negative effects such as massive consumption of energy, destruction of the natural ecological environment, and harm to human health. Agricultural green development aims to protect the ecological environment, reasonably develop and utilize resources, improve resource utilization efficiency, and produce organic and ecologically harmless agricultural products (Chen et al., 2018). Therefore, with the help of "Internet +" and the Rural Revitalization Strategy, agricultural green development aims to inherit the natural ecology of agricultural civilization, shape the extended value of agricultural tourism, improve the quality of green organic agricultural products, improve the rural living environment and production and living standards, release the demographic dividend with the help of agricultural green development informationization, and finally facilitate the construction of an ecological civilization (Xie et al., 2019).

Traditional agricultural development and ecological environment protection are a compromise to some extent. The extension of green agricultural development focuses on promoting production and development through scientific research. The essence of the extension of agricultural green development is to ensure agricultural development and protect the natural ecological environment, and meanwhile to improve agricultural production capacity by relying on scientific research and solve the constraints and bottlenecks of the natural ecological environment on increasing agricultural income and agricultural economic development (Wu et al., 2020, etc.). Therefore, in the face of the pressure on the ecological environment accumulated in the development of traditional agriculture, the popularization and application of agricultural scientific and technological innovation achievements is the external driving force to change the agricultural development model. Fundamentally speaking, at the starting point, ensuring the comprehensive quality of human resources of rural society and agricultural employees in the future, narrowing the gap between urban and rural education, realizing the equity of urban and rural education, and improving the national physical quality of rural agricultural population are the cornerstones of green agricultural development (Kang et al., 2020).

With the government's goal of green agricultural development and environmental protection as the cornerstone, along with the government's goal of sustainable agricultural development and economic security as the foundation, the government's goal of green agricultural development and environmental regulation and control is to take green agricultural development and economic development as the cornerstones. Based on the existing literature and the innovation points in the research, this paper lays out the main factors affecting agricultural green development from the perspective of rural revitalization, including seven aspects, namely food security, agricultural structure, market mechanism, innovation drive, ecological construction, cultural inheritance, and benefiting the people. Then, the mechanism analysis is carried out according to the seven subsystems to select the measurement indicators and content (Liu and Liu, 2020).

(1) Green agricultural development and food security. Agriculture is the net primary productivity of the national economy and the source of human food. Food security is an important part of national security. China's grain production generally meets the needs of 1.4 billion people, but the amount of chemical fertilizer required is 2.7 times the world average, the utilization rate of chemical fertilizer is <40%, and the problem of soil eutrophication is serious. During the 13th Five-Year Plan period, the average annual use of pesticides in China was 270,300 tons, which was 9.84% lower than that during the 12th Five-Year Plan period, exceeding the goal of the Action Programme for Zero Growth in Pesticide Use by 2020 formulated by the Ministry of Agriculture and Rural Affairs (the former Ministry of Agriculture). However, the pesticide utilization rate of the three staple food grains of rice, wheat, and corn in China is 40.6%. There is a long way to go to achieve the agricultural green development goal of "seizing grain from insects", ensuring bumper harvest, and reducing pesticide use.

(2) Agricultural green development and agricultural structure. In recent years, the overall investment in agricultural capital has increased significantly, from 69.524 billion yuan in 2004 to 133.02 billion yuan in 2020, accounting for 3% of the total investment in fixed assets. The entry of a large amount of capital has resulted in agricultural structural overcapacity. The distribution of China's agricultural industrial structure is affected by multiple factors such as natural geographical resources, policy guidance, and economic factors. On the whole, there is a tendency for strong industry, weak agriculture, heavy industry, and light agriculture. As the ballast stone and reservoir of the national economy, agriculture bears the weight of the supply of production resources, price scissors, and city–countryside dualization, resulting in obvious development weaknesses in the agricultural structure. In history, the subordinate position of agriculture in evolution makes the agricultural structure unbalanced. The green development of agriculture is restricted, the emphasis on quantity in the agricultural structure hurts quality, the added value of agricultural products is not high, and the agricultural competitiveness is not strong, which inhibits the integrated development of agriculture with the secondary and tertiary industries and is not conducive to the green development of agriculture.

(3) Agricultural green development and market mechanism. Since 2002, China has become a net importer of agricultural products, especially since 2013, with an average annual import volume of more than USD 50 billion. The main reasons for China's large import of agricultural products are the appreciation of the RMB exchange rate, the rapid rise of domestic agricultural production costs, the high risk and thin profits in agricultural production, and the low price of international agricultural products. Statistics show that in 2020, the average net profit per mu of rice, wheat, and corn was at a loss. The weak market competitiveness of China's agricultural products is mainly due to high product costs, low prices, and low product quality. Due to the double squeeze of price and cost, the willingness to pay for agricultural green development is insufficient. Since 2020, China's middle-income group reached 600 million people, and the consumer group of agricultural products changed from being satisfied with food to eating well and eating healthy. There is an urgent need to improve the market competition of agricultural products through green agricultural development, adapt to the needs of upgrading the consumption structure, and deal with the squeeze of low foreign prices, increase the sales price of agricultural products to hedge the impact of the rising cost of agricultural production factors and ecological environment factors.

(4) Green agricultural development and innovation-driven. The innovation-drive of agricultural green development is reflected in two aspects. First, agricultural green development requires scientific and technological production means and methods, modern agricultural production facilities, reducing production costs, reducing dependence on the natural ecological environment, improving the utilization efficiency of natural resources and production factors, enhancing the scientific and technological content of agricultural products, improving and extending the added value of agricultural products, and enhancing the market competitiveness of agricultural products. The second is the innovation of management systems of agricultural production. The green development of agriculture requires an efficient and complete production and management system. The innovation of agricultural management system needs to cultivate more new business entities and improve production efficiency by realizing intensive, professional, large-scale, ecological, and big data modern production methods.

(5) Agricultural green development and ecological civilization. China's agricultural green development is affected by both exogenous environmental pollution from industry and endogenous pollution caused by rural agriculture itself. The exogenous pollution of industry is mainly the pollution of farmland, forest vegetation, water, soil, and atmosphere by industrial emissions. The endogenous pollution of rural agriculture is mainly the long-term overuse of chemical fertilizers and pesticides. Unreasonable treatment of rural domestic waste, livestock manure, and farmland residual film has caused damage to the ecological environment. Therefore, agricultural green development must strictly control the two major pollution sources, classify and gradually degrade the historical pollution stock, and repair the ecological environment.

(6) Green agricultural development and cultural heritage. China is a country with extremely developed agricultural civilization in history. The countryside has become a living fossil of China's agricultural civilization, and also inherits Chinese traditional culture. Chinese traditional culture has simple wisdom of ecological civilization, such as being close to nature, and the unity of man and nature. It has a simple ecological philosophy. Therefore, the green development of

agriculture is closely related to the inheritance of Chinese traditional culture. In the vast countryside, there are many valuable relics of cultural and natural heritage remain in the field of rural agriculture. On the basis of fully inheriting and carrying forward Chinese culture, agricultural green development makes use of its own functions to play an important role in the stable and sustainable development of rural agricultural economy and society, retaining green mountains and rivers and promoting the integration of primary, secondary, and tertiary industries.

(7) Green agricultural development and benefitting people's livelihood. China has a large rural population, and the overall income of farmers is low. Rural income mainly depends on farmers' going out to work. The construction of rural infrastructure has been greatly improved in recent years, but there are still shortcomings in the central and western regions. Rural infrastructure and public service facilities in the fields of transportation, medical and health care, education, elderly care, communication, Internet, and so on are seriously lagging behind those of cities. The foundation of agricultural production is weak, and the disaster resistance is weak, which is not conducive to the green development of agriculture. Therefore, it is necessary to realize the overall requirements of people-oriented sustainable economic and social survival and development in accordance with the ultimate goal of agricultural green development, as well as to promote agricultural efficiency, farmers' prosperity, and ecological livability and let rural areas, agriculture, and farmers share the fruits of green development.

3 Measurement of agricultural green development level

3.1 Constructing the measurement system of agricultural green development

Based on the above theoretical logic and mechanism analysis of agricultural green development measurement from the perspective of rural revitalization, taking into account the hierarchy, scientificity, rationality, and data availability of measurement indicators, an agricultural green development level measurement system with 55 measurement indicators in seven subsystems is constructed, as shown in Table 1.

In this paper, the selection of agricultural green development evaluation indicators and the determination of the target value of indicators are based on the existing relevant research, mainly referring to the agricultural modernization standards of the Ministry of Agriculture of China in 2016 and the research results of relevant scholars (Li, 2013, 2014; Ge et al., 2018; Zhang and Xu, 2018). Therefore, the measurement system can better cover the connotation of the Rural Revitalization Strategy and the needs of agricultural green development, and provide practical implications.

3.2 Measurement method and data source of agricultural green development level

The empirical research data of this paper are based on the 2019 China Statistical Yearbook, China Rural Statistical Yearbook 2019, the statistical data of national economic and social development of provinces (municipalities directly under the central government and autonomous regions), and government work reports publicly released by the national statistics department. The research data of scholars in this field are used to supplement the work, so that the empirical research can fully reflect the real situation.

The empirical method of this paper uses the gray correlation analysis method and entropy weight method to analyze the agricultural green development level from the perspective of Rural Revitalization. Firstly, the measurement indicators are standardized, and then the measurement indicators are assigned by entropy weight method. Then, the agricultural green development level of all provinces (municipalities directly under the central government and autonomous regions) is intuitively ranked by gray correlation analysis and then analyzed according to the empirical situation. The specific steps are as follows:

The first is to set the reference sequence for data preprocessing. X_0 represents the initial value after data preprocessing:

$$X_0 = (1, 1, \ldots, 1)$$

The second is to calculate the correlation coefficient of each index. X_1 to x_{55} represent the regression value of each measurement indicator:

$$\begin{aligned} X_1 &= [x_1(1), x_1(2), \ldots, x_1(28), x_1(29), x_1\ (30)] \\ X_2 &= [x_2(1), x_2(2), \ldots, x_2(28), x_2(29), x_2\ (30)] \\ X_{55} &= [x_{55}(1), x_{55}(2), \ldots, x_{55}(28), x_{55}(29), x_{55}\ (30)] \end{aligned}$$

Data standardization; $r_i(j)$ represents the correlation coefficient of the j-th index of i province (municipality directly under the central government, autonomous region):

$$r_i(j) = \frac{\text{minmin}\ \left|x_i(j) - x_0(j)\right| \text{maxmax}\ \left|x_i(j) - x_0(j)\right|}{x_i(j) - x_0(j) + p \times \text{maxmax}\ \left|x_i(j) - x_0(j)\right|} \quad (1)$$

The third is the weighted assignment through gray correlation analysis. r_j represents the gray correlation degree of the j-th measurement index:

$$r_j = \frac{\sum_{j=1}^{55} r_i(j)}{55} \quad (2)$$

The fourth is to introduce the entropy method to build the index weighting matrix. R represents n rows of records, m variables, and the entropy value of n * m matrix:

TABLE 1 Measurement system of agricultural green development.

Subsystem item	Index item	Content description	Value
Food security F1	Per capita grain output (M11)	Total grain output/resident population of the year	Moderate
	Cultivated land area per capita (M12)	Total cultivated land area/resident population of the year	Forward
	Main grain composition (M13)	Proportion of China's three main grains (rice, corn, and wheat)	Moderate
	Non-grain crops (M14)	(sown area of non crops/sown area of crops) * 100 (%)	Moderate
Agricultural structure F2	Agricultural production structure (M21)	Proportion of planting, forestry, animal husbandry, and fishery	Negative
	Grain feeding structure (M22)	Grain, economy, grass, and Livestock Association dispatching	Forward
	Investment structure (M23)	Investment in rural areas	Moderate
	Opening to the outside world (M24)	Foreign capital utilized in agricultural production/total agricultural output value	Forward
	Import and export (M25)	Agricultural import and export volume/total agricultural output value	Forward
	Rural output structure (M26)	Agricultural primary, secondary, and tertiary output	Moderate
	Investment degree (M27)	Area output value/area investment	Forward
Market mechanism F3	Government consumption (M31)	National Agricultural purchase amount/total agricultural consumption	Negative
	Private investment (M32)	Private investment/total agricultural investment	Forward
	Private output (M33)	Private output/total agricultural output	Forward
	Capital element (M34)	Financial added value/total agricultural output	Forward
	Labor factors (M35)	Agricultural population/total social employment	Moderate
	Agricultural legal person (M36)	Agricultural legal person/permanent resident population of the year(persons/10000 persons)	Moderate
	Agricultural services (M37)	Added value of agricultural service industry/total agricultural output value * 100 (%)	Moderate
	Farmers' participation in cooperatives (M38)	Number of households participating in cooperatives/total number of farmers	Forward
	Family farm (M39)	Household farm output/total agricultural output	Forward
	New professional farmers (M310)	Number of professional farmers/total number of farmers	Forward
	Inclusive finance (M311)	Total agricultural financial support per unit area/total agricultural output per unit area	Forward
	Agricultural insurance (M312)	Agricultural insurance amount/agricultural land area(yuan/hectare)	Forward
Innovation-driven F4	Agricultural science and technology (M41)	Number of agricultural scientific and technological personnel/agricultural land area(person year/hectare)	Forward
	Mechanization level (M42)	Total power/cultivated land area(kW/ha)	Forward
	Land utilization rate (M43)	Total output/total area	Forward
	Labor productivity (M44)	Total agricultural output/total number of agricultural employees	Forward
	Agricultural scientific and technological achievements (M45)	Number of agriculture related patents/total number of patents	Forward
	Agricultural technology market (M46)	Agricultural technology transaction volume/total agricultural output value	Forward
	Agricultural high-tech income generating capacity (M47)	Output value of high additional agricultural products/total agricultural output value	Forward

(Continued)

TABLE 1 (Continued)

Subsystem item	Index item	Content description	Value
Ecological civilization F5	Soil conservation (M51)	Water and soil conservation per unit area	Forward
	Pollution control (M52)	Total agricultural emissions/total agricultural output	Negative
	Use of chemical fertilizer (M53)	Fertilizer application amount/total crop yield	moderate
	Pesticide application (M54)	Pesticide use/total crop yield	Negative
	Harmless straw (M55)	Comprehensive utilization efficiency of straw	Forward
	Forest vegetation (M56)	Rural forest coverage	Forward
	Rural environmental sanitation (M57)	Drinking water safety, toilet reconstruction, and garbage harmless treatment	Forward
Inherit culture F6	Village intangible cultural heritage (M61)	Number of agricultural intangible cultural heritage and natural ecological heritage	Forward
	Geographical indications of agricultural products (M62)	Number of agricultural geographical indications above national level	Forward
	Integration of agriculture, culture, and tourism (M63)	Number and scale of rural cultural festivals	Forward
	Cultural creativity of agricultural content (M64)	Number of rural cultural creations above the provincial level	Forward
	Situation of famous cultural villages (M65)	Amount of financial investment of local government in the protection of rural agricultural culture, history, and culture	Forward
	Agricultural culture market (M66)	Output value of rural characteristic culture	Forward
Achievements benefit the people F7	Farmers' income (M71)	Per capita net income of farmers and its proportion to that of urban and rural residents	Forward
	Rural population living (M72)	Engel coefficient of rural families	Negative
	Farmers' income structure (M73)	Proportion of agricultural operating income, labor income, and property income	moderate
	Residence of rural population (M74)	Per capita living area	Forward
	Quality of rural life (M75)	Number of cars per household	Forward
	Rural traffic conditions (M76)	Highway density	Forward
	Rural education (M77)	Enrollment rate of school-aged children and adolescents	Forward
	Rural cultural status (M78)	Times of rural library and culture going to the countryside	Forward
	Internet status (M79)	Home network coverage	Forward
	Status of medical facilities (M710)	Coverage rate of rural cooperative medicine and the number of doctors and hospital beds per capita in villages and towns	Forward
	Rural balance (M711)	Rural Gini coefficient	Negative
	Rural poverty control (M712)	Incidence of relative poverty among rural population	Negative

$$R = \begin{vmatrix} x_{11}x_{12}x_{13}\ldots\ldots x_{1n} \\ x_{21}x_{22}x_{23}\ldots\ldots x_{2n} \\ x_{31}x_{32}x_{33}\ldots\ldots x_{3n} \\ x_{m1}x_{m2}x_{m3}\ldots\ldots x_{mn} \end{vmatrix} \tag{3}$$

The fifth is to calculate the contribution of X_{ij} and gradually calculate the entropy of the j-th index. f_{ij} represents the characteristic proportion of the index, and H_j represents the information entropy:

$$f_{ij}=\frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}, H_j=\frac{1}{m} \times \sum_{i=1}^{m} f_{ij} Inf_{ij} \tag{4}$$

Sixth, calculate the entropy method weight. w_j represents the entropy weight of the j-th index:

$$w_j = \frac{1 - H_j}{n - \sum_{i=1}^{m} H_j} \tag{5}$$

Seventh, substitute the model correlation coefficient $r_i(j)$ to obtain the correlation degree of entropy weight. r_j represents the correlation degree of entropy weight of the j-th index:

$$r_i(j)=\frac{\sum_{j=1}^{55} r_i(j)w_j}{55} \tag{6}$$

4 Analysis on the measurement results of china's agricultural green development level

According to the previous empirical measurement, the agricultural green development level of seven subsystems in China's provinces (municipalities directly under the central government and autonomous regions) in 2019 is measured. The results are shown in Table 2.

The following conclusions are drawn through empirical analysis:

(1) Food security level: In 2019, the average level of food security under the requirements of China's green agricultural development is 0.604.China's food security is basically self-sufficient and generally balanced. However, there are great differences in grain production capacity, per capita cultivated land area, food structure, and urban–rural structure among provinces (municipalities directly under the central government and autonomous regions) in China.

(2) Agricultural structure level: In 2019, the overall situation of agricultural green development in all provinces measured from the subsystem of optimizing industrial structure level is the national average level of 0.583. It can be seen that there is much room for agricultural structure optimization. In addition, the agricultural structure level of municipalities directly under the central government and southeast provinces is relatively good, which is positively related to the degree of economic development. The optimization of agricultural structure in the central and western regions is mainly reflected in the integration level, investment, and openness of primary, secondary, and tertiary industries.

(3) Level of market mechanism: There is a large gap between the improvement level of China's agricultural market mechanism and China's agricultural green development, mainly due to the impact of the attributes of agricultural public products. There are obvious differences in the improvement of the market mechanism among provinces (municipalities directly under the Central Government and autonomous regions) in China, because the agricultural natural production conditions, the degree of agricultural organization, and the degree of scale vary greatly among regions. Therefore, efforts should be made to strengthen the cultivation of new agricultural production and operation organizations, promote the development of agricultural financial markets and agricultural insurance markets, and steadily increase farmers' income and enthusiasm for growing food according to the actual situation in various regions.

(4) Innovation-driven level: from the measurement, Beijing and Shanghai lead the China's agricultural innovation level. However, the agricultural output of these places is not optimal, indicating that the structural contradiction of China's agricultural green development is prominent. It is necessary to strengthen innovation-driven coordination between provinces and regions to promote China's agricultural green development.

(5) Level of ecological civilization: the construction of ecological civilization is one of the five development concepts in China, one of the core contents of the Rural Revitalization Strategy, and a worldwide topic. The green development of agriculture is based on ecological civilization. In recent years, China has attached great importance to the construction of agricultural and rural ecological civilization, especially in the transformation of rural human settlements, rural water and soil conservation, soil improvement, rural forest conservation, and agricultural waste treatment. Therefore, from the measurement results, except for Xinjiang, Ningxia, Inner Mongolia and Shanxi, the balance of ecological civilization in other regions is good.

(6) Cultural heritage level: traditional culture is closely related to the endless national spirit in agricultural and rural areas. From the measurement level, all regions have made great progress in inheriting traditional culture, with a relatively balanced overall distribution, showing a better situation between economically developed regions and central regions, reflecting the important role of investment intensity in the inheritance of agricultural and rural culture.

(7) Benefit people's livelihood: there are great differences among provinces (municipalities and autonomous regions) in China in terms of people's livelihood. Municipalities directly under the Central Government and economically developed provinces are significantly higher than those in the central and western regions and northeast regions. This is mainly because the public infrastructure and public service facilities in the central and western regions are backwards, and the prominent livelihood problems in rural areas of provinces with large agricultural populations are areas with significantly lower levels of urbanization and industrialization, such as education, medical care, pension, rural e-commerce, and economic income. The Gini coefficient of the whole country is relatively balanced and the incidence of poverty is relatively balanced, indicating that the country has made remarkable achievements in poverty alleviation, but there is still a lot of room for overall planning in sharing the achievements of development and benefiting people's livelihood.

The overall level of agricultural green development is not high, and there are obvious differences between different regions. According to the measurement results, 30 provinces (municipalities directly under the central government and autonomous regions) are divided into class I, class II, and class III. The first class is strong, and the comprehensive value of agricultural green development level is above 4.8. The second category represents medium, and the comprehensive value of agricultural green development level is between 3.5 and 4.8. The three types of representatives are weak,

TABLE 2 Level of measurement subsystem of China's inter-provincial green development in 2019.

Subsystem item	Food safety	Agricultural structure	Market mechanism	Innovation-driven	Ecological civilization	Inherit culture	Benefit people's livelihood	Gross value
Average value	0.604	0.583	0.529	0.604	0.593	0.595	0.589	4.097
Beijing	0.443	0.769	0.688	0.819	0.797	0.833	0.902	5.251
Tianjin	0.462	0.725	0.639	0.739	0.728	0.763	0.835	4.891
Shanghai	0.473	0.823	0.739	0.824	0.839	0.802	0.901	5.401
Chongqing	0.538	0.695	0.629	0.699	0.699	0.695	0.699	4.654
Hebei	0.563	0.613	0.599	0.580	0.562	0.602	0.524	4.043
Shanxi	0.574	0.602	0.498	0.502	0.493	0.550	0.499	3.718
Liaoning	0.640	0.599	0.520	0.613	0.502	0.499	0.479	3.852
Jilin	0.642	0.602	0.492	0.635	0.513	0.502	0.460	3.846
Heilongjiang	0.651	0.599	0.503	0.620	0.450	0.499	0.447	3.769
Jiangsu	0.730	0.673	0.655	0.734	0.692	0.688	0.702	4.874
Zhejiang	0.732	0.694	0.673	0.730	0.683	0.680	0.692	4.884
Anhui	0.611	0.643	0.504	0.582	0.602	0.580	0.599	4.121
Fujian	0.624	0.599	0.615	0.633	0.652	0.633	0.563	4.319
Jiangxi	0.649	0.560	0.499	0.593	0.612	0.613	0.520	4.046
Shandong	0.717	0.694	0.622	0.719	0.644	0.646	0.615	4.657
Henan	0.844	0.702	0.606	0.660	0.620	0.624	0.610	4.666
Hubei	0.675	0.634	0.635	0.702	0.659	0.679	0.659	4.643
Hunan	0.769	0.644	0.612	0.692	0.640	0.655	0.635	4.647
Guangdong	0.746	0.646	0.702	0.699	0.670	0.689	0.683	4.835
Hainan	0.532	0.621	0.524	0.543	0.540	0.592	0.564	3.916
Sichuan	0.660	0.535	0.499	0.620	0.635	0.613	0.655	4.217
Guizhou	0.550	0.499	0.340	0.512	0.528	0.524	0.513	3.466
Yunnan	0.528	0.480	0.402	0.499	0.524	0.502	0.525	3.460
Shaanxi	0.613	0.520	0.499	0.624	0.604	0.613	0.625	4.098
Gansu	0.564	0.402	0.403	0.490	0.512	0.490	0.520	3.381
Qinghai	0.494	0.398	0.355	0.413	0.502	0.474	0.483	3.119
Inner Mongolia	0.518	0.389	0.368	0.402	0.487	0.453	0.469	3.095
Guangxi	0.599	0.402	0.399	0.476	0.499	0.502	0.472	3.349
Ningxia	0.492	0.377	0.342	0.400	0.457	0.433	0.437	2.938
Xinjiang	0.488	0.342	0.324	0.373	0.424	0.415	0.418	2.784

and the comprehensive value of agricultural green development level is below 3.5. The statistical situation is shown in Table 3.

According to the table above. The economy of class I regions is relatively developed, strong ability to feedback agriculture, the market mechanism is relatively perfect, the innovation-driving capacity is strong, and agricultural infrastructure is relatively good, which effectively improve the utilization efficiency and the efficiency of production factors and materials, and effectively improves the output capacity. Class II areas are large agricultural provinces and national granaries, which play an important role in ensuring national food security. However, in the process of agricultural green development, due to the pressure of the ecological environment and the influence of capital and talent factors, the problems of soil and water conservation, land resource utilization rate, and environmental pollution control ability are difficult to alleviate in a short period of time. The economy of class III areas are relatively underdeveloped, the natural ecological environment is fragile, and basic conditions are weak. There are obvious deficiencies in the process of green agricultural development.

TABLE 3 Green development of three types of agriculture.

Type/area	Eastern region	Central region	Western region
Class I	Shanghai, Beijing, Jiangsu, Tianjin, Guangdong, Zhejiang		Chongqing
Class II	Shandong, Fujian, Liaoning, Hebei, Hainan	Hunan, Hubei, Henan, Anhui, Jilin, Heilongjiang, Jiangxi, and Shanxi	Sichuan, Shaanxi
Class III			Guizhou, Yunnan, Guangxi, Gansu, Qinghai, Inner Mongolia, Ningxia, and Xinjiang

5 Research conclusions

5.1 Conclusions

(1) The overall level of agricultural green development in China is not high. The overall evaluation value of agricultural green development measurement is generally <0.610, which is at a low level. The main reason is that in the three decades since the founding of the People's Republic of China, we have ignored agricultural green development in the process of paying attention to and giving priority to the development of industry, national defense, and urban construction. In the three decades since the Reform and Opening Up, we have concentrated advantageous resources to promote industrialization and urbanization. Urban and rural areas have a considerable siphon effect on rural finance, talents, and resources, and large amounts of rural populations, funds, and resources have converged to cities. In the past decade, the green development of agriculture has made great progress, but there are many historical arrears, and the restoration of the rural natural ecological environment and the self-circulation process are long.

(2) The bottleneck restricting the green development of agriculture is obvious, with weak self-sufficiency in the field of food security, a lack of high-quality agricultural products, insufficient promotion of quality ecological agriculture, excessive application of chemical fertilizers and pesticides per unit area, insufficient agricultural investment intensity, an inactive agricultural market trading mechanism, and other prominent problems. The developed and underdeveloped regions are obviously insufficient in the coordination mechanism of agricultural green development, resulting in the lack of a flow mechanism for elements such as science and technology, capital, land, and talents among provinces. Therefore, resources cannot be fully utilized, the coordinated development of ecological environment protection and governance among provinces is not sufficient, and the phenomenon of fighting alone is common in agricultural green development. This proves that China's inter-provincial internal circulation system needs to be further strengthened in accordance with the requirements of double circulation in the new era.

(3) The inherent value of agricultural green development and the dependence of the national economy on the agricultural economy are ignored. When facing the structural contradictions between agricultural ecology, food security, cultivated land protection, cultural inheritance, and economic growth, regions are divorced from each other in policy formulation, specific measures and plans, and there are deviations in understanding and implementation.

(4) Agricultural non-green development areas still exist. The overall level of green development of agriculture in western China is low; the ability of comprehensive ecological management and the improvement of rural living environment are especially weak. Quality ecological agriculture has not formed a long-term mechanism for sustainable development. The traditional planting and breeding industry occupies the vast majority of space, and there is still considerable room for improvement in the integrated development of agricultural primary, secondary, and tertiary industries and the integrated development of agriculture, culture, and tourism.

5.2 Proposal

According to the above research conclusions, the following suggestions are put forward:

(1) Attach great importance to the Rural Revitalization Strategy and promote the transformation of the concept of agricultural green development from the pursuit of quantity to the pursuit of quality and order. We should systematically rectify the source, clarify the strategic significance of Rural Revitalization and the value of giving priority to agricultural and rural development, correctly understand the coupling relationship between agricultural green development and national economic and social sustainable development, and formulate a scientific and reasonable regulation system for agricultural green development, including legislation on rural revitalization and agricultural green development, fiscal and financial policies, innovation-driven policies, policies on the dominant position of agricultural and rural farmers, and implementation measures. The implementation measures should ensure the implementation of the Rural Revitalization Strategy and the green development of agriculture.

(2) Formulate strategic measures to improve the comprehensive level of agricultural green development in the whole ecological chain system, and promote the overall improvement of the level of agricultural green development. Based on a large number of existing studies literature and official data, we

constructed seven complex subsystems and 55 evaluation indexes, and analyzed the mechanism of the connotation of each index. It is a comprehensive level measurement and ecological chain system of composite representation. Therefore, the research conclusions are relatively objective. On the basis of national overall planning, all provinces (municipalities directly under the central government and autonomous regions) can implement policies according to their circumstances, learn from each other, give full play to their comparative advantages and make up for their comparative disadvantages, and comprehensively and systematically formulate the path, improvement methods, and improvement measures to increase the level of agricultural green development.

(3) Build a monitoring information platform for collaborative research institutions to measure the level of agricultural green development from the perspective of national overall rural revitalization.

Build a national collaborative research institution and information monitoring and evaluation system for agricultural green development; establish a national complete large data center and database for agricultural green development; timely discover, summarize, and refine practical experience and existing problems; promote the dynamic improvement of the measurement system; and continuously promote the measurement of agricultural green development as a continuous research work.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

Formal analysis and data curation: HoL. Writing—original draft and writing—review and editing: HuL. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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