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EDITED BY
Haider Mahmood,
Prince Sattam Bin Abdulaziz University,
Saudi Arabia

REVIEWED BY
Nabil Maalel,
Prince Sattam Bin Abdulaziz University,
Saudi Arabia
Abbas Ali Chandio,
Sichuan Agricultural University, China

*CORRESPONDENCE
Shaowen Wang,
364550703@qq.com

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The positive effect of green agriculture development on environmental optimization: Measurement and impact mechanism

Shaowen Wang*

School of Business, China University of Political Science and Law, Beijing, China

According to the study of the environmental impact of green agricultural development, this paper selects 12 basic indicators from the three dimensions of "ecological agriculture, green production, and output benefits" for the construction of China's green agricultural development index. There are eight basic indicators used in the construction of the environmental index system, including the area of nature reserves and the level of environmental protection expenditures. It is based on the panel data of 13 provinces in China from 2011 to 2019. For the calculation and analysis of the green agricultural development index and the environmental index, the entropy weight method is used. The calculation results show that there are significant differences in the development level of green agriculture and environmental development among these 13 major provinces; the green agriculture level and environmental development level of Jiangsu Province and Sichuan Province are in the leading position; further using dynamic panel regression, the results show that the development of green agriculture has a significant role in promoting the improvement of the environment, and in the early stage of green agriculture development, the effect of improving the environment is more obvious; the index of green agriculture development can be further divided into ecological agriculture index, green production index and output benefit index. As a result, the improvement of ecological agriculture, green production, and output benefits can contribute to the optimization of the ecological environment. As well, the development of green agriculture has some intermediary effects on the optimization of the environment. It is the intermediary effect of promoting environmental optimization through guiding residents' green consumption that has the greatest effect, while the intermediary effect of promoting industrial structure upgrading and enterprise technology innovation has a relatively small effect. The empirical results presented in this paper suggest that a variety of measures can be taken to improve the environment, including improving green agriculture development in various regions, increasing government expenditures, and promoting the transformation of economic structures in order to improve the environment.

KEYWORDS

green agriculture, environment optimization, entropy weight method, impact mechanism, impact

1 Introduction

As well as being the foundation of the national economy, agriculture also forms the basis for social stability in China. China is a large agricultural country. Rural development has always been about improving grain production and paying attention to agricultural products. What matters most is solving the problem of food and clothing, as well as introducing economic development programs. According to Abbas Ali Chandio et al. (2022), cereal and oilseed crops play an important role in meeting global food security needs. A study of annual data from 1978 to 2020 examined the impact of meteorological factors on China's soybean production. In the long-term and short-term analysis, average temperature and carbon dioxide emissions in the next year have reduced soybean production, whereas agricultural subsidies will increase soybean production. Therefore, subsidies for crops should be provided by the government (Chandio et al., 2022). Yuansheng Jiang et al. (2022) used the Autoregressive Distribution Lag (ARDL) method to analyze the comprehensive impact of these factors on China's grain crop output from 1990 to 2017, and believed that the Chinese government should support the easy acquisition of high-tech cultivating machinery to harvest crops swiftly and explore substantial markets for further business (Ali Chandio et al., 2022). As the economy and society have developed, traditional agriculture has gradually failed to meet the people's growing needs for spiritual and material civilization and has caused an array of environmental problems. During the 19th National Congress of the Communist Party of China, a report recommended that we adhere to the harmonious coexistence of man and nature, followed by a civilized development path that led to production development, a rich life, and a healthy ecosystem; Central Document No. 1 recommended promoting the development of green agriculture and the prevention and control of green agriculture technologies. It is crucial to achieve a green development of agriculture in order to deal with the problems of ecological environment pressure and resource shortages. It is a "positive sum game" that requires both green water and green mountains and golden and silver mountains. Additionally, it provides a means to alleviate the contradiction between the growing material and cultural needs of the new generation and unbalanced and insufficient development. Developing green agriculture is the basis and guarantee for meeting the development needs of farmers and improving the rural ecological environment.

In this paper, the following aspects will be discussed: 1) A green agriculture development index is constructed based on three dimensions: ecological agriculture, green production, and output benefit. The entropy weight method is used for measurement and analysis, laying the groundwork for the subsequent quantitative analysis of the effects of various factors on the environment. 2) It is difficult to directly measure data that affects the environment. An environmental index is developed by using eight indicators and utilizing the entropy weight method to calculate and analyze. This paper offers a new perspective and idea regarding the development of green agriculture. 3) According to the regression results, there is a positive correlation between the development of green agriculture and the environment, and green agriculture contributes significantly to the creation of an ecological environment. 4) The three subsystems of green agriculture development, ecological agriculture, green production, and output benefits all play a positive role in optimizing the ecological environment. 5) The development of green agriculture has some indirect effects on the optimization of the environment. There have been varying degrees of environmental optimization due to green consumption, upgrading of industrial structure, and technological innovation of enterprises.

Based on the analysis and induction of previous studies, this paper explores a new way to calculate the green agriculture development index by entropy weight method, and explores a new path to better promote environmental optimization through the development of green agriculture. As a first point, this paper examines the development of green agriculture and ecological environment in the context of "carbon neutrality", and provides an additional source of information that complements the existing research on rural development and ecological environment. Secondly, this paper studies and measures the development index and environmental index of green agriculture in China by using quantitative analysis, which is useful for a follow-up empirical analysis. A third finding of this paper is that there is a significant difference in the development of green agriculture and environmental development among Chinese provinces, which allows for a horizontal comparison of the ecological environment in various regions of China and the development of green agriculture. Fourth, this paper analyzes the positive impact of green agriculture on the ecological environment by using the dynamic panel regression method, and analyzes the mechanisms of the effects, which is essential for understanding the internal mechanism of green agriculture development.

2 Literature review

2.1 Research on the development of green agriculture

In the early 20th century, foreign researchers began studying green agriculture. It was not until the end of World War II that the green revolution began to gradually gain momentum and depth. The green agriculture movement represents the pinnacle of modern agriculture. On the connotation of green agriculture, there are several main viewpoints: Albert Howard 1931) and kamga (2013) emphasized the relationship between natural resources and economic benefits. Agriculture based on the petroleum industry has caused great danger to society, resources, and the environment. Green agriculture should pay full attention to the relationship with nature and reduce the use of petroleum products in the agricultural production process (Howard, 1931; Kamga et al., 2013). Haggblade 1989) believed that green agriculture should follow the ecological law, make rational use of agricultural ecological resources, develop agriculture on the basis of recycling of material flow, energy flow, and information flow, and make the agricultural economic system harmoniously integrated into the cycle of the natural ecological system, and realize the green transformation of agricultural economic activities (Haggblade and Hazell, 1989). Labatt (2002) believes that the existence of green finance can effectively transfer the risk of environmental pollution and is an effective financial tool to optimize the environment. (LabattEnvironmetal Finance, 2002).Donald W. Lotter (2003) believed that sustainable land use should be evaluated by nine indicators, including fertilizer, integrated water resources management, land output rate, pest control management, output assurance, and corresponding output rate of inputs (Lotter, 2003). Q Zhou and LI Cheng-Gu (2004) studied the attributes of green agriculture and pointed out that the development of green agriculture cannot be separated from the support of the environment and is a new agricultural model that needs to be developed in a reasonable environment (Zhou and Cheng-Gu, 2004). Mohammad S. Allahyari (2009) made a quantitative analysis on the sustainable development of green agriculture by means of sampling survey. The research shows that the expansion mechanism of green agriculture development path is conducive to the development of green agriculture (Mohammad, 2009). David Carfi, Daniele Schiliro5 (2012) proposed a synergetic game model for the sustainability of global green environment, advocating the use of renewable energy to maintain the current natural resources, and at the same time, ensuring the sustainable realization of the environment from the aspects of people's awareness and relevant policies (Carfi and Schiliro, 2012). Sri Novianthi Pratiwi (2013) discussed the role of the agricultural sector in developing green agriculture against the background of Indonesia, and affirmed the importance of green agriculture development (Sri Novianthi, 2013). Prabhat Barnwal and Kotani K (2013) believed that the production basis of green agriculture is high-quality land and water. In production, it is necessary to ensure the quality of land resources and water resources, effectively use resources (nutrients, water, energy, etc.), reduce the dependence of agriculture on external inputs, ensure the sustainable use of resources, and ensure the safety of resources (Barnwal and Kotani, 2013). Jie, LI and Shuzhuo LI (2010) pointed out that the compensation and reward of ecosystem services (CRES) is an effective tool for poverty reduction and mitigation. The government can establish corresponding mechanisms and systems to reduce transaction costs, thus promoting the development of green agriculture (Jie and Shuzhuo, 2010). Since "ecological agriculture" was put forward, agricultural ecologization has begun to flourish. With the deepening of the road of agricultural ecologization, organic agriculture has gradually emerged and has taken the lead in the practice of some developed countries in Europe and achieved success (Luttikholt, 2007; Padel et al., 2009). The European Community believes that five indicators, such as per capita arable land, land use change, and the use of chemical fertilizers and pesticides, should be used to monitor the green development of agriculture. Foreign countries have established green agriculture information technology websites in an earlier period, which can enable farmers to obtain the latest knowledge, technology, market changes, and other green agriculture-related information. The popularization of new agricultural science and technology is of great help in improving production efficiency (Tadesse, 2001). Ju et al. (2018) discussed that China's traditional extensive agricultural production mode is not conducive to the development of agricultural modernization and pointed out that the formation of green agricultural ecological subsidies is the key to promoting the development of green agriculture in China (JU et al., 2018). However, these literature studies are rather one-sided and not exhaustive.

2.2 Research on environmental assessment methods

In the 1960s, the importance of ecological environment assessment attracted the attention of foreign scholars. Researchers have found that changes in land use have a significant impact on the regional ecological environment as the research field of land use expands. The use of land plays an important role in assessing the ecological environment. Since the 1990s, foreign ecological environment assessment has made rapid development in both methods and technologies, and most of them are from multiple perspectives. The United States is the first country to assess the environmental quality by building an ecological index (Hu et al., 2021); Not long ago, Canada used the indicators of air, water and land to assess the environment (Zhang, 2012); Carlson et al. (2000) applied the influence of urbanization on vegetation coverage, humidity and surface temperature to explore the causes of surface microclimate change and predict the future value of microclimate (Carlson and Arthur, 2000); Godwin et al. (2018) studied grassland coverage as an indicator of land degradation, and the results showed that soil fertility and crop output were affected by coverage (Muhati et al., 2018); XZ Yuan and YE Lin-Qi (2001) Selected eight indicators that endanger the ecological environment, built an evaluation system based on the situation of the study area, and analyzed the status of the ecosystem in the study area (Yuan and Lin-Qi, 2001); Sharma T (2001) applied remote sensing monitoring technology to study the change of vegetation coverage before and after coal mining and evaluated the ecological environment (Sharma et al., 2001); Majid. A and Syafinie (2012) found that land use would have a strong impact on local ecosystems through the analysis of land use change, and further analyzed the global greenhouse gas imbalance (Majid and Syafinie, 2012); Chandana et al. (2016) used remote sensing index to analyze the wetland cover types in the basin area of northeast India and found that the impact of land use on wetlands will increase with the increase of wetland eutrophication (CHANDANASARMADILIPKUMARDEKA, 2016). Bayramoglu (2018) used aerial photos and remote sensing images to evaluate the impact of land use change on the ecological environment at the landscape scale (Bayramoglu and Kadiogullari, 2018). However, these methods and theories of environmental assessment have more or fewer defects.

At present, there are few articles devoted to the impact of green agricultural development on the environment. Domestic and foreign scholars have focused their research on the development of green agriculture more on evaluating green agricultural indicators, the status quo, and the existing problems related to green agriculture. The development of green agriculture cannot be separated from the ecological environment. There is an urgent need to study the relationship between green agricultural development and the environment. This paper examines the relationship between green agriculture development and the environment from both a theoretical and empirical perspective.

3 Theoretical analysis and research hypothesis

3.1 Theoretical analysis of green agriculture development conducive to ecological environment optimization

In 2020, the No. 1 central document of the central government proposed to promote the prevention and control technology of green agriculture and promote the development of green agriculture. Greening agriculture is an important way of responding to the pressure of the ecological environment and the shortage of resources. It is also a "positive sum game" that requires both green water and green mountains as well as gold and silver mountains. Green agriculture is a new type of modern agriculture. Ecological economics is based on the advance of green technology, incorporates green high-tech methods, conserves energy, improves the agricultural ecological environment, and develops the agricultural economy. This is a mode of sustainable agricultural development that promotes a green lifestyle and impacts the environment positively. As shown in Figure 1:

1) Green agriculture avoids the excessive use of pesticides and chemical fertilizers. The development of green agriculture first requires reducing the excessive use of pesticides and fertilizers. Compared with traditional agriculture, chemical fertilizers and pesticides are indispensable means of production for agricultural development. With the development of green agriculture in China, more and more attention is paid to green and organic agricultural products, which inevitably requires reducing the excessive use of pesticides and fertilizers in agricultural production.
2) Green agriculture is conducive to the transformation of agricultural management mode from decentralized to intensive with the transformation of agricultural production from traditional labor-intensive to green agricultural production, the degree of production intensification will continue to improve, which is conducive to centralizing the scattered pollution sources for treatment. The biggest change brought about to the environment was the change of scattered and difficult-to-control non-point source pollution to centralized and factory-type point source pollution. This change creates conditions for the implementation of economic means of pollution control and the promotion of waste recycling and harmless treatment technology.
3) Green agriculture avoids the change in the environmental function of land. Green agriculture uses modern science and technology to transform traditional agriculture. The progress of science and technology will inevitably bring about an increase in the factor return rate, improve the productivity of labor, land, and other factors, and thus avoid changing the environmental function of the land. With the continuous improvement of agricultural labor productivity, the income of farmers will gradually increase, and the number of poor rural people will gradually decrease. These are conducive to fundamentally changing people's predatory management of natural resources. Changes in the agricultural input mode and improving the technical level are important ways to prevent those living in poor mountain areas and forest edge areas from continuing to reclaim forest and grassland in ecologically fragile areas and damaging water sources.
4) Green agriculture improves the agricultural management concept, thus protecting the environment. Green agriculture uses the concept of green development to lead agriculture and promote agricultural development. This change will undoubtedly bring about a major change in the mode of agricultural growth, attach great importance to the development and utilization of resource-saving and environment-friendly technologies, further promote new

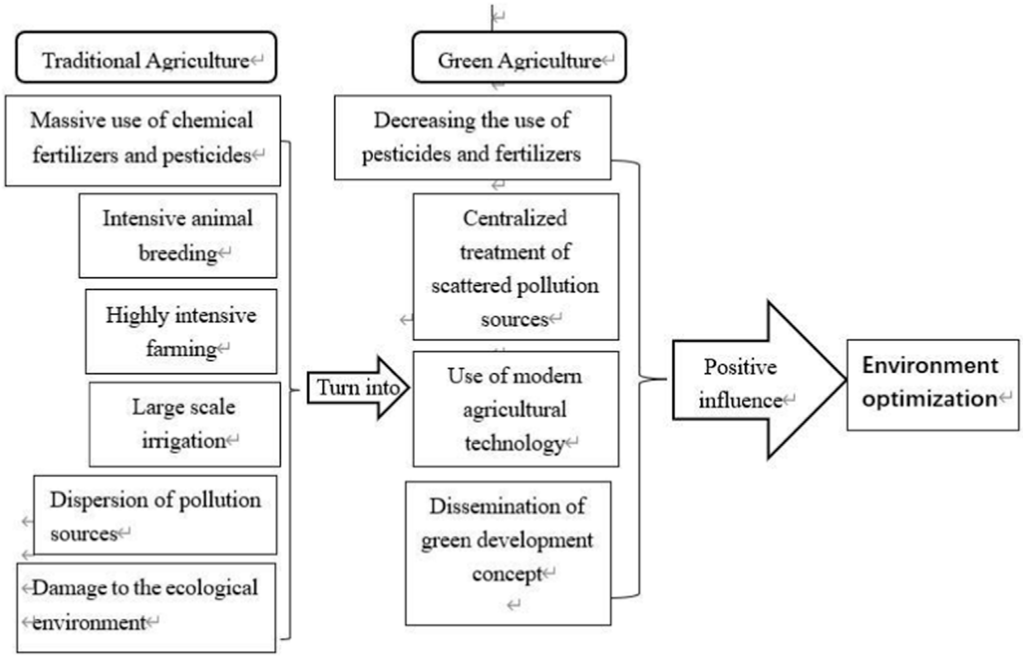

FIGURE 1
Theoritical analysis of green agriculture development on environment optimization.

agricultural forms such as circular agriculture and ecological agriculture, and also improve the environment.

3.2 Research hypothesis

Green agriculture promotes the integration of green industries. Green agriculture will promote green enterprises to improve their management model, take a global development path, and promote the integration of green industries. Industrial integration will reconfigure the production factors to form a group capital so that enterprises will have more advantages and competitiveness. The trend of various capital elements flowing into green industries has the potential to provide green industries with the funds needed to grow so as to achieve an efficient allocation of production factors across a wider range, promote the optimization and upgrading of the industrial structure, and take a path of energy conservation and environmental protection. This not only reduces the resource pressure under the high-speed development of China but also provides great help for environmental governance. Therefore, I propose hypothesis 1:

H1: The development of green agriculture promotes industrial upgrading, thus promoting environmental optimization.

Technological innovation is one of the key factors in promoting environmental optimization. The development of green agriculture promotes technological innovation. Government as the main promoter of green agriculture development has a great ability to collect information, which can be made public, including environmental credit records, a list of polluting enterprises, and other information that can be useful to investment decision-makers. At the same time, the establishment of green information systems such as green rating and certification can provide investors with accurate credit, price, cost, and other information, so that investors can quickly and accurately find green investment projects, and enterprises can also focus more on scientific and technological innovation activities. Technological innovation is conducive to the realization of pollution prevention and control from the source to the end so as to achieve good environmental protection. Therefore, I propose hypothesis 2:

H2: The development of green agriculture promotes technological innovation, thus promoting environmental optimization.

The development of green agriculture can not only influence producers, but also guide residents' green consumption behavior. Green agriculture can increase the green consumption demand of residents and promote the optimization and upgrading of the consumption structure. Green consumption can change consumer preferences, promote the development of the green industry through the market supply and demand mechanism, solve environmental protection problems from the source, and achieve optimal development of the environment. Green consumption can lead to the supply and

TABLE 1 Evaluation System of green agriculture development.

Evaluation dimension	Basic indicators	Computing method	Attribute
Ecological agriculture	Intensity of pesticide use	Pesticide use/total agricultural output value	Negative
	Intensity of fertilizer use	Fertilizer use/total agricultural output value	Negative
	Intensity of agricultural film	Agricultural film use/total agricultural output value	Negative
	Forest coverage	Forest area/land area	Positive
Green production	Share of green food label products	Quantity of green food label products/area of cultivated land	Positive
	Proportion of green enterprises	Number of green enterprises/area of cultivated land	Positive
	Water consumption per unit of agricultural output value	Agricultural water consumption/total agricultural output value	Negative
	Multiple cropping index of cultivated land	Area sown by crops/area of cultivated land	Negative
Output benefit	grain yield per unit area	Total grain output/grain sown area	Positive
	labor productivity	Total output value of agriculture, forestry, and fishery/employees in the primary industry	Positive
	Land productivity	Total agricultural output value/sown area	Positive
	per capita disposable income	statistical indicators	Positive

demand of green agricultural products marked by environmental protection, which is also an important engine for promoting environmental development. Therefore, I propose hypothesis 3:

H3: Green agriculture guides green consumption, thus promoting environmental optimization.

4 Variable selection and model construction

4.1 Variables

In this paper, the entropy weight method is used to measure the development degree of green agriculture and the environmental index of each province in China, and the regression analysis method is used to study the impact of green agriculture development on the environment. It is the purpose of this section to introduce the basic indicators and methods of green agricultural development index measurement and environmental index construction.

4.1.1 Basic indicators of green agriculture development index

This paper selects the basic indicators of green agricultural development based on the three categories of "ecological agriculture", "green development", and "output benefit", as shown in Table 1.

4.1.2 Index selection of environmental index

This paper builds the environmental index based on the three dimensions of "waste discharge", "environmental construction", and "environmental protection investment", as shown in Table 2.

4.1.3 Intermediary variable

According to the previous analysis, there are three intermediary variables in this study: industrial structure (IS), technological innovation (TI) and green consumption (GC). Variable definitions are shown in Table 3:

4.1.4 Controlled variable

According to the previous research of relevant scholars and the actual situation of the environmental impact study in this paper, the following control variables are mainly selected: Government expenditure level (general budget expenditure/regional GDP), Infrastructure construction (mileage/area of grade roads), Urbanization level and Education level. Data are from China Statistical Yearbook, and the main control variables are shown in Table 4.

4.2 Entropy method

In this paper, the entropy method is used to calculate the green agriculture development index and environmental index of 13 major agricultural provinces in China from 2011 to 2019. The specific process is as follows:

TABLE 2 Environmental assessment system.

Evaluation dimension	Basic indicators	Computing method	Attribute
Waste discharge	Emission intensity of sulfur dioxide	Sulfur dioxide emission/total industrial output value	Negative
	Wastewater discharge intensity	Wastewater discharge/total industrial output value	Negative
	Solid waste discharge intensity	Solid waste discharge/total industrial output value	Negative
Environmental Construction	Number of nature reserves	statistical indicators	Positive
	Area of Nature Reserve	statistical indicators	Positive
	Coal consumption index	Coal consumption/regional GDP	Negative
Environmental protection investment	Pollution-free treatment rate of domestic garbage	Non-pollution treatment capacity of domestic garbage/treatment capacity of domestic garbage	Positive
	Environmental protection expenditure (100 million yuan)	statistical indicators	Positive

TABLE 3 Definition of intermediary variables.

Variable name	Variable meaning	Construction method
IS	Industrial structure	Tertiary industry value/secondary industry value
TI	Technological innovation	Number of patent applications authorized
GC	Green consumption	Green consumption index

TABLE 4 Definition of main variables.

Variable name	Variable meaning	Construction method
GADI	Green agriculture development index	Green agriculture development index
GOV	Government expenditure level	General budget expenditure/regional GDP
INF	Infrastructure construction	Mileage/area of grade highway
URB	Urbanization level	Urban population/total population of each province
PRO	Education level	Proportion of Higher Education

$$x_{ij^1} = \frac{\left(x_{ij} - m_j\right)}{\left(M_j - m_j\right)} \text{Positive indicator} \tag{1}$$

$$x_{ij^1} = \frac{\left(M_j - x_{ij}\right)}{\left(M_j - m_j\right)} \text{Negative indicator} \tag{2}$$

Where, x_{ij} is the actual value of the indicator, and x_{ij^1} is the normalized value; i is the year and j is the specific index item; M_j is the maximum value of index j, and m_j is the minimum value of index j.

Calculate the proportion of index value of item j in year i:

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

Calculate the entropy value of index j:

$$e_j = -k \sum_{i=1}^{m} B_{ij} \ln B_{ij} \tag{4}$$

Calculate the entropy redundancy of index j:

$$b_j = 1 - e_j \tag{5}$$

Calculate the weight of index j:

$$w_j = \frac{b_j}{\sum_{j=1}^{n} b_j} \tag{6}$$

Calculate the comprehensive evaluation score:

$$V_i = \sum_{j=1}^{n} x_{ij^1} {}^* w_j \tag{7}$$

Where V_i represents the comprehensive index of the subsystem in year i, and x_{ij^1} represents the normalized index value.

4.3 models

4.3.1 settings of the panel model

It is not rigorous to analyze environmental change with a static relationship since it is a dynamic process. We need to use the dynamic panel model to study the dynamic relationship between the development of green agriculture and the environment. In this paper, the first-order lag term of the green agriculture development index is introduced into the model. The dynamic panel model presented in this paper is:

$$\begin{aligned} EI_{it} = \alpha + \alpha_1 EI_{it-1} + \beta_1 GADI_{it} + \beta_2 GOV_{it} + \beta_3 INF_{it} + \beta_4 URB_{it} \\ + \beta_5 PRO_{it} + \beta_6 ISSit + \beta_7 GDP_{it} + u_t + \lambda_{it} \end{aligned} \tag{1}$$

EI is the interpreted variable and represents the environmental index, α and β represent the regression coefficient, GADI represents the green agriculture development index, GOV_i represents the level of government expenditure, INF_i refers to infrastructure construction, URB_i represents urbanization level, PRO_i stands for education level, ISS stands for advanced industrial structure, and GDP stands for gross domestic product.

In order to further analyze the function mechanism of green agriculture development on ecological environment optimization, this paper uses the ecological agriculture index (EAI), green production index (GPI), and output benefit index (ObI) to conduct an empirical analysis of the ecological environment, and establishes the following models:

$$\begin{aligned} EI_{it} = \alpha + \alpha_1 EI_{it-1} + \beta_1 EAI_{it} + \beta_2 GOV_{it} + \beta_3 INF_{it} + \beta_4 URB_{it} \\ + \beta_5 PRO_{it} + \beta_6 ISSit + \beta_7 GDP_{it} + u_t + \lambda_{it} \end{aligned} \tag{2}$$

$$\begin{aligned} EI_{it} = \alpha + \alpha_1 EI_{it-1} + \beta_1 GPI_{it} + \beta_2 GOV_{it} + \beta_3 INF_{it} + \beta_4 URB_{it} \\ + \beta_5 PRO_{it} + \beta_6 ISSit + \beta_7 GDP_{it} + u_t + \lambda_{it} \end{aligned} \tag{3}$$

$$\begin{aligned} EI_{it} = \alpha + \alpha_1 EI_{it-1} + \beta_1 OBI_{it} + \beta_2 GOV_{it} + \beta_3 INF_{it} + \beta_4 URB_{it} \\ + \beta_5 PRO_{it} + \beta_6 ISSit + \beta_7 GDP_{it} + u_t + \lambda_{it} \end{aligned} \tag{4}$$

The difference GMM method and the System GMM method are primarily used to analyze the dynamic panel model. The difference GMM has a serious problem of "weak instrumental variables". The System GMM method can correct the problem of individual heterogeneity that has not been observed. Compared with the difference GMM method, the System GMM method is more widely used to estimate the parameters of panel regression. Therefore, the System GMM method is used to estimate the parameters of the dynamic panel regression model.

4.3.2 Mediation model

In order to test the mechanism and theoretical hypothesis of the previous article, this paper constructs the mediation model as shown below to test and analyze the mediation effect.

$$IS_{it} = \alpha + \theta_1 GAI_{it} + \lambda_{it} \tag{5}$$

$$EI_{it} = \alpha + \omega_1 GAI_{it} + \delta_1 IS_{it} + \gamma X_{it} + \lambda_{it} \tag{6}$$

$$TI_{it} = \alpha + \theta_2 GAI_{it} + \lambda_{it} \tag{7}$$

$$EI_{it} = \alpha + \omega_2 GAI_{it} + \delta_2 TI_{it} + \gamma X_{it} + \lambda_{it} \tag{8}$$

$$GC_{it} = \alpha + \theta_3 GAI_{it} + \lambda_{it} \tag{9}$$

$$EI_{it} = \alpha + \omega_3 GAI_{it} + \delta_3 GC_{it} + \gamma X_{it} + \lambda_{it} \tag{10}$$

Among them, IS_{it} stands for industrial structure, TI_{it} stands for technological innovation, and GC_{it} stands for green consumption. This paper uses the stepwise regression method to test the intermediary effect. The detailed test process is as follows: Step 1: Regress the benchmark Eq. 1 to test the significance of coefficient α_1. If α_1 is significant, it indicates that the overall effect of green agriculture development on environmental optimization exists, and subsequent tests are carried out. Step 2: Test the coefficients θ_i and δ_i of Eqs. 5–7, Eq. 8–10 in turn. If the coefficients θ_i and δ_i are significant, the indirect effect is significant, and go to the next step; If at least one of θ_i and δ_i is not significant, use Bootstrap test: $H_0{:}\theta_i\delta_i = 0$. If significant, then the indirect effect is significant, and turn to the third step; If not, stop the analysis. Step 3:Test whether the coefficient ω_i of Eq. 6, 8 and 10 is significant. If not, there is a complete intermediary effect; If it is significant, the direct effect is significant, and go to Step 4. Step 4: Compare the symbols of $\theta_i\delta_i$ and ω. If their symbols are the same, they will contain some intermediary effects, of which the proportion of intermediary effects in the total effects is $\theta_i\delta_i/\alpha_1$.

5 Empirical analysis

5.1 Data

In this paper, the research object is the panel data of 13 major agricultural provinces, such as Jiangsu, Shandong, Liaoning, Shanxi, and Jilin, from 2011 to 2019. Due to the impact of the epidemic in 2020, the data was not representative, so they were not used. The calculation results of the environmental index are shown in Table 5. The data are from China Statistical Yearbook, China Agricultural Statistical Yearbook, China Rural Financial Statistical Yearbook, Green Food Statistical Annual Report, etc. Some missing data are supplemented by the trend supplement method.

Table 5 shows the environmental index of each major agricultural province from 2011 to 2019. It can be seen that:

1) From the perspective of each region, there are certain differences in the environmental index of these 13 major agricultural provinces. The environmental indexes of Sichuan, Shandong, and Jiangsu are higher, while those of Inner Mongolia, Jilin, and Liaoning are lower.

TABLE 5 Calculation results of environmental index.

Region	2011	2012	2013	2014	2015	2016	2017	2018	2019	Ranking
Hebei	0.356	0.360	0.411	0.489	0.536	0.570	0.625	0.610	0.634	9
Inner Mongolia	0.395	0.376	0.455	0.575	0.508	0.577	0.556	0.563	0.570	13
Liaoning	0.496	0.518	0.547	0.564	0.583	0.601	0.623	0.615	0.629	11
Jilin	0.407	0.387	0.460	0.481	0.542	0.588	0.547	0.545	0.584	12
Heilongjiang	0.401	0.389	0.452	0.499	0.568	0.597	0.638	0.621	0.668	6
Jiangsu	0.597	0.609	0.633	0.646	0.676	0.678	0.690	0.687	0.704	3
Anhui	0.489	0.466	0.509	0.530	0.550	0.592	0.628	0.613	0.648	8
Jiangxi	0.631	0.570	0.519	0.593	0.568	0.605	0.648	0.662	0.679	5
Shandong	0.631	0.669	0.638	0.648	0.653	0.673	0.685	0.699	0.707	2
Henan	0.545	0.589	0.486	0.538	0.555	0.603	0.628	0.648	0.651	7
Hubei	0.513	0.540	0.499	0.547	0.561	0.606	0.627	0.606	0.633	10
Hunan	0.616	0.655	0.541	0.599	0.597	0.637	0.653	0.660	0.681	4
Sichuan	0.600	0.580	0.620	0.636	0.664	0.690	0.709	0.730	0.750	1

TABLE 6 Calculation results of the green agriculture development index.

Region	2011	2012	2013	2014	2015	2016	2017	2018	2019	Ranking
Heibei	0.356	0.421	0.440	0.436	0.435	0.418	0.441	0.477	0.501	11
Inner Mongolia	0.380	0.390	0.414	0.416	0.414	0.422	0.424	0.460	0.487	12
Liaoning	0.421	0.433	0.463	0.442	0.477	0.477	0.495	0.511	0.557	5
Jilin	0.467	0.480	0.493	0.490	0.492	0.472	0.477	0.484	0.515	8
Heilongjiang	0.401	0.467	0.505	0.523	0.530	0.539	0.516	0.583	0.632	2
Jiangsu	0.445	0.451	0.477	0.517	0.515	0.542	0.566	0.622	0.663	1
Anhui	0.314	0.331	0.345	0.378	0.375	0.397	0.489	0.469	0.509	10
Jiangxi	0.335	0.344	0.353	0.382	0.390	0.432	0.447	0.479	0.514	9
Shandong	0.377	0.385	0.422	0.455	0.451	0.452	0.472	0.508	0.543	7
Henan	0.328	0.336	0.346	0.363	0.371	0.374	0.393	0.419	0.442	13
Hubei	0.385	0.387	0.420	0.442	0.448	0.465	0.489	0.514	0.551	6
Hunan	0.412	0.412	0.457	0.429	0.436	0.432	0.453	0.481	0.560	4
Sichuan	0.421	0.428	0.448	0.467	0.468	0.507	0.523	0.546	0.576	3

2) On the whole, from 2011 to 2019, the environmental index of most provinces showed a stable improvement trend, which indicates that the environmental conditions of these large agricultural provinces are improving year by year.
3) The change in the environmental index of some provinces is not stable enough. For example, the environmental index of Anhui and Heilongjiang fell in 2012, then increased steadily, and then fell in some subsequent years.

Table 6 shows the green agriculture development index of each major agricultural province from 2011 to 2019. It can be seen that:

1) From the perspective of each region, there are certain differences in the green agriculture development index of these 13 major agricultural provinces. The green agriculture development index of Jiangsu, Heilongjiang, and Sichuan is higher, while that of Henan and Inner Mongolia is lower.
2) On the whole, the green agriculture development index of these 13 major agricultural provinces has increased year by year, which indicates that the green agriculture development level of these identities is getting higher and higher with the passage of time. Provinces with high green agriculture development index, such as Jiangsu and Sichuan, also rank among the top in the environmental index; Provinces whose green agriculture development needs to be improved, such

TABLE 7 Regression analysis results of the environmental impact of green agriculture development.

Variable	EI	EI	EI
	Full sample	2011–2016	2017–2019
EI (-1)	0.381*** (3.51)	0.324*** (3.35)	0.533*** (3.63)
GADI	0.583*** (3.14)	0.614*** (4.06)	0.488*** (3.47)
GOV	1.437** (2.53)	0.830** (2.17)	0.202** (1.99)
INF	0.081** (2.89)	0.164** (2.94)	0.008** (2.11)
URB	−0.026** (2.56)	−0.005** (2.19)	−0.010** (−2.53)
PRO	0.117** (2.37)	0.066* (1.89)	2.070** (1.99)
ISS	0.001 (0.33)	0.001 (0.09)	0.001** (2.31)
GDP	1.28e-06 (0.46)	−9.18e-07 (0.30)	7.47e-07 (0.67)
_cons	0.813* (1.71)	−0.468 (−0.71)	0.196 (0.06)
N	104	65	39
Hansen test	0.256	0.298	0.267
AR (2)	0.133	0.123	0.129

z statistics in parentheses.
$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

as Inner Mongolia and Hebei, also have relatively low environmental indexes.

3) The development of green agriculture in some provinces is not stable enough. Anhui's green agriculture development index dropped twice in 2015 and 2018.

5.2 Empirical results

5.2.1 Principal component regression analysis

In this paper, the System GMM method is used to estimate the parameters of the dynamic panel regression model. It is divided into one-step GMM and two-step GMM, and the two-step GMM is more effective, so it is adopted. The regression results of the green agriculture development index and environmental index are shown in Table 7.

According to Table 7, it can be seen from the System GMM analysis that after the residual is tested, the p values of the Hansen test and Arellano bond in the System GMM estimation are greater than 0.1. The p-value indicates the lowest probability level of rejecting the errors made by the original hypothesis. Therefore, the original assumptions of "all instrumental variables are valid" and "all disturbance items are not autocorrelated" cannot be rejected. That is, the model passes the correlation test, and the estimated empirical analysis results are valid. The results show that the first-order lag term of the explained variable is significantly positive in the model, which proves that the development of the environment is a gradual process. This conclusion is consistent with previous studies. It can be found that the development of green agriculture will increase by 1%, and the environmental index will increase by 0.583%, which is significant at the level of 1% significance. The level of government expenditure, infrastructure construction, education level, advanced industrial structure, and GDP have a significant positive impact on the development of the environment. The level of urbanization has a significant negative impact on the environment. Considering that factors in different time periods may have different effects on environmental optimization, which was not involved in previous studies. Further subdividing the time period, it can be found that the coefficient of the green agriculture development index from 2011 to 2016 is larger than that from 2017 to 2019, which indicates that in the early stage of the development of green agriculture, its role in improving the environment is more obvious. When green agriculture develops to a certain extent, its role in improving the environment weakens.

TABLE 8 Regression analysis results of the environmental impact of sub-dimensions of green agriculture.

Variable	EI		
	(1)	**(2)**	**(3)**
EI (-1)	0.544*** (3.27)	0.552*** (4.01)	0.449*** (3.56)
EAI	0.643*** (4.21)		
GPI		0.448*** (3.61)	
OBI			0.544*** (3.97)
Control	Control	Control	Control
_cons	0.068*(1.91)	−1.167*** (−3.75)	1.076* (2.01)
N	104	104	104
Hansen test	0.226	0.196	0.212
AR (2)	0.137	0.151	0.130

z statistics in parentheses.
$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

5.2.2 Analysis of impact mechanism

(1) Impact mechanism of ecological agriculture, green production, and output benefit on the environment

In order to further study the impact mechanism of green agricultural development on the environment, the green agricultural development index is subdivided into three aspects: ecological agriculture index (EAI), green production index (GPI), and output benefit index (ObI). In view of these three aspects, a Two-Stage System GMM regression is carried out to explore its impact on the environmental index. The results of the regression analysis are shown in Table 8.

Column (1) of Table 8 shows the regression results of green agricultural development on the environment, and columns (2)–(4) show the regression results of ecological agriculture, green production, and output efficiency on the environment index, and this is not involved in previous

TABLE 9 Regression results of the intermediary effect.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	IS	EI	TI	EI	GC	EI
GADI	3.009 *** (0.057)	0.232 *** (0.021)	2.579 ** (1.122)	0.428 *** (0.013)	2.076 *** (0.028)	0.379 *** (0.038)
IS		0.118 *** (0.069)				
TI				0.119 *** (0.002)		
GC						0.232 *** (0.057)
_cons	2.421 *** (0.112)	0.927 *** (0.313)	1.771 *** (0.346)	0.772 *** (0.232)	0.991 *** (0.228)	0.889 *** (0.211)
Control	Control	Control	Control	Control	Control	Control
AR (2)	0.322	0.327	0.412	0.245	0.347	0.288

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

studies. It can be found that for every 1% increase in green agriculture development, the ecological agriculture index will increase by 0.643%, the green production index will increase by 0.448%, and the output benefit level will increase by 0.544%, which is significant at the 1% significance level. The regression results show that the total green agriculture development index has a positive role in promoting the real economy, which is significant at the level of 1%. Moreover, ecological agriculture, green production, and output benefits can promote the development of the environment and are also significant at the level of 1%.

(2) The mechanism test of the intermediary effect

Previous studies on environmental impact factors were mostly about direct effects. According to the intermediary effect model, this study has tested the mechanisms of green agriculture development on environmental optimization, and the results are shown in Table 9. According to Table 9, the regression coefficients of industrial structure, technological innovation and green consumption are all positive and significant at the 1% significance level. This shows that industrial structure, technological innovation and green consumption are positively related to environmental optimization. Industrial structure, technological innovation, and green consumption have intermediary effects in the impact of green agriculture on environmental optimization, accounting for 30.6%, 26.4%, and 43.0% of the total effects respectively. It can be seen that green consumption accounts for the largest proportion of intermediary effects, followed by industrial structure and finally technological innovation. The reason may be that the early extensive economic growth has led to increasing pressure on China's consumption of resources and environment. From the perspective of green development measures, China's measures in the field of consumption are relatively weak, so the marginal benefit of promoting environmental optimization through green consumption is relatively large. The development of green agriculture can guide residents' usage and behavior of resources, create an environmentally friendly and resource-saving consumption mode, and effectively promote the construction of the environment. The intermediary effect of green agriculture development promoting industrial structure upgrading and promoting environmental optimization is shown in that green agriculture development promotes the development of efficient, low pollution and low energy consumption industries, and at the same time, increases the cost of high pollution and high energy consumption enterprises. Differentiated threshold restrictions will attract more capital to green industries, providing adequate financial support for their development. This will ensure an optimal allocation of resources and the upgrading and adaptation of industrial structures, and promote the construction of a green environment. In addition, the development of green agriculture can also promote environmental optimization by promoting the technological innovation of enterprises. The development of green agriculture is committed to the research, development, and promotion of new agricultural technologies, which is conducive to promoting the innovation of agricultural enterprises. Green agriculture can also rely on its own advantages to provide investors with accurate and reliable green project investment information so as to improve the utilization efficiency of resources and improve environmental quality.

6 Conclusions and policy recommendations

In this paper, the entropy weight method is used to extract the green agriculture development index in China, and the dynamic panel regression method is used to study the role and impact mechanism of green agriculture development on environmental optimization. There is a significant positive correlation between the development level of green agriculture and the environment. The development of green agriculture can also promote environmental optimization by upgrading the industrial structure, fostering technological innovation in enterprises, and guiding green consumption on the part of residents. Accordingly, the higher the level of development of green agriculture, the better the environment. The sustainable development of green agriculture can improve China's economic development mode and meet resource conservation and environmental protection demands. By further studying the impact mechanism, we can find three dimensions of green agriculture development: ecological agriculture, green production, and output efficiency. All of them have a significant role in promoting the optimization of the ecological environment. Therefore, we can improve the development level of green agriculture from these three dimensions so as to optimize the ecological environment.

Based on the existing research conclusions, this paper puts forward the following policy recommendations:

1) Promote the development of green agriculture and improve the environment. As a result of empirical analysis, we can conclude that the development of green agriculture contributes significantly to the improvement of the environment. The concept of green agriculture can be broadly divided into three segments: ecological agriculture, green production, and output benefit. The improvement of the environment can be promoted by increasing the ecological agriculture index, the green production index, and the output benefit index.

In order to achieve ecological agriculture, a sound legal and regulatory framework is necessary. Firstly, agricultural production activities should be restricted scientifically and strictly in all provinces, and those who do not apply chemical fertilizers and pesticides according to the regulations should be punished. Regulatory measures should be taken to regulate the use of agricultural film, and agricultural film with a thickness of less than 0.01 mm should be prohibited. Meanwhile, the provisions should also encourage agricultural operators to adopt a green agricultural development mode, such as encouraging straw incorporation, recycling agricultural films, and monitoring soil quality. Secondly, we should restrict the use of seeds, resolutely prohibit the promotion and sale of unapproved crop varieties, and strengthen the management of the seed market, which will prevent inferior seeds from entering the market and assure seed quality. Finally, further improving the legal system of green agriculture, standardizing the production behavior of green agriculture, standardizing the use standards and use processes of chemical fertilizers and pesticides, strengthening the management of crop seeds, developing support standards for seed research and development, and standardizing seed production and sales are also necessary.

It is necessary to have a standardized green production system in order to achieve green production. In order to create an optimized management system project, create medium- and high-end agricultural products, a standardized operation will be conducted to manage the front, middle, and rear links of agricultural production by integrating production, technology, management, logistics, and packaging. Extend the scale of vegetables and improve industrial standards in accordance with the requirements of "pollution-free, green, and organic". It is important to restrict the construction of agricultural parks with high standards and to create distinctive agricultural brands. In accordance with the requirements of "three promotion and four control" (i.e., water control, fertilizer control, drug control, pollution control, technology promotion, standard promotion, and legal system promotion), a supervision mechanism should be established. Ensure the safety of agricultural products from production to consumption and meet the needs of the masses with agricultural products that are "green + safe + high-quality".

In terms of expanding output benefits, green scientific and technological innovation can be adopted. The "14th Five Year Plan" points out that we should comprehensively promote rural revitalization, build a scientific and technological innovation system for green development, and accelerate the modernization of agriculture and rural areas. First, develop intelligent agriculture. The Internet, cloud computing, artificial intelligence, and other modern information technologies are applied to the whole process of agricultural production, and intelligent and mechanized tools are used to promote green and efficient technologies: water-saving irrigation and soilless cultivation. In the second step, circular agriculture is being developed in a more innovative manner. In order to prevent breeding and chemical pollution, we should learn from the advanced concepts and technologies of foreign countries, optimize the sustainable development mode of breeding, combine farming and breeding technologies, strengthen the promotion of recycling technology, and use green agricultural fertilizer.

2) Raise the level of government expenditure and promote technological innovation. According to the results of empirical analysis, government expenditure can promote environmental improvement. In the construction of green agriculture development, the government should give preferential assistance in policy, promote the reform of agricultural subsidy policy guided by green ecology, establish a green agricultural subsidy system, and link agricultural subsidy behavior with green agricultural production behavior. First, the government should subsidize the agricultural machinery and tools needed in green agricultural production activities to promote the process of agricultural mechanization; Secondly, subsidies should be given to the behaviors of "reducing pesticides, chemical fertilizers and herbicides" in the process of agricultural operation, and agricultural operators should be encouraged to actively change their

agricultural operation behaviors; Thirdly, the government should reform and improve the price formation mechanism of agricultural products, and coordinate the price subsidies of agricultural commodities. Finally, the government should support the scientific and technological progress of green agriculture, reward agricultural scientific and technological innovation, and provide certain financial subsidies to agricultural scientific and technological organizations.

3) Strengthen infrastructure construction and promote environmental improvement. From the above empirical analysis, it can be seen that infrastructure construction plays a positive role in promoting the improvement of the environment. In view of the low living standards of the people, infrastructure construction should be strengthened. It can be started from the following points: first, the government should do overall planning, integrate various agricultural support funds and project development funds, supervise the scope and input of funds, improve the efficiency of funds utilization, and speed up the construction of agricultural infrastructure; second, governments at all levels should increase investment in agricultural infrastructure, strive to make the annual investment of local finance in agricultural infrastructure grow faster than the growth of total fiscal revenue, and strengthen the role of fiscal funds in “guiding”, “starting” and “gathering” in infrastructure construction; third, introduce market mechanism into agricultural infrastructure construction, give full play to the flexibility of financial funds, actively innovate mechanisms, absorb credit funds and private capital, and broaden financing channels and systems. For the prefectures and cities with poor environmental conditions, it is necessary to ensure rural access communication, take the initiative to connect the local farmers with the outside world, sell their own products to expand the market, introduce developed technologies, use their own advantages to attract foreign investment, promote the transformation of agricultural development mode to green, and promote the optimization and upgrading of industrial structure to achieve the goal of improving the environment.

4) Advanced industrial structure to promote environmental improvement. First of all, we should focus on all links before, during, and after the production of agricultural products, build a standardized system integrating production, R and D, and management, create medium and high-end agricultural products, strengthen the R and D and processing of characteristic agricultural products, create well-known local trademarks, and make green agricultural brands and green food industry brands complement each other. Secondly, in the direction of “green ecology”, we should give play to the multi-functional added value of agriculture, promote the organic integration of the primary, secondary and tertiary industries, and let farmers and other new farmers use the high-added value of the secondary and tertiary industries to innovate agricultural development models and use the Internet to strengthen the application and promotion of new agricultural development models such as the combination of planting and breeding and the combination of agriculture and tourism, so as to expand agricultural development space, increase farmers’ income and improve the environment.

5) Improve green consumption system and promote green consumption. Green consumption concepts and modes are taken into consideration as important components of environmental optimization. First of all, we should promote the construction of green consumption-related infrastructure and improve the capacity of green consumption infrastructure construction by building a green consumption evaluation index system. Secondly, the concept of green consumption must be deeply rooted in the hearts of people through advertising and other methods to inspire a trend towards green consumption. Finally, strengthen the supply of green products and services. Lower the market access threshold for green agricultural products, guide the flow of funds to green agriculture, and use online platforms to promote the consumption of green agricultural products.

Due to the different development levels of green agriculture in different regions of China, there may be spatial correlation between different regions. Because of the sample size, this paper does not use spatial econometric model risk, which is the limitation of this study. Therefore, in future research, the spatial econometric model can be used to study the spatial correlation between the development level of green agriculture and the environmental index.

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

SW contributed to the writing, empirical analysis, and revision of the manuscript.

Conflict of interest

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

Publisher's note

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