Agricultural Green Development in China

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Green development is a concept of sustainable development, aiming to protect the environment and ecosystems while meeting economic development needs. In the field of agriculture, green development has emerged as a crucial pathway for reconciling the conflicts between agricultural development and ecological conservation. Agricultural green development is a globally significant topic of concern, and as one of the world's largest agricultural countries, China's progress in this area holds substantial demonstration and reference value for global agricultural sustainability. To investigate the level of green development in Chinese agriculture, regional variations, and the evolutionary patterns, this paper is based on the framework of sustainable development theory.

Keywords: agricultural green development ; regional disparities ; spatial dynamics ; evolutionary trends

1. Introduction

In recent decades, with the continuous growth in the global population and the rapid development of the economy and society, human activities have had a tremendous impact on the Earth’s environment and ecosystems. The conventional economic development model has focused solely on maximizing current benefits and short-term economic growth, leading to the excessive consumption of natural resources and the emission of waste, while neglecting the importance of environmental protection and resource conservation. This has resulted in global-scale climate change and frequent natural disasters, posing increasingly severe ecological challenges to human survival and development [1]. In the face of the escalating environmental problems and the challenges of sustainable development, the concept of green development, which emphasizes the coordinated development of economic growth and environmental protection, has garnered growing attention and recognition. The United Nations’ Sustainable Development Goals (SDGs) have incorporated green development into the global development agenda, with 56 out of 169 specific goals directly related to the green economy [2]. The International Energy Agency (IEA) is dedicated to promoting green economic growth through initiatives such as publishing global reports on green economic growth, providing policy recommendations, and supporting technological cooperation to strengthen international collaboration and foster green economic development [3]. Currently, as the global ecological environment continues to deteriorate, global agricultural development faces a series of challenges related to land degradation, water scarcity and pollution, as well as food insecurity. These challenges have a significant impact on global food security and pose a major threat to the sustainable development of agriculture.

China, as a major agricultural nation, continues to hold a significant position in the national economy. Since the introduction of economic reforms and opening up, China’s agricultural economy has experienced rapid growth. The agricultural gross value added has increased from CNY 102.75 billion in 1978 to CNY 7.834 trillion in 2021, while grain production has risen from 609.5 billion jin in 1978 to 1.3657 trillion jin in 2021. With just 7% of the world’s arable land, China manages to feed 21% of the global population, achieving remarkable accomplishments in agricultural development [4]. However, the rapid development of Chinese agriculture has also led to increasingly prominent ecological issues, such as land degradation, the eutrophication of water bodies, and excessive carbon emissions [5]. The traditional extensive development model, which relied on input-driven agricultural growth, is no longer sustainable. To address the challenges of sustainable agricultural development, China considers green development in agriculture as a crucial pathway to ensure food security and protect the ecological environment [6]. In July 2018, the Ministry of Agriculture and Rural Affairs published the “Technical Guidelines for agricultural green development. (2018–2030),” which promotes the application of green production technologies throughout the agricultural production process, including green inputs, green production techniques, and post-production value-added technologies. Since 2017, the central government of China has consistently emphasized the acceleration of green agricultural prevention and control technologies, the promotion of agricultural input reduction and efficiency improvement technologies, and the establishment of agricultural green development pilot zones and experimental bases. These measures aim to conserve agricultural resources, protect the ecological environment, and shift agricultural production from quantity-oriented to quality- and efficiency-oriented production. The 19th National Congress of the Communist Party of China highlighted the need to transition from traditional agricultural development

models to ecologically oriented agricultural production models and elevated the importance of agricultural green development to a national strategic level.

Agricultural green development embodies a conceptual and practical approach that seeks to achieve agricultural production through a sustainable, resource-efficient, and environmentally harmonious paradigm. The essence of agricultural green development lies in its emphasis on minimizing the depletion of natural resources and mitigating the adverse environmental impacts to the utmost extent during the agricultural production process. Simultaneously, it aims to enhance the quality of agricultural products and optimize the efficiency of agricultural production, leading to increased benefits and prosperity. As a comprehensive and systematic endeavor, agricultural green development encompasses a wide range of areas. Gaining a comprehensive and systematic understanding of the state of agricultural green development, is an important prerequisite and foundation for promoting its progress [7]. Measuring and analyzing the level of agricultural green development aids in monitoring and evaluating the environmental impact of agricultural activities while ensuring the sustainability of agricultural systems. It helps achieve goals related to ecosystem protection, efficient resource utilization, and future development. Additionally, measuring and analyzing the level of agricultural green development provides scientific evidence and guidance for policymakers. The application of evaluation frameworks can provide relevant information for agricultural policy formulation and decision-making, facilitating the harmonization of agricultural development with environmental sustainability, social equity, and economic growth. Therefore, research on measuring the level of agricultural green development is highly necessary.

2. The Connotation of Agricultural Green Development

From the perspective of academic research, there is currently no unified understanding of the connotation of agricultural green development. It is widely recognized as a profound transformation in the agricultural development perspective and a long-term systematic endeavor. At present, the definition of the connotation of agricultural green development remains diverse in academia. Kansanga et al. (2019) defined agricultural green development as a process that respects natural laws, utilizes advanced scientific and technological means, explores sustainable agricultural development, and achieves the harmonious integration of economic, social, and ecological benefits to mitigate the adverse impacts of climate change [8]. Alsanius et al. (2019) suggested that agricultural green development involves the use of innovative technologies to address agricultural environmental issues and maximizes the utilization of local sustainable resources. It encompasses not only climate change and greenhouse gas reduction but also broader environmental sustainability concerns [9]. Gargano et al. (2021) viewed agricultural green development as the application of various professional skills to promote cleaner production in the agricultural sector and facilitate the ecological transformation of agriculture [10]. Huang et al. (2022) regarded agricultural green development as an extension and practice of the green development concept in the agricultural field. Its primary objectives are to deepen and sustain the development of sustainable agriculture, affirm and integrate ecological and green agricultural models, and embody features such as a low carbon footprint, economic viability, and safety [11]. Liu et al. (2022) described agricultural green development as a comprehensive undertaking that encompasses six aspects: the greenization of the entire process, including agricultural production layout, resource utilization, technological means, industrial systems, agricultural product supply, and consumption [12]. Zhang et al. (2021) defined agricultural green development as a process that respects natural laws, utilizes advanced scientific and technological means, explores sustainable agricultural development, and achieves the harmonious integration of economic, social, and ecological benefits [13]. Wang et al. (2021) perceived agricultural green development as a new development concept that aims to undertake sustainable development, relies on the establishment of green institutions and innovative mechanisms, and realizes the greenization of the entire process and all aspects of agricultural production [14]. Hou et al. (2022) consider agricultural green development as an extension and practice of the green development concept in the agricultural field, with the primary objectives of deepening and sustaining the development of sustainable agriculture, affirming and integrating ecological and green agricultural models, and embodying features such as a low carbon footprint, economic viability, and safety [15]. Huang et al. (2022) portrayed agricultural green development as a comprehensive undertaking that involves the greenization of the entire process, including the agricultural production layout, resource utilization, technological means, industrial systems, agricultural product supply, and consumption [11].

3. Factors Influencing Agricultural Green Development

By means of a literature review, the factors influencing agricultural green development can be categorized into economic, policy, technological, and other factors. In terms of economic factors, Luo et al. (2023) assessed the green total factor productivity of agriculture using a non-radial and non-angular super-efficiency measurement model. Their study examined the impact of agricultural production agglomeration on green total factor productivity in agriculture and found an inverted U-shaped relationship between agricultural production agglomeration and green total factor productivity [16]. Saghaian

(2022) employed panel data from 23 developed countries and 43 developing countries to empirically analyze the impact of agricultural product exports on environmental quality. This study revealed that the expansion of agricultural product export trade had adverse effects on the environmental quality of developing countries but reduced environmental pollution, such as N2O emissions, in developed countries [17]. Xu et al. (2021) investigated the relationship between trade openness, agricultural trade, and agricultural carbon emissions using a panel threshold model. The study found a significant single threshold effect of agricultural trade openness on agricultural carbon emissions [18]. Ge et al. (2023) measured China's green total factor productivity (AGTFP) and agricultural labor surplus using the SBM-DDF–Luenberger method. They empirically examined the heterogeneous effects of urbanization on the efficiency of agricultural green development. The results showed that both household registration urbanization and permanent population urbanization significantly promoted the efficiency of agricultural green development, although the former had a smaller effect [19]. Ben Jebli M (2017) studied the relationship between agricultural product trade and agricultural sustainability using a vector error correction model (VECM) and Granger causality. The research concluded that international trade can optimize the allocation of development resources in the agricultural sector and reduce agricultural resource and environmental pollution [20]. Meanwhile, Wein ZJ (2018) used a mixed multi-regional input–output (MRIO) approach to examine the relationship between agricultural product trade and agricultural ecological environment. The findings indicated that agricultural product trade had a negative impact on agricultural green development to a certain extent [21].

In terms of policy factors influencing agricultural green development, Du et al. (2023) conducted an empirical study using panel data from Chinese prefecture-level cities between 2011 and 2020. They employed a difference-in-differences model to construct a quasi-natural experiment and investigated the impact of policies on agricultural carbon emissions. The research found that environmental protection policies significantly reduced agricultural carbon emissions by reducing emission sources [22]. Sun et al. (2022) measured the impact of environmental regulations on green total factor productivity in agriculture across 30 provinces and cities in China using a partially linear coefficient panel model. This study revealed that the impact of environmental regulations on green total factor productivity in agriculture was limited when the regional economic development level was low. However, as the regional economic development level gradually increased, the influence of environmental regulations on green total factor productivity in agriculture became more significant [23]. Wang et al. (2022) simulated the impact of various government policies on agricultural green development using a system dynamics model. They found that government policies for green development played a significant role in improving ecological benefits in agriculture [24]. Xu et al. (2022) investigated the interactive effects of environmental regulation and fiscal support for agriculture on agricultural green development using provincial panel data from China. Their study concluded that the interaction between environmental regulation and fiscal support for agriculture had a positive spatial spillover effect on agricultural green development [25].

In terms of technological factors influencing agricultural green development, Lin et al. (2023) conducted a study using interprovincial data from China. They employed the entropy method and SBM-GML index to investigate the impact of digital technology on green total factor productivity in agriculture. The research found that digital technology in agriculture can effectively promote green growth through green technological innovation, agricultural scale management, and the optimization of agricultural planting structures [26]. Zhu et al. (2022) analyzed the impact of agricultural mechanization on green total factor productivity (GTFP) in crop production using panel data from 30 provinces in China. They employed a stochastic frontier analysis based on the output-oriented distance function and found that agricultural mechanization significantly promoted green total factor productivity in crop production. As the level of mechanization increases, the promotion effect on green total factor productivity becomes more evident [27]. Zhang et al. (2022) studied the influence of agricultural technological innovation on agricultural green development from the perspectives of factor spillover pathways and product spillover pathways. The research revealed that the level of agricultural technological innovation not only improves the level of agricultural green development within a region but also promotes the agricultural green development of neighboring areas through positive spillover effects [28].

In terms of financial service factors influencing agricultural green development, Gao et al. (2022) used the GML model to measure the green total factor productivity (GTFP) in 30 provinces in China. They explored the impact of digital inclusive finance on GTFP in agriculture and its mechanisms. The research found that digital inclusive finance can indirectly help improve GTFP in agriculture by promoting agricultural technological innovation and optimizing industrial structure [29]. Hou et al. (2022) studied the role and effects of agricultural insurance on agricultural green development from an insurance perspective. The results indicated that agricultural insurance had a restraining effect on agricultural green development in China, and the impact of agricultural insurance on agricultural green development varied across different regions [30]. In contrast, Fang et al. (2021) used the SBM-GML index model based on provincial panel data from China to measure green total factor productivity in agriculture and analyzed the impact and mechanisms of agricultural insurance on GTFP. The study found that agricultural insurance significantly improved GTFP by expanding the scale of agricultural business [31]. Mei et al. (2020) conducted a sample survey to examine the constraining role of finance in agricultural green

development. The research revealed that finance had a certain degree of inhibition on agricultural green development, necessitating financial reform to alleviate its inhibitory effects on agricultural green development [32].

4. Pathways to Achieve Agricultural Green Development

Existing research in academia suggests that, under the traditional agricultural development model, excessive resource consumption and severe environmental pollution have rendered agriculture unsustainable. It is essential to comprehensively explore paths to agricultural green development, encompassing agricultural technological innovation, institutional reforms, and management models, in order to promote sustainable agricultural development goals. Jiang et al. (2022) proposed the use of organic fertilizers and biological pest control methods to protect crop health and reduce environmental pollution in agricultural production [33]. Xiu et al. (2023) suggested assisting farmers in adopting agricultural water-saving irrigation technologies such as drip irrigation, sprinkler irrigation, and rainwater harvesting to reduce water wastage and improve water use efficiency in agriculture [34]. Tan et al. (2023) proposed integrating crop cultivation and livestock farming, utilizing crop straw as feed or organic fertilizer and utilizing livestock manure as fertilizer for crops to achieve agricultural ecological recycling [35]. Luo et al. (2023) proposed establishing a tripartite cooperation model among agricultural enterprises, universities, and governments to promote agricultural technological innovation, develop new agricultural production techniques and management models, and enhance agricultural productivity and reduce the negative environmental impacts of agricultural production [36]. Qian et al. (2021) suggested implementing ecological engineering measures such as vegetation restoration, soil improvement, and soil and water conservation to restore the ecological functions of farmland, improve the quality of arable land resources, and enhance the ecological environment [37]. Zou et al. (2022) emphasized the promotion of the resource utilization of agricultural waste, such as utilizing crop straw and livestock manure for the production of biomass energy to reduce the emission of agricultural waste [38].

Lei et al. (2023) proposed the formulation of policies to address agricultural development issues such as the misallocation of agricultural capital, labor, and land with low efficiency. The government should prioritize the regional allocation of agricultural production factors and adopt a green production-oriented agricultural production concept to promote the transformation and upgrading of the agricultural industry structure and the application of green agricultural technologies, thereby facilitating agricultural green development [39]. Liu, D. et al. (2021) suggest accelerating the implementation of clean agricultural production, increasing investment in agricultural science and technology research and development, establishing a more open platform for foreign trade, expanding the level of agricultural openness, and formulating policies to promote the deep integration of industry and agriculture, all aimed at enhancing green total factor productivity in agriculture [40]. Jiang et al. (2022) propose leveraging the development of the digital economy to achieve the integration of digital technology and agricultural production. The government should fully leverage the radiating role of the digital economy, share its dividends, and vigorously implement the digital economy development strategy to bridge the digital divide between regions. Policies should be implemented to drive the construction of rural digital infrastructure and empower agricultural green development through digital economic development [41]. Mo et al. (2023) suggested actively developing green finance to achieve goals such as optimizing the agricultural industry structure and promoting agricultural technological progress, thus promoting the sustainable development of Chinese agriculture [42].

5. The Measurement of Agricultural Green Development Level

Constructing evaluation indicators for agricultural green development is an important method for quantitatively assessing and evaluating the level of agricultural green development. The construction of an evaluation system for agricultural green development is also a prerequisite for exploring paths and designing institutions to promote agricultural green development. Currently, there are two main approaches in academia for measuring the level of agricultural green development. The first approach involves measuring with single indicators, primarily including the green total factor productivity in agriculture and agricultural carbon intensity. Green total factor productivity in agriculture measures the level of greening in the agricultural production process based on productivity improvement and reduced resource consumption. A higher value of green total factor productivity indicates a higher level of agricultural green development. Measurement models such as non-radial directional distance function models with global benchmarks and Luenberger productivity indices are used to assess the level of agricultural green development [16][29][31][43][44][45][46][47]. On the other hand, agricultural carbon intensity measures the degree of greening in agriculture from the perspective of reducing emissions from agricultural non-point source pollution. A smaller agricultural carbon emissions value represents a higher level of agricultural green development. The carbon emissions from agriculture are examined based on a broad agricultural scope, reflecting the level of agricultural green development [48][49][50][51][52][53][54][55].

The second approach involves measuring the level of agricultural green development from multiple dimensions. As agricultural green development is a comprehensive system, involving complex content, constructing a comprehensive

evaluation indicator system for agricultural green development can encompass richer information. Chen et al. (2023) constructed 15 evaluation indicators for the agricultural green development from three dimensions: socio-economic, technological progress, and resource environment. They used the entropy weight comprehensive evaluation method to measure the level of agricultural green development [56]. Liu et al. (2020) constructed an evaluation indicator system for green agricultural production from five dimensions: agricultural supply capacity, resource utilization, environmental quality, ecosystem maintenance, and farmers' livelihoods. They used data from the Chinese Agricultural Census and statistical data from the National Statistical Yearbook to assess and analyze the level of green agricultural production. They provided suggestions for optimizing paths and upgrading green agricultural production in China [57]. Wan et al. (2023) measured the level of agricultural green development in China from four dimensions: policy greenness, industry greenness, technological greenness, and awareness greenness. They combined the Gini coefficient with the hesitant fuzzy multi-attribute decision-making method to analyze the state of agricultural green development in China [58]. Wang et al. (2021) adopted a new perspective based on the symbiosis of agricultural ecosystems to construct an evaluation indicator system for agricultural green development, including green production, green innovation, green ecological protection, and green economy. They measured and analyzed the level of agricultural green development in the Ili River Basin in China [14]. Liu, Y. et al. (2019) used panel data on agricultural production in China and constructed a five-dimensional indicator system for sustainable agricultural green development based on the population, social, economic, environmental, and resource dimensions. They used the entropy value method and coordination degree method to study the spatiotemporal dynamics and coordination of China's agricultural green development index [59].

In summary, it can be seen that the academic community has made rich research achievements in the field of agricultural green development, and some important research findings have been obtained, which provide valuable references for this study. However, there are still some limitations. Firstly, there is no unified definition of the concept of agricultural green development in the academic community. Some scholars lack theoretical basis in defining agricultural green development, and the distinction and connection between agricultural green development and sustainable agricultural development are not clearly addressed. Furthermore, as agricultural green development is a comprehensive system, involving a wide range of content, measuring the level of agricultural green development solely through green total factor productivity and agricultural carbon intensity has certain limitations. Some scholars constructing comprehensive evaluation indicator systems for agricultural green development lack theoretical frameworks, and the selection of indicators may be subjective. Moreover, some scholars only conduct the simple measurement and evaluation of agricultural green development in China using indicator systems, without conducting systematic research and analysis on the regional differences, spatial evolution, and state transitions of agricultural green development in China, thus failing to fully reflect the level, regional differences, spatial variations, and evolutionary characteristics of agricultural green development in China. Finally, in terms of regional division and comparison, some scholars only divide China into simple categories such as "east, central, and west" or "grain-producing and non-grain-producing areas," neglecting the vast territory and diverse ecological environments in China, which leads to a lack of consideration of the differential impacts of ecological environmental differences on the level of agricultural green development in different regions.

Based on these considerations, this study aims to construct a comprehensive evaluation system for agricultural green development based on the theory of sustainable agricultural development. In accordance with the standards of the eight comprehensive economic regions published by the Development Research Center of the State Council of China, which are more aligned with regional economic and social development as well as geographical and environmental characteristics, this study adopts these eight economic regions as the basis for regional division. This division is considered to be more reasonable. This study will employ various methods, including entropy value and the TOPSIS weighting method, Dagum Gini coefficient and its decomposition method, kernel density estimation method, Moran's I index method, and Markov chain method to analyze the regional differences, their sources, and the spatiotemporal dynamic evolution trends of agricultural green development in China.

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