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Original Research

Agricultural Science and Technology Innovation and Agricultural Green Development: China's Experience

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Abstract

This study focuses on the impact of agricultural science and technology innovation and its decomposition indicators on green agricultural development, providing valuable insights not only for China but also for other countries to further optimize agricultural technological innovation and empower green agricultural development. The research finds that agricultural science and technology innovation and its decomposition indicators have a significant positive impact on agricultural green development, and this research conclusion remains robust after replacing the explained variables and conducting endogeneity tests. Meanwhile, although there are certain differences in the level of agricultural green development among sample regions, the significant positive impact of agricultural science and technology innovation and its decomposition indicators on agricultural green development holds true in different regions. Mechanism tests indicate the existence of an intermediary mechanism through which agricultural science and technology innovation and its decomposition indicators promote agricultural green development by enhancing the levels of human capital and urbanization.

Keywords: agricultural science and technology innovation, agricultural green development, human capital, urbanization

Introduction

Green development is an extension of sustainable agriculture [1] and contributes to the overall progress of the economy and society [2]. Technological innovation can promote green development [3], and agricultural science and technology innovation is a key influencing factor for agricultural green development. On one hand, due to threats such as climate and pests, agricultural development often faces risks such as low predictability of production, high susceptibility to spoilage, and minimal control over production units, which necessitate agricultural science and technology innovation to improve functionality and overcome constraints [4]. On the other hand, agricultural production not only consumes natural resources but also

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generates pollutants, increasing environmental pressure. From the perspective of sustainable development, it is necessary to utilize agricultural science and technology innovation to reduce consumption, minimize pollution emissions, and restore damaged environments, thereby pursuing the path of green development and achieving the unity of economic and ecological benefits. Some scholars, while focusing on agricultural science and technology innovation, have also discussed other related factors. For example, the paper emphasized the utility generated by the combination of agricultural science and technology innovation with institutional, organizational, and policy innovations in agricultural development [5]. Considering factors such as environmental management, profits, and commerce, the paper found that agricultural technological progress can help achieve sustainable green development in agriculture [6]. Based on a research project implemented in Benin and Ghana from 2002 to 2006, the paper comparatively analyzed the effects of participatory technology development and institutional change [7].

As a core content of China's rural agricultural development, green development should not only play a role as a safety barrier but also serve as a catalyst for the internal transformation of resource values [8]. At present, the greenization of policies supporting agricultural green development in China is continuously strengthening, and the policy system is constantly being reinforced [9]. In recent years, China has increasingly emphasized the impact of agricultural technological innovation on green agricultural development. By employing both policy and market mechanisms and implementing a series of measures, such as promoting integrated technological innovation, accelerating the application of technologies, and improving service systems, China continues to strengthen the technological support for green agricultural development. In studies focusing on China, Zhang F. found that the improvement of the level of agricultural science and technology innovation not only significantly promotes agricultural green development in the local area but also stimulates agricultural green development in neighboring provinces through positive spillover effects [10]. The research by He X.X. verified that agricultural science and technology innovation can significantly promote the improvement of total factor productivity in agricultural green production [11]. Another study by He X.X. found a nonlinear relationship of an inverted U-shape between agricultural technological progress and total factor productivity in agricultural green development [12]. Li Z. believes that the enhancement of the capacity for agricultural green development mainly depends on the quality and level of agricultural technological innovation [13]. Li L. found that agricultural technology services have a significant and robust promoting effect on the adoption of green production technologies by farmers [14]. Zhang Y.F. demonstrated the role of agricultural technological innovation as an intermediary variable in the process of promoting total factor productivity in agricultural green development through the digital economy [15].

Previous studies have two main shortcomings: first, although they analyze the impact of agricultural science and technology innovation on agricultural green development, there is a lack of further exploration under the comprehensive concept of agricultural science and technology innovation; second, most studies only focus on proving the influence of agricultural science and technology innovation on agricultural green development, and the analysis of influencing mechanisms is not sufficient.

Green agricultural development is an essential component of achieving sustainable development, not only in China but also in other countries around the world. The marginal contributions of this paper are twofold: on the one hand, based on empirical analysis of the impact of agricultural science and technology innovation on agricultural green development, agricultural science, and technology innovation is decomposed into dimensions such as agricultural knowledge innovation, agricultural technology innovation, and the connection between agricultural knowledge innovation and technological innovation. The impact of these three decomposition indicators on agricultural green development is further analyzed, providing a relatively comprehensive analysis. On the other hand, this study explores the mechanisms through which agricultural science and technology innovation influence agricultural green development from the perspectives of human capital and urbanization, thereby not only increasing the diversity of such research but also providing a reference path for other countries to further optimize agricultural technological innovation to empower green agricultural development.

Experimental Procedures

Theoretical Mechanism and Research Hypothesis

The Impact of Agricultural Science and Technology Innovation on Green Agricultural Development

Science and technology innovation play a positive role in improving the quality of economic development [16, 17]; similarly, agricultural science and technology innovation has a sustained endogenous driving force for green agricultural development. Agricultural science and technology innovation is the specific manifestation of scientific and technological innovation within the agricultural sector. It is based on innovation theory, technological innovation theory, and knowledge innovation theory. This type of innovation includes key players, input, and output elements, and is characterized by strong regionality, comprehensiveness, and complexity. From the perspective of sustainable development, agricultural science and technology innovation is a crucial force driving green agricultural development. On a macro level, the development of agricultural science and technology innovation has promoted the widespread and deep understanding of green development concepts, encouraged the development of the environmental protection industry, changed agricultural development planning and design, and driven agricultural development along a green path. On a micro level, it either relies on scientific and technological innovation to find new, environmentally friendly production factors to replace traditional, polluting ones; or it reduces the pollution emissions of currently used production factors through the development of new processes and equipment; or it innovates technologies and methods to repair and improve soil, water sources, etc., that have been polluted; or it improves the quality of labor, enhancing the green production efficiency of the workforce.

From the essence of technological innovation, technological innovation is a generalization of technological innovation phenomena based on scientific discoveries, reflecting the close connection and integration of knowledge innovation (scientific discoveries) and technological innovation [18]. Based on this, agricultural science and technology innovation is decomposed into agricultural knowledge innovation, agricultural technology innovation, and the connection between agricultural knowledge innovation and technology innovation to further analyze the impact of these three decomposed indicators on green agricultural development.

From the dimension of agricultural knowledge innovation, on the one hand, knowledge has the characteristics of being imperfectly competitive and a public good, with a strong spillover effect. As specialized knowledge, agricultural knowledge innovation can generate intrinsic economic effects, giving it the momentum to promote green agricultural development. On the other hand, knowledge innovation is at the upstream of technological innovation, serving as the source of technological innovation; agricultural knowledge innovation provides theoretical guidance for agricultural technological innovation, driving the occurrence of agricultural technological innovation, providing technical support for green agricultural development, and promoting green agricultural development through agricultural technological innovation.

From the dimension of agricultural technological innovation, agricultural technological innovation promotes green agricultural development through the effect of technological progress. On one hand, agricultural technological innovation directly provides new tools, equipment, and methods for green agricultural development, achieving the advancement of production factors, improving the allocation of production factors, increasing the quantity of resources-saving and environmentally friendly factors, and promoting the improvement of green agricultural productivity through the "substitution effect". On the other hand, agricultural technological innovation increases the output of resources-saving and environmentally friendly factors, reduces the input of factors required per unit of output, alleviates the pressure of agricultural production activities on the ecological environment, and promotes the improvement of green agricultural productivity through the "scale of returns effect". Also, from the perspective of technological spillover, as technological innovation results flow from high to low, regions where agricultural technological innovation has a better promotion effect on agricultural green development will drive the development of regions with poorer promotion effects. Therefore, under the impetus of the "demonstration effect," agricultural technological innovation will promote the overall progress of agricultural green development.

From the dimension of the connection between agricultural knowledge innovation and technological innovation, the connection between knowledge innovation and technological innovation is manifested in the transformation of scientific discoveries into new technologies and their adoption, making scientific discoveries timely and effectively transformed into products and technologies, promoting the vigorous development of new technologies, new industries, and new business formats [19]. Therefore, the effective connection between agricultural knowledge innovation and technological innovation relates to the transformation of agricultural science and technology innovation achievements into real productive forces, contributing to a stronger synergy of innovation and providing a driving force for green agricultural development.

Hypothesis 1: Agricultural science and technology innovation and its decomposed indicators can effectively promote green agricultural development.

The Impact Mechanism of Agricultural Science and Technology Innovation on Green Agricultural Development

Human Capital

Knowledge and technology are the basic elements that constitute human capital. The improvement of agricultural science and technology innovation can drive the enhancement of human capital and alleviate the scarcity of human capital. On one hand, the original achievements of knowledge innovation increase the stock of knowledge. The increase in knowledge stock promotes the occurrence of knowledge spillovers. In the interaction and learning among talents, the accumulation of tacit and explicit knowledge is increased, thereby promoting the accumulation of human capital. On the other hand, the application of technological innovation results requires a higher level of human capital, thus forcing the improvement of human capital; during the application process of technological innovation results, high-quality talents not only directly learn the cutting-edge technological knowledge in the results of technological innovation but also generate new cognitions in their mutual exchanges and collisions. While further promoting the development of technological innovation, they also enhance their own knowledge, capabilities, and technical levels, realizing the appreciation of human capital.

The improvement of human capital drives the development of green agriculture. With the deep integration of cloud computing, big data, the internet, the Internet of Things, and green agricultural development, the characteristics of intelligent, informational, and digital green agricultural development become more and more obvious, and the requirements for human capital correspondingly increase. Compared to physical capital, the improvement of human capital has a more significant and longer-lasting impact on green agricultural development. On one hand, as an important production factor, high-level human capital has a stronger awareness of green and environmental protection. The improvement of human capital further promotes the popularization of the concept of green agricultural development through the path of knowledge and technology spillover. On the other hand, human capital is the core element of innovation, the inventor and creator of innovation, and its contribution value to innovation far exceeds the enhancement of the quantity of labor and physical capital [20]. High-quality human capital has stronger learning ability, innovation ability, and innovative spirit, is more likely to innovate the modes and paths of green agricultural development, and injects new energy into green agricultural development through innovation, further promoting the progress of green agricultural development. Moreover, human capital is the carrier of knowledge innovation and technological innovation, the user of scientific and technological innovation results; the higher the human capital, the lower the transaction costs of education and training, the faster the speed, and the higher the proficiency in mastering various agricultural technologies and management methods, and also more inclined to use advanced production means. Therefore, when higher human capital is directly involved in agricultural production as a labor factor, it can effectively enhance the application level of new technologies in practice, thereby improving the efficiency of green agricultural development and enhancing the competitiveness of green agricultural development.

Hypothesis 2: Agricultural science and technology innovation and its decomposed indicators promote green agricultural development by improving human capital.

Urbanization

Firstly, agricultural science and technology innovation drives urbanization development by promoting rural industrial development. On one hand, agricultural knowledge innovation provides global, directional, and regular guidance for the development of rural industries at the scientific level, and its original outcomes increase the knowledge stock of the rural industrial system. On the other hand, agricultural technological innovation strengthens the vertical linkage of the industrial chain, extends the rural industrial chain, increases the multifunctionality of rural industries, broadens the boundaries of rural industries; drives the transformation and upgrading of traditional agricultural industries, leads to a new industrial structure, enhances product added value, drives the rural industrial structure from a lower to a higher form, making the rural industrial structure more advanced and rational. The development of rural industries not only increases the fluidity of elements between urban and rural areas but also improves the symmetry of element flow between urban and rural areas, guiding more capital, technology, and other resource elements into rural areas, optimizing the equality of urban-rural element exchange, enhancing the balance of urban-rural development, achieving coordinated urban-rural development. The development of rural industries helps form small towns and industrial parks characterized by agricultural product processing, sales, logistics, and leisure tourism, not only providing industrial support for the local and nearby transfer of surplus rural labor but also promoting the local urbanization of rural residents [21]. Simultaneously, the development of rural industries brings about the improvement of rural infrastructure and the public service system, better achieving the interconnection of urban and rural infrastructure and the equalization of public services, promoting urbanization development. Secondly, agricultural science and technology innovation realize urbanization development based on the improvement of the ecological environment. Agricultural science and technology innovation focus on providing knowledge and technical support in ecological environment monitoring and early warning, water pollution prevention and control and aquatic ecosystem restoration, air pollution prevention and control, soil pollution prevention and control, ecosystem protection, and restoration, etc., solving ecological environment problems in agricultural and rural development, increasing expected outputs while reducing unintended outputs. Urbanization is a process of coordinated development of population, resources, environment, and economy. Maintaining a good state of the ecological environment system is an important support for urbanization development, and ensuring the carrying capacity of the ecological environment system relates to the sustainability of urbanization. On one hand, the improvement of the agricultural and rural ecological environment reduces the ecological environment element constraints in urbanization development, facilitating the overall governance of urban and rural ecological environments; on the other hand, the improvement of the agricultural and rural ecological environment provides a better external environment for urbanization development, promoting the green development of urbanization.

Urbanization brings about the flow and concentration of elements, affecting the process of green agricultural development. Firstly, urbanization brings more capital to green agricultural development. Due to the long investment cycle, low rate of return, high risk, and imperfect exit mechanism of agricultural investment, capital entry into the field of agricultural production and operation is somewhat limited. Urbanization attracts more capital, and under the effect of strong policy orientation, the capital flowing into agriculture will correspondingly increase, expanding the source of funds, solving the problem of insufficient funds, and relaxing the financial constraints of green agricultural development. Secondly, urbanization causes rural land transfer, thereby affecting green agricultural development. Not only does the expansion of urban areas lead to rural land transfer, but the flow of surplus rural labor, agricultural socialization services, etc., during the urbanization process also causes land transfer to occur and promotes its process. The emergence of land transfer affects green agricultural development, and as the land transfer market continues to improve, this impact will gradually increase. On one hand, compared to fragmented and small-scale operations, land transfer leading to the expansion of scale operations helps promote the application of more environmentally friendly technologies and management in production, especially larger-scale operators tend to adopt pro-environment technologies [22]; in fact, under the constraints of environmental protection policies and environmental regulations, investment in, research and development of, and adoption of environmental technologies have become key necessary conditions in the process of agricultural scaling and specialization, thereby achieving the goals of improving net energy output efficiency, reducing environmental load rates, and enhancing sustainability, ensuring the smooth operation of the agricultural ecosystem [23]. On the other hand, the establishment of land transfer contracts plays an important role in protecting the ecological function of the land, and stable land transfer contracts can significantly reduce the intensity of chemical fertilizer application by the land transferee [24]; moreover, the extension of the land transfer contract period also helps operators adopt more inter-temporal technologies, such as fallowing, restoration, etc., thereby improving the long-term productivity of the land.

Hypothesis 3: agricultural science and technology innovation, along with its specific components, propels green agricultural development by facilitating urbanization.

Model Setting

To empirically analyze the impact of agricultural science and technology innovation on green agricultural development, this study establishes the following model:

$$\mathrm{lnagd}_{it} = \alpha_0 + \alpha_1 \mathrm{lnx}_{it} + \beta_1 \mathrm{lncontrols}_{it} + \varepsilon_{it} \dots\dots \quad (1)$$

Here, i and t represent region and time, respectively; agd denotes green agricultural development; x represents the core independent variables, including agricultural science and technology innovation, agricultural knowledge innovation, agricultural technology innovation, and the integration of agricultural knowledge and technology innovation. Given the high correlation among these variables, the study employs a stepwise regression analysis approach. If α_1 is significantly positive, it indicates that the core independent variable significantly promotes agricultural green development; controls represents a set of control variables; ε_{it} represents random error terms.

Variable Description

Dependent Variable

The dependent variable of this study is green agricultural development (agd). To comprehensively reflect the state of green agricultural development, considering the complexity of green agricultural development and the availability of research data, this study refers to the "14th Five-Year National Plan for Green Agricultural Development" implemented in China in 2021. It also draws on and adjusts the existing research findings of Zou Y.Y., Su K., and He K. [25-27]. From dimensions of resource utilization, green production, ecological environment management, livelihood assurance, and economic benefits, 25 indicators were selected to construct a green agricultural development level measurement index system (Table 1), using the entropy method to calculate the green agricultural development index.

Core Independent Variables

The core independent variables of this research include agricultural science and technology innovation (asti), agricultural knowledge innovation (aki), agricultural technology innovation (ati), and the integration of agricultural knowledge and technology innovation (akti). Agricultural science and technology innovation is measured by input and output indicators, including personnel input, funding input, paper output, and patent output; specifically, full-time equivalent of agricultural R&D personnel, agricultural invention and utility model patent applications granted, Chinese agricultural science and technology papers included in major foreign search tools, and internal expenditure on agricultural research and experimental development. Agricultural knowledge innovation is measured by input and output indicators, including personnel input, funding input, and paper output; specifically, full-time equivalent of agricultural basic research and applied research R&D personnel, internal expenditure on agricultural basic research and applied research, and the number of Chinese agricultural science and technology papers included in major foreign search tools.

Agricultural technology innovation is measured by input and output indicators, including personnel input, funding input, and patent output; specifically, full-time equivalent of agricultural experimental development R&D personnel, internal expenditure on agricultural experimental development, and agricultural invention and utility model patent applications granted. The reason for using different statistical calibers for personnel and funding inputs in agricultural basic research and applied research versus agricultural experimental development is based on the goal of expanding scientific knowledge in basic and applied research, which is a process of creating knowledge, while experimental development is the process of creating new applications using or synthesizing existing knowledge, without adding to scientific knowledge. The agricultural science and technology innovation index, agricultural knowledge innovation index, and agricultural technology innovation index are calculated using the entropy method, and the coupling coordination degree model is used to calculate the coupling coordination degree between agricultural knowledge innovation and agricultural technology innovation as a proxy variable for the integration of agricultural knowledge and technology innovation.

Mechanism Variables

The mechanism variables in this study are human capital (rhc) and urbanization (urb). Human capital is measured using the total actual human capital calculated

Table 1. Evaluation indicator system for the level of green agricultural development.

Primary Indicator	Secondary Indicator	Indicator Definition
Resource Utilization	Agricultural Electricity Intensity	Agricultural electricity consumption / Total agricultural output value
	Agricultural Water Intensity	Total agricultural water usage / Total agricultural output value
	Multiple Cropping Index	Crop sowing area / Arable land area
	Per Capita Arable Land Area	Rural population / Arable land area
Green Production	Pesticide Usage Intensity	Amount of pesticides used / Crop sowing area
	Fertilizer Usage Intensity	Amount of fertilizer used / Crop sowing area
	Agricultural Film Usage Intensity	Agricultural film used / Crop sowing area
	Effective Irrigation Rate	Area of effective irrigation / Arable land area
	Agricultural Machinery Intensity	Total power of agricultural machinery / Crop sowing area
	Scale of Facility Agriculture	Area of facility agriculture / Arable land area
Ecological Environment Management	Forest Coverage Rate	Forested area / Provincial area
	Forest Stock Volume	Total volume of wood in forests
	Soil Erosion Control Rate	Area of soil erosion control / Provincial area
	Proportion of Wetland Area	Wetland area / Jurisdiction area
	Proportion of Nature Reserve Area	Nature reserve area / National land area
	Level of Ecological Afforestation	Ecological afforestation area
	Artificial Ecological Environmental Water Replenishment	Amount of artificial ecological environmental water replenishment
	Disaster Resistance Index	(Affected area - Disaster-struck area) / Affected area
	COD Emission Intensity Per Unit Output	Agricultural COD emissions / Total agricultural output value
	Ammonia Nitrogen Emission Intensity Per Unit Output	Agricultural ammonia nitrogen emissions / Total agricultural output value
Livelihood Security	Rural Medical Security	Average number of rural doctors and health workers per thousand rural population
	Rural Social Security	Minimum living security expenditure
Economic Benefits	Urban-Rural Income Ratio	Urban resident income / Rural resident income
	Contribution Rate of Agricultural Service Industry	Output value of the agricultural service industry / Primary industry output value
	Level of Development of Leisure Agriculture	Business income from leisure agriculture / Total output value of agriculture, forestry, animal husbandry, and fishery

by the Jorgenson-Fraumeni (JF) method as its proxy variable. Urbanization is represented by the proportion of the urban population as its proxy variable.

Control Variables

This research considers several factors closely related to green agricultural development as control variables, including:

Agricultural Product Circulation (apc): Links agricultural production with consumption, affecting the realization of agricultural product value and closely related to green agricultural development. Following Sun J approach, this study uses the total wholesale and retail sales of food, beverages, and tobacco products as its proxy variable [28].

Economic Openness (reo): Facilitates the efficient allocation of domestic and international resources, thereby impacting green agricultural development. This study uses the ratio of total imports and exports to the year-end population as its proxy variable.

Rural Transportation (rtf): Reflects the state of rural infrastructure construction. Since China's secondary roads connect suburban areas indirectly affecting the rural economy, and tertiary and quaternary roads directly facilitate urban-rural connections impacting the rural economy [29], this study uses the combined mileage of secondary, tertiary, and quaternary roads as its proxy variable.

Fiscal Support for Agriculture (fae): Measures the level of financial support from the government during the agricultural development process. This study uses the ratio of agricultural fiscal expenditure to the rural population as its proxy variable.

Rural Finance Level (rf): Relates to the financial support available during the process of green agricultural development. This study uses the balance of agricultural loans as its proxy variable.

Regional Economic Level (re): Influences green agricultural development at the regional level. This study uses the ratio of the year-end population to the gross regional product as its proxy variable.

These variables are crucial for understanding the multifaceted factors that contribute to green agricultural development, providing a comprehensive analysis of its determinants.

Data Source

Due to the availability of certain variable data, this study analyzes panel data from 30 provinces in China, excluding Hong Kong, Macau, Taiwan, and Tibet, for the years 2006-2021. The sample data used in this research are sourced from various yearbooks and databases, including the China Rural Statistical Yearbook, China Science and Technology Statistical Yearbook, China Statistical Yearbook, China Financial Yearbook, China Leisure Agriculture Yearbook, China Tertiary Industry Statistical Yearbook, the National Greenhouse Data System, and the China Center for Human Capital and Labor Market Research at the Central University of Finance and Economics. For the price data, the CPI index with 2006 as the base year is used to deflate the figures, thereby eliminating the impact of price factors. For certain missing data, linear interpolation is employed to complete the dataset.

Results

Baseline Regression

The baseline regression focuses on agricultural science and technology innovation, agricultural knowledge innovation, agricultural technology innovation, and the integration of agricultural knowledge and technology innovation as core independent variables, employing a two-way fixed effects model for the regression analysis. The estimated results (Table 2) indicate that the coefficients of all four core independent variables are positive and pass the 1% significance test. This outcome supports Hypothesis 1, demonstrating that agricultural science and technology innovation and its decomposed indicators can effectively promote green agricultural development.

Endogeneity Analysis

While the baseline regression has demonstrated that agricultural science and technology innovation, agricultural knowledge innovation, agricultural technology innovation, and the integration of agricultural knowledge and technology innovation significantly promote green agricultural development, there might be endogeneity issues due to bidirectional causality, omitted variable bias, measurement errors, and sample selection bias, which could lead to endogeneity bias. To alleviate potential endogeneity in the equation, this study further analyzes it using the Instrumental Variable Two-Stage Least Squares (IV-2SLS) method.

As an instrument, this study utilizes the geographical distances from provincial capitals to China's globally influential technology innovation centers (Beijing, Shanghai, Shenzhen), calculated by road distances. This instrumental variable is considered a strictly exogenous variable derived from social space. According to the estimation results (Table 3), all equations have passed the underidentification test and weak instrument variable test, and there are no overidentification issues, indicating the chosen instrumental variable is reasonably justified. The estimated coefficients for agricultural science and technology innovation, agricultural knowledge innovation, agricultural technology innovation, and the integration of agricultural knowledge and technology innovation are all positive and pass at least the 5% significance level, supporting the baseline regression conclusions. This indicates that, even after addressing endogeneity, the core independent variables still have

Table 2. Baseline regression.

Variable	Equation1	Equation2	Equation3	Equation4
asti	0.0159***	—	—	—
aki	—	0.0288***	—	—
ati	—	—	0.0333***	—
akti	—	—	—	0.0353***
apc	0.1119***	0.1174***	0.1190***	0.1208***
reo	0.0252***	0.0273***	0.0299***	0.0335***
rtf	0.1527***	0.1604***	0.1651***	0.1349***
fae	0.1530***	0.1498***	0.1738***	0.1549***
rf	0.0129	-0.0018	-0.0208	0.0100
re	0.0383**	0.0318*	0.0307*	0.0455***
c	-2.8095***	-2.8715***	-2.7722***	-2.8522***
R^2	0.4700	0.4754	0.4686	0.4730
F	59.80***	61.10***	59.45***	60.12***

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

a significant positive effect on green agricultural development.

Robustness Test

To account for the potential lag effect in green agricultural development, this paper conducts a robustness test using the lag effect. Specifically, it incorporates the lagged term of green agricultural development into the regression model to test the robustness of the baseline regression results. The estimation results reported in Table 4, where the estimated coefficients for the core independent variables (agricultural science and technology innovation, agricultural knowledge innovation, agricultural technology innovation, and the integration of agricultural knowledge and technology innovation) are all positive and pass the 1% significance level, affirm that the baseline regression outcomes are robust. This demonstrates that agricultural science and technology innovation and its decomposed indicators significantly contribute to green agricultural development.

Heterogeneity Test

Further relaxing the "regional homogeneity" assumption, this study divides the sample regions into three categories (high, medium, and low) based on the green agricultural development index, creating three sub-samples. The high-level green agricultural development regions (range: 0.201 to 0.250) include Beijing, Hebei Province, Inner Mongolia Autonomous Region, Heilongjiang Province, Shanghai, Shandong Province, Henan Province, Sichuan Province, and Yunnan Province. The medium-level regions (range: 0.160 to 0.200) include Tianjin, Shanxi Province, Liaoning Province, Jiangsu Province, Zhejiang Province, Anhui Province, Fujian Province, Jiangxi Province, Hubei Province, Hunan Province, Guangdong Province, Shaanxi Province, Gansu Province, and Xinjiang Uyghur Autonomous Region. The low-level regions (range: 0.110 to 0.160) include Jilin Province, Guangxi Zhuang Autonomous Region, Hainan Province, Chongqing, Guizhou Province, Qinghai Province, and Ningxia Hui Autonomous Region.

Table 5 presents the regression results for regions with a low level of the green agricultural development index. The estimated coefficients for the core independent variables are all positive, with agricultural science and technology innovation, agricultural knowledge innovation, and agricultural technology innovation passing the 1% significance level, and the integration of agricultural knowledge and technology innovation passing the 5% significance level. This indicates that even in regions with a lower level of the green agricultural development index, agricultural science and technology innovation and its decomposed indicators still significantly promote green agricultural development.

The results from Tables 6 and 7, which detail the regression outcomes for regions with medium and high levels of green agricultural development, respectively, demonstrate a consistent and significant pattern. In all eight equations across these sub-samples, the estimated coefficients for agricultural science and technology innovation and its decomposed indicators (agricultural knowledge innovation, agricultural technology

Table 3. Endogeneity analysis.

Variable	Equation1	Equation2	Equation3	Equation4
asti	0.1698***	—	—	—
aki	—	0.0477**	—	—
ati	—	—	0.0709**	—
akti	—	—	—	0.0884***
apc	0.1023***	0.0993***	0.1053***	0.0809***
reo	0.0172	0.0176	0.0184	-0.0022
rtf	0.1956***	0.2740***	0.2564***	0.1954***
fae	0.0067	0.0072	0.0156	0.0277
rf	-0.0009	0.0104	0.0134	0.0095
re	0.1580***	0.0641**	0.0958***	0.0566*
K-P LM	48.276***	48.946***	60.758***	33.099***
C-D Wald F	29.741***	57.446***	92.712***	29.115***
Hansen	0.411（0.5217）	0.057（0.8117）	0.928（0.3354）	0.274（0.6005）

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively; values in parentheses represent the p-values for the Hansen test.

Table 4. Robustness Test.

Variable	Equation1	Equation2	Equation3	Equation4
asti	0.0144***	—	—	—
aki	—	0.0295***	—	—
ati	—	—	0.0359***	—
akti	—	—	—	0.0452***
apc	0.1133***	0.1165***	0.1161***	0.1189***
reo	0.0318***	0.0332***	0.0366***	0.0402***
rtf	0.1845***	0.1907***	0.1894***	0.1579***
fae	0.1441***	0.1394***	0.1646***	0.1507***
rf	0.0159	0.0014	-0.0216	0.0109
re	0.0555***	0.0485***	0.0467***	0.0609***
c	-2.7635***	-2.8201***	-2.7226	-2.7807***
R^2	0.4442	0.4523	0.4486	0.4541
F	50.47***	52.14***	29.63***	52.28***

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

innovation, and the integration of agricultural knowledge and technology innovation) are positive and pass at least the 5% significance level. This indicates a significant positive impact of these variables on green agricultural development within both sub-samples.

The results of heterogeneity testing indicate that although the levels of agricultural green development vary among the sample regions, the significant positive impact of agricultural technological innovation and its decomposition indicators on agricultural green development holds true across regions at different levels, without apparent regional disparities.

Mechanism Test

This study explains the mechanism by which agricultural technology innovation and its decomposed indicators affect agricultural green development through

Table 5. Heterogeneity Test: Regions with low levels of agricultural green development.

Variable	Equation1	Equation2	Equation3	Equation4
asti	0.0605***	—	—	—
aki	—	0.0587***	—	—
ati	—	—	0.0975***	—
akti	—	—	—	0.0531**
apc	0.1398***	0.1506***	0.1467***	0.0782*
reo	0.0353***	0.0407***	0.0279*	0.0164
rtf	0.1034***	0.1243***	0.1228***	0.1312***
fae	0.3243***	0.3321***	0.3718***	0.3363***
rf	-0.1188***	-0.1190***	-0.1601***	-0.1548***
re	0.0130	0.0306	0.0056	-0.0637
c	-2.7767***	-2.7738***	-2.6869***	-0.7227
R^2	0.5572	0.5764	0.5558	0.7623
F	18.69***	20.22***	18.59***	17.73***

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 6. Heterogeneity Test: Regions with medium levels of agricultural green development.

Variable	Equation1	Equation2	Equation3	Equation4
asti	0.0277***	—	—	—
aki	—	0.0251***	—	—
ati	—	—	0.0469***	—
akti	—	—	—	0.0442***
apc	-0.0595***	-0.0516***	-0.0726***	-0.0269*
reo	0.0015	-0.0024	-0.0023	0.0007
rtf	0.0835***	0.1488***	0.1651***	0.1216***
fae	0.1517***	0.1079***	0.1188***	0.1214***
rf	0.0304**	0.0541***	0.0380**	0.0419***
re	-0.2106***	-0.2066***	-0.2213***	-0.1637***
c	-0.9184***	-0.8857***	-0.6162***	-0.9451***
R^2	0.7334	0.6775	0.6793	0.6695
F	58.60***	64.82***	65.35***	61.94***

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

the introduction of two mediating variables: human capital and urbanization.

Table 8 reports the mediation effect model estimation results, with human capital as the mediating variable. According to the estimation results, in Equations 1, 3, 5, and 7, the estimated coefficients for agricultural technology innovation, agricultural knowledge innovation, agricultural technical innovation, and the linkage between agricultural knowledge and technical innovation are positive and pass at least the 5% significance test. This indicates that the aforementioned variables have a significant positive impact on human capital, suggesting that improvements in agricultural technology innovation and its decomposed indicators can effectively enhance the level of human capital. After introducing human capital into the model, in Equations 2, 4, 6, and 8, the estimated coefficients for human capital and agricultural technology innovation

Table 7. Heterogeneity Test: Regions with high levels of agricultural green development.

Variable	Equation1	Equation2	Equation3	Equation4
asti	0.0349***	—	—	—
aki	—	0.0456***	—	—
ati	—	—	0.0437**	—
akti	—	—	—	0.0462***
apc	0.1302***	0.1938***	0.0740**	0.1457***
reo	-0.0259	-0.0477***	-0.0314	-0.0388***
rtf	0.1935***	0.2459***	0.0597	0.2062***
fae	0.1949***	0.0742*	-0.0488	0.0479
rf	0.0509***	-0.0088	0.0497***	0.0135
re	0.1649***	0.1252***	0.0635*	0.0909***
c	-2.6354***	-3.0151***	-2.8841***	-2.2691***
R^2	0.7176	0.7092	0.8104	0.6124
F	20.17***	19.36***	22.30***	30.47***

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 8. Human capital mediation effect.

Variable	Equation1	Equation2	Equation3	Equation4	Equation5	Equation6	Equation7	Equation8
rhc	—	0.2232***	—	0.1759***	—	0.2456***	—	0.1510***
asti	0.0294***	0.0085*	—	—	—	—	—	—
aki	—	—	0.0783***	0.0150**	—	—	—	—
ati	—	—	—	—	0.2100***	0.0375***	—	—
akti	—	—	—	—	—	—	0.0651**	0.0450***
apc	0.6154***	0.0006	0.6382***	0.0051	0.6235***	-0.0294	0.5631***	0.0547***
reo	0.0474**	-0.0625***	0.0108	0.0254***	0.0482**	-0.0085	0.0111	-0.0011
rtf	0.4527***	0.1269***	0.2121***	0.1230***	0.4915***	0.1012***	0.3933***	0.1450***
fae	-0.1315**	0.0908***	-0.4474***	0.2285***	-0.2134***	0.1547***	-0.5433***	0.1473***
rf	0.1871***	-0.0499***	0.2792***	-0.0509***	0.0737**	-0.0851***	0.3092***	-0.0549***
re	0.6092***	-0.0922***	0.5264***	-0.0608***	0.5722***	-0.1340***	0.5373***	0.0203
c	0.2195	-2.1602***	-3.2518***	-2.2993***	-1.0832***	-2.4593***	-0.7034**	-2.3369***
Sobel Test	0.0066***		0.0138***		0.0516***		0.0098**	
Mediation Effect / Total Effect	43.71%		47.57%		57.80%		17.85%	

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

and its decomposed indicators are positive and pass at least the 10% significance test, with the Sobel tests being significantly positive. This indicates that the enhancement of human capital can, to some extent, promote agricultural green development, implying that improving the level of human capital is a positive mechanism through which agricultural technology innovation and its decomposed indicators affect agricultural green development. Thus, the pathway from agricultural technology innovation and its decomposed indicators → human capital → agricultural green development is validated, confirming Hypothesis 2.

Table 9. Urbanization mediation effect.

Variable	Equation1	Equation2	Equation3	Equation4	Equation5	Equation6	Equation7	Equation8
urb	—	0.2622^{***}	—	0.2454^{***}	—	0.2531^{***}	—	0.3227^{***}
asti	0.0101^{***}	0.0136^{**}	—	—	—	—	—	—
aki	—	—	0.0133^{**}	0.0195^{***}	—	—	—	—
ati	—	—	—	—	0.0262^{***}	0.0271^{**}	—	—
akti	—	—	—	—	—	—	0.0371^{***}	0.0544^{***}
apc	0.0414^{***}	0.1020^{***}	0.0637^{***}	0.1399^{***}	0.0511^{***}	0.1059^{***}	0.0414^{***}	0.1549^{***}
reo	0.0182^{***}	0.0191^{**}	0.0069	0.0211^{*}	0.0141^{**}	0.0263^{***}	0.0209^{***}	0.0010
rtf	0.2557^{***}	0.0836^{***}	0.2572^{***}	0.1246^{***}	0.2564^{***}	0.1004^{***}	0.2060^{***}	0.0481^{**}
fae	-0.2575^{***}	0.2185^{***}	-0.2899^{***}	0.1990^{***}	-0.2490^{***}	0.2372^{***}	-0.2409^{***}	0.2225^{***}
rf	-0.0565^{***}	0.0277^{**}	-0.0357^{***}	-0.0158	-0.0839^{***}	-0.00004	-0.0520^{***}	0.0040
re	-0.1149^{***}	0.0677^{***}	-0.1246^{***}	0.0729^{***}	-0.1265^{***}	0.0625^{***}	-0.1330^{***}	0.1581^{***}
c	-0.4507^{***}	-2.7145^{***}	-0.9549^{***}	-2.8148^{***}	-0.5109^{***}	-2.6406^{***}	-0.5921^{***}	-2.9692^{***}
Sobel Test	0.0027^{**}		0.0033^{**}		0.0066^{**}		0.0119^{***}	
Mediation Effect / Total Effect	15.95%		14.04%		19.53%		17.92%	

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 9 presents the estimation results of the mediation effect model with urbanization as the mediating variable. According to the estimation results, in Equations 1, 3, 5, and 7, the estimated coefficients for agricultural technology innovation, agricultural knowledge innovation, agricultural technical innovation, and the linkage between agricultural knowledge and technical innovation are positive and pass at least the 5% significance test. This proves that these four variables have a significant positive impact on the level of urbanization, indicating that the enhancement of agricultural technology innovation and its decomposed indicators can lead to an increase in the level of urbanization. Equations 2, 4, 6, and 8 show the model estimation results after introducing urbanization as a mediating variable, where the estimated coefficients for urbanization and agricultural technology innovation and its decomposed indicators are positive and pass at least the 5% significance test, with the Sobel tests being significantly positive. This indicates that the improvement in the level of urbanization can, to some extent, drive the progress of agricultural green development, implying that enhancing the level of urbanization is a positive mechanism through which agricultural technology innovation and its decomposed indicators affect agricultural green development. Thus, the pathway from agricultural technology innovation and its decomposed indicators → urbanization → agricultural green development is validated, confirming Hypothesis 3.

Discussion

High-quality agricultural green development is inseparable from the support of agricultural technological innovation. At this stage, what impact do agricultural technological innovation and its decomposed variables have on agricultural green development in China? If there is an impact, what are the mechanisms? The discussion of these two questions is related to the extent to which agricultural green development is achieved in China.

Addressing the aforementioned questions, this study, based on theoretical analysis and using empirical analysis methods, examined the impact of China's agricultural technology innovation and its decomposed indicators (agricultural knowledge innovation, agricultural technical innovation, and the integration of agricultural knowledge and technology innovation) on agricultural green development. It also explored the mechanisms through which agricultural technology innovation influences agricultural green development from the aspects of human capital and urbanization.

Our findings indicate that agricultural technology innovation and its decomposed indicators significantly positively impact agricultural green development, consistent with the research conclusions of Ma X.H., Zhang T., Zhao M.J., and Gong B.L. [30-33]. This scenario is partly due to the continuous deepening of China's agricultural technological reforms, which have been notably effective [34], the ongoing optimization of agricultural technology innovation policies [35], and the significant development of agricultural technology innovation capabilities [36]. Additionally, it benefits from the solid advancement of China's agricultural green development. In recent years, China has committed to accelerating the green transformation of development modes, promoting the greening and decarbonization of economic and social development, leading to the establishment of green and low-carbon production and lifestyle models [37-40].

The examination of mechanisms revealed two pathways of impact: agricultural technological innovation and its decomposed indicators → human capital → agricultural green development, and agricultural technological innovation and its decomposed indicators → urbanization → agricultural green development. Findings related to agricultural technological innovation and its components with human capital, and human capital's impact on agricultural green development align with the research conclusions of Deng X., Fu J.H., and Yang Z.Q. [41-43]. Furthermore, studies on the relationship between agricultural technological innovation and its components with urbanization and urbanization's impact on agricultural green development are consistent with the views of Ning Q.M., Ye S., and Fang F. [44-46]. The validity of these two pathways is closely linked with the recent continuous improvements in the levels of human capital and urbanization in China.

Finally, it should be noted that although this study empirically analyzed the impact of China's agricultural technological innovation and its decomposed indicators on agricultural green development and explored the mechanisms involved, there are still limitations that necessitate further research and improvement. First, constrained by the availability of data, the construction of the indicator system for agricultural green development and agricultural technological innovation remains incomplete. Second, the analysis of the impact of agricultural technological innovation and its decomposed indicators on agricultural green development was conducted only from a linear perspective, without examining potential nonlinear relationships between them.

Conclusions

This study takes agricultural technology innovation as the entry point and further decomposes it into agricultural knowledge innovation, agricultural technology innovation, and the integration of agricultural knowledge and technology innovation to explore the impact of these variables on agricultural green development. The study finds that agricultural technology innovation and its decomposed indicators have a significant positive impact on agricultural green development, and this conclusion remains robust after replacing the dependent variable and conducting endogeneity tests. While there are some differences in the level of agricultural green development among the sample regions, the significant positive impact of agricultural technology innovation and its decomposed indicators on agricultural green development holds across regions with different levels of development, without significant regional differences. Mechanism tests show that there is a mediating mechanism through which agricultural technology innovation and its decomposed indicators promote agricultural green development by enhancing human capital and urbanization levels. This study's findings provide valuable insights for other countries attempting to enhance agricultural green development through agricultural science and technology innovation.

Policy Implications

As China's rural revitalization has entered a comprehensive advancement stage, agricultural green development faces better opportunities and greater challenges, with an urgent need for support from agricultural technology innovation. The conclusions of this study offer the following policy implications:

First, optimize agricultural technology innovation around the three dimensions of agricultural knowledge innovation, agricultural technology innovation, and the integration of agricultural knowledge and technology innovation, strengthening the driving force of agricultural technology innovation on agricultural green development. Effective improvement of the level of agricultural technology innovation to drive agricultural green development aligns with the evolutionary orientation of reality, relying mainly on the realization of these three dimensions. The key lies in three aspects: First, using universities and research institutions as carriers and focusing on the construction of agricultural disciplines to further promote the development of agricultural disciplines through the optimization of the academic environment, thereby achieving the goal of improving the level of agricultural knowledge innovation. Second, using enterprises as carriers, enhancing their innovation capabilities, conditions, initiative, and enthusiasm to elevate the level of agricultural science and technology innovation. Third, using agricultural science and technology parks as carriers, optimizing risk, benefit, talent, and supporting service mechanisms to continuously improve the collaborative innovation mechanism, strengthen and develop the bridge between agricultural knowledge innovation and technological innovation, accelerate their integration, and enhance their synergy.

Second, enhance the level of agricultural green development. Green is one of the keywords in China's rural revitalization strategy, and agricultural green development is an essential part of rural revitalization. To continue improving the level of agricultural green development, it is necessary to focus on improving resource utilization efficiency from aspects such as agricultural electricity, water use, and arable land; effectively reducing the use of pesticides, fertilizers, and agricultural films, increasing the effective irrigation rate and the scale of facility agriculture, optimizing green production behaviors; solidly managing the ecological environment in areas such as forests, wetlands, natural reserves, soil erosion, ecological environmental replenishment, disaster resilience, COD, and ammonia nitrogen emissions; consolidating livelihood protection through medical and social security; and striving to narrow the urban-rural income gap, accelerating the high-quality development of the agricultural service industry and leisure agriculture, and enhancing economic efficiency.

Third, strengthen the role of agricultural science and technology innovation in promoting agricultural green development. Firstly, focusing on the keyword “green,” provide more green achievements through agricultural science and technology innovation, effectively solve various “green bottlenecks” faced in agricultural development, and build a good support system for agricultural green development at the technological level. Secondly, continue to gradually improve the level of human capital through education, training, and other means, better play the intermediary role of human capital in supporting agricultural science and technology innovation for agricultural green development. Thirdly, promote urbanization in an orderly manner, effectively improve the quality of urbanization, further optimize the rational allocation of urban and rural resources and factors, and give full play to the intermediary role of urbanization in supporting agricultural science and technology innovation for agricultural green development. Fourthly, improve the policy supply and demand mechanism by formulating and implementing targeted policies to address the key points and difficulties in the process of agricultural science and technology innovation empowering green agricultural development, thus providing a favorable policy environment for this empowerment.

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Conflict of Interest

The authors of this article declare no conflict of interest.

References

1. KOOHAFKAN P., ALTIERI M.A., GIMENEZ E.H. Green agriculture: foundations for biodiverse, resilient and productive agricultural system. International Journal of Agricultural Sustainability. **10** (1), 61, **2012**.
2. BIANO A. Green jobs and policy measures for a sustainable agriculture. Agriculture and Agricultural Science Procedia. **8**, 346, **2016**.
3. POTER M.E., VAN DER LINDE C. Toward a new conception of the environment competitiveness relationship. The Journal of Economic Perspectives. **9** (4), 97, **1995**.
4. KABAHENDA M., KAPIRIRI M.N. Analyzing agricultural science and technology innovation systems: a case study of the banana sub-sector in Uganda. Second Ruforum Biennial Meeting, Entebbe, Uganda. **2010**.
5. ASENSO K., DAVIS K. Knowledge and innovation for agricultural development. International Food Policy Research Institute (IFPRI), Policy Brief, 11, Washington, DC. **2009**.
6. KAHN A. Green agriculture newer technologies, 1rd ed.; Agrotech Press: Jaipur, India. **3**, **2014**.
7. VAN H.A., JIGGINS J., KOSSOU D., LEEUWIS C., ROLONG N., SAKYI D.O., STRUIK P.C., TOSSOU R.C. Can convergence of agricultural sciences support innovation by resource-poor farmers in Africa? The cases of Benin and Ghana. International Journal of Agricultural Sustainability. **2** (3), 92, **2007**.
8. FENG D.M., XU T.C. The historical retrospect and logical evolution of China’s agricultural green development. Agricultural Economy. **10**, 90, **2021**.
9. LI X.M., GONG Q.W. Evolution and optimization of agricultural green development support policies since the founding of new China. Word Agriculture. **4**, 40, **2020**.
10. ZHANG F., WANG F., HAO R., WU L. Agricultural science and technology innovation, spatial spillover and agricultural green development- taking 30 provinces in China as the research object. Applied Sciences. **12**, 845, **2022**.
11. HE X.X., MA W. Spatial effect of agricultural science and technology innovation on agricultural green total factor productivity. Anhui Rural Revitalization Studies. **1**, 58, **2021**.
12. HE X.X., MAO W. Impact of agricultural technology progress on agricultural green total factor productivity: from the perspective of self – organization theory. Journal of Hebei Agricultural University (Social Sciences). **23** (6), 1, **2021**.
13. LI Z. The green development of agriculture in China: innovation and evolution. Chinese Rural Economy. **2**, 2, **2023**.
14. LI L., HAN J.L., ZHU Y.C. Dose Agricultural science and technology service promote farmers’ adoption of green production technology: moderation effect based on incentive measure. Journal of China Agricultural University. **28** (12), 232, **2023**.
15. ZHANG Y.F., JI M.X., ZHENG X.Z. Digital economy, agricultural technology innovation, and agricultural green total factor productivity. Sage Open. **8**, 1, **2023**.
16. AGHION P., HOWITT P. A model of growth through creative destruction. Econometrica. **60**, 323, **1992**.
17. KELLER W. Trade and the transmission of technology. Journal of Economic Growth. **7**, 5, **2002**.
18. HONG Y.X. Mechanism of industrial innovation and transformation of industrial structure. Economic Theory and Business Management. **11**, 5, **2015**.
19. HONG Y.X. The discussion on perfection of scientific and technological innovation system and coordinated development. Economic Perspectives. **2**, 4, **2016**.
20. KAUFFELD-MONZ M. Knowledge spillovers within regional networks of innovation and the contribution made

by public research. 45th Congress of the European Regional Studies Association, Amsterdam, Netherlands. **2005**.
21. LI X.L., RANA G.H. How does the rural industrial convergence development affect the urban-rural income gap: based on the dual perspective of rural economic growth an urbanization. Journal of Agrotechnical Economics. **8**, 17, **2019**.
22. ANDERSONG J.B., JOLLY D.A., GREEN R.D. Determinants of farmer adoption of organic production methods in the fresh-market produce sector in California: a logistic regression analysis. Western Agricultural Economics Association Annual Meeting, San Francisco, California, America. **2005**.
23. CHENG X.Y., XIN G.X., CHEN R.R., LI C.H. Impact of farmland transfer on agro-ecosystem. Chinese Journal of Eco-Agriculture. **34** (3), 335, **2016**.
24. LI B.W. The effect of the stability of land transfer contract on the fertilization intensity and environmental efficiency of the farmer who transfers in land. Journal of Natural Resources. **34** (11), 2317, **2019**.
25. ZOU Y.Y., KONG L.L., MA T.Y. Measurement of agricultural green development level and its influencing factors under the protection of black land. Journal of Northeast Agricultural University (Social Science Edition). **21** (3), 52, **2023**.
26. SU K., MENG H.B., ZHANG H. Construction of the green development indicators for agriculture and its prediction in the 14th five-year plan in China. Transactions of the Chinese Society of Agricultural Engineering. **37** (20), 287, **2021**.
27. HE K., LI F.L., ZHANG J.B., LI X.T. Green development levels and regional differences of agriculture in the Yangtze river economic belt. Journal of Huazhong Agricultural University. **40** (3), 43, **2021**.
28. SUN J. The measurement and evolution trends of the circulation efficiency of agricultural products in China: an empirical analysis based on the panel data from 1998 to 2009. China Business and Market. **25** (5), 21, **2011**.
29. ZHOU Z., DUAN J.Q., Li W.X., GENG S.Q. Rural roads construction, agricultural labor productivity, and urban-rural income gap. Economic Theory and Business Management. **42** (8), 23, **2022**.
30. MA X.H., YANG X.X. Promoting high-quality agricultural development by accelerating the formation of new quality productivetiy. Issues in Agricultural Economy. **4**, 4, **2024**.
31. ZHANG T., LEI X.K. The logical turn and pratical approach of agricultural development driven by scientific and technological innovation. Journal of University of Jinan (Social Science Edition). **33** (6), 76, **2023**.
32. ZHAO M.J., SHI H.R. Agricultural green development under carbon peak and carbon neutrality goals: implications, challenges and pathways selection. Social Science Journal. **2**, 162, **2024**.
33. GONG B.L., WANG S., DAI S.H., ZHANG S.R. Strategic thinking and research prospect of strengthening agricultural sicence & technology innovation support under the perspective of the greater food approach. Issues in Agricultural Economy. **5**, 74, **2023**.
34. GUO H.H. The significance and the next step of the reform of agricolutural science and technology system during forty years of reform and openning up. Issues in Agricultural Economy. **1**, 86, **2019**.
35. MAO S.P., YANG Y.L., LIN Q.M. The evolution and effect of Chinese agricultural science and technology innovation policies since reform and opening up: empirical data analysis from Chinese agricultural research institutions. Issues in Agricultural Economy. **1**, 73, **2019**.
36. SUN C.D., CHEN Y.Y. Evaluation and improment countermeasures of China's agricultural science and technology innovation capability in the new period. Chinese Journal of Agricultural Resources and Regional Planning. **41** (6), 91, **2020**.
37. DU Z.X., HU L.X. The Achievements and Interpretationgs of the High-quality Agricultural Development in China Since the 18th National Congress of the Communist Party of China. Chinese Rural Economy. **1**, 2, **2023**.
38. LI Z. The Green Development of Agriculture in China: Institutional Evolution and Practical Action. Seeker. **5**, 97, **2022**.
39. ZHANG L.X., BAI Y.L., SUN M.X., XU X.B. Views on Agricultural Green Production from the Perspective of System Science. Issues in Agricultural Economy. **10**, 42, **2021**.
40. GAO Q., CHEN H.Y., ZHANG X.L. Evolution and Focal Features of China's Agricultural Green Development Policies: Text Analysis Based on Attention Perspective. Resource Science. **45** (12), 2433, **2023**.
41. DENG X., WANG S.Z. Research on the impact of investment in agricultural science and technology innovation on agricultural economic growth. Dong Yue Tirbune. **41** (12), 109, **2020**.
42. FU J.H., XUE J.X. Digital village construction, rural human capital and agricultural green development. The World of Survey and Research. **1**, 15, **2024**.
43. YANG Z.Q. How does education affect agricultural green development productivity: an empirical study based on different educational forms in rural China. China Soft Science. **8**, 52, **2019**.
44. NING Q.M., HU G.Y., TANG F.H., ZENG Z.W. Correlation between technology innovation and new-type urbanization: a case study of the Changsha-Zhuzhou-Xiangtan urban agglomeration. Economic Geography. **42** (8), 81, **2022**.
45. YE S., WU D. Research on the promotion effect of new agricultural science and technology innovation to local urbanization. Scientific Management Research. **34** (6), 94, **2016**.
46. FANG F., ZHANG L.J., ZHAO J. Multiple paths of agricultural green total factor productivity improvement from the perspective of institutional grouping: a panel data analysis based on dynamic QCA. Chinese Rural Economy. **2**, 44, **2024**.