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Original Research

Construction of Diffusion Driving Mechanism of Wheat Green Production Technology Based on System Simulation: A Case Study in Hebei Province

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Abstract

Promoting the application of wheat green production technology is an important way to effectively realize the green development of the wheat industry. Here, we utilized the investigation data of microscopic farmers and members of an industrial consortium in the main wheat-producing areas of Hebei Province to conduct a systematic simulation of the diffusion of wheat green production technology based on the composition and factor relations of the diffusion system and explored its diffusion driving mechanism. The results showed that the diffusion effect of wheat green production technology could be significantly enhanced by improving the support of wheat green production technology research and development (R&D) through multiple channels, strengthening professional organization service and supervision responsibility, and improving the production skills of wheat farmers. Moreover, the diffusion mechanism of wheat green production technology should be coordinately constructed to focus on one system (improving the diffusion system of wheat green production technology) and five links (technology R&D, regulatory traceability, farmer cultivation, government support, and financial support for agriculture).

Keywords: wheat, green production technology diffusion, driving mechanism, system dynamics

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Introduction

The development of green production technology is crucial for realizing a sustainable wheat production industry [1, 2]. Green production technology encompasses pre-production, mid-production, and post-production links that ensure sustainable, high-quality wheat production. The technology involves integrating a series of sustainable modern agricultural technologies, including conservative tillage, improved variety selection, soil testing and fertilizer formulation, green pest and disease control, micro-irrigation and water saving, and green storage. The No. 1 Document of the Communist Party of China (CPC) Central Committee of 2022 and Technical Guidelines for Green Agricultural Development (2018-2030) regards key technology of green production and its application as the main task for accelerating the green and high-quality development of grain industry.

Hebei province is the main wheat-producing area in China. The province ranks among the top four in sown area, yield per unit area, and total yield. Also, leading wheat processing enterprises in China, including Jinshahe and Jinmailang, are located in Hebei Province [3]. Since 2015, Hebei provincial government has accelerated the improvement of the green wheat production technology system featuring "high quality, stable yield, water-saving, and high efficiency." The government has also vigorously guided scientific research and enterprises to jointly develop and promote green high-quality wheat varieties and supporting technologies. However, green wheat production technology has not been ideally adopted. For example, a survey of wheat farmers in Hebei Province revealed that the adoption rate of water-saving irrigation technology is only 12.16% [4]. The diffusion of green wheat production technology is dependent on many factors. Thus, there is a need to identify the factors affecting the technology and the logical relationship and action mechanism between them. Additionally, it is crucial to determine how to construct an effective driving mechanism to accelerate the application of green production technology.

According to the existing literature, research on the dissemination of green production technology has mainly focused on the mode and mechanism of technology diffusion. Regarding the adoption behavior of farmers, many scholars have explored the impact of internal driving factors (personal characteristics, family characteristics, and farmers' appreciation of the value of the technology) and external driving factors (service quality of green production technology promotion, social relation network, policy incentive and constraint, market demand for green agricultural products) [5-9]. Furthermore, scholars have summarized the typical diffusion modes of green production technology as "government+ experts+ farmers", "government+ leading enterprises+ experts+ farmers" and "government+ association+ farmers" [10, 11]. Demand-pull, incentive and constraint and technology induction mechanisms were proposed mainly from the perspectives of government, market, and technology to promote the application of green production technology synergistically [12-14]. Regarding research methods, designing the diffusion mechanism for green production technology is mainly based on qualitative analysis. Although a few researchers used the evolutionary game model to quantitatively analyze the evolutionary game path of different subjects of technological diffusion, the dynamic evolution trend of the system has not been simulated scientifically. This is due to the idealization of evolutionary game model assumptions and the limitations of the payoff matrix construction [15, 16]. The system dynamics method is superior to dealing with multi-variable, nonlinear, and complex problems since it provides a detailed explanation of the relationship between the internal and external influencing factors of the system and dynamically simulates the action mechanism of the associated key factors [17-19]. In recent years, many scholars have applied system dynamics in the diffusion of technological innovation and green agricultural development [20-22].

Although the existing literature provides a research basis for an in-depth understanding of the diffusion mechanism of green production technology, further discussion is still needed for many reasons. Firstly, studies have mainly focused on the agricultural production process while ignoring the diffusion mechanism of green production technology from a local perspective. Also, relatively few studies have focused on the perspective of the "production-life-ecology" system. Secondly, the internal mechanism and evolution law of green wheat production technology has not been systematically analyzed through quantitative analysis to identify the important driving force of technology diffusion. Therefore, from the perspective of systems science, this study regards the diffusion of green wheat production technology as a dynamic, open, and synergetic complex system. Here, we determined the causal feedback relationship of each subsystem element and established a system simulation fitting model based on the investigation data of microscopic farmers and members of the industrial consortium in the main wheat-producing areas of Hebei Province. Furthermore, we constructed the driving mechanism of technology diffusion by systematically analyzing the key driving factors of green wheat production technology diffusion. The findings of the present study provide a reference for the development of the green and high-quality wheat industry.

Theoretical Analysis

According to the technological innovation diffusion theory, technology diffusion is a complex system project in which internal and external factors continuously act to form the driving force for promoting technology application [23]. Therefore, we divided the driving forces of wheat green production technology diffusion into external environment drive and target group internal drive, as shown in Fig. 1.

Influence Mechanism of External Drive

A policy is an essential exogenous institutional variable. The government can intervene in the market price of production factors and supervise and streamline the market of green agricultural products. Also, the government can improve environmental laws and regulations of agricultural production to influence the allocation of resources, thus promoting the sharing behavior of green wheat production [24]. The modern marketing concept holds that consumer behavior should dictate the production of marketable products [25]. In recent years, consumers have gradually enhanced their awareness of green products and purchase intention, constantly driving the green transformation of the wheat industry [26]. The high added value of green wheat processing products brings more benefits to producers, further encouraging them to promote and apply green production technology to produce more green wheat products, thus stimulating green consumption. As the source of diffusion, the characteristics of wheat green production technology directly affect the diffusion effect [27]. Improving the comprehensive advantages of wheat green production technology can improve farmers' understanding of technical complexity and change their adoption behavior, leading to the extensive application of the technology.

Influence Mechanism of Internal Drive

The Rational Peasant School pointed out that the economic behavior of peasants is rational; they allocate various resources for profit maximization under the Pareto Optimality principle [28]. Therefore, the cost-benefit ratio of wheat green production technology adoption is the direct driving force affecting farmers' decision-making behavior. Affected by traditional ideas and planting habits, farmers' awareness of the ecological environment and food safety and health directly affects their cognition of green production technology [29]. The education level of farmers is a crucial factor in learning new technology [30]. Moreover, due to limited information accessed by farmers, social relationship networks and learning functions among subjects play a more critical role in technology diffusion [31]. The demonstration and communication effect of farmers adopting wheat green production technology at an early stage was an important driving force for the diffusion of green production technology.

Model Construction and Data Sources

System Boundary Determination and Basic Assumptions

System Boundary Determination

The key to building a system dynamics model is to clarify the subsystems and composition of essential elements of diffusing wheat green production technology and determine the system boundary [32]. Regarding the structure, the agricultural technology diffusion system comprises the technology supply subsystem, diffusion intermediary subsystem, adoption subsystem, and environment subsystem [33]. Currently, the primary goal of green and high-quality development of the wheat industry is to realize the coordination and unity between economic development and the ecological environment. Based on the system methodology of "production-ecology-life", this study introduces the evaluation feedback subsystem based on the original system architecture and selects "economic and ecological benefits of green production technology diffusion" as a key variable. "Production-ecology-life" system theory emphasizes technological innovation as the core to changing the extensive traditional mode of production. Therefore, a "comprehensive level of green

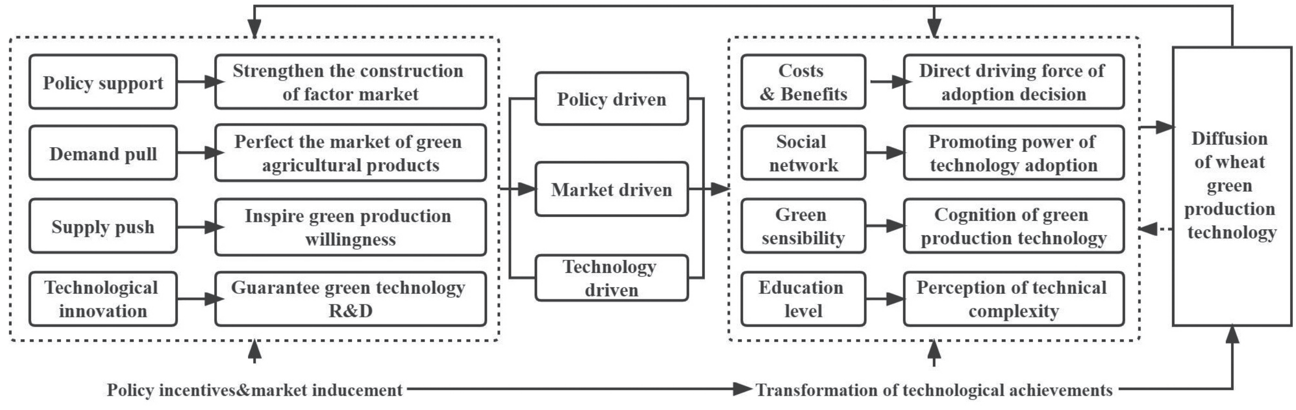

Fig. 1. Driving Mechanism of Wheat Green Production Technology Diffusion.

production technology" should be considered a crucial element of the technology supply subsystem. Sharing is the goal of coordinated development of production, life, and ecology. The "promotion service level of green production technology" should be considered in the diffusion intermediary subsystem to accelerate the transfer and industrialization sharing of wheat green production technology. The influence of "information exchange efficiency among wheat farmers" and "technology absorption capacity" on the technology diffusion effect should be emphasized in the technology adoption subsystem. As a general form of coordinated development of production, life, and ecology, green development should promote the formation of green production and lifestyle. In addition to considering the policy and financial support for the diffusion of wheat green production technology in the environmental subsystem, the "consumer purchase behavior of wheat processing products" is included in the key elements (Table 1).

Basic Assumptions of the Model

H1: Considering the complex psychological process of wheat farmers adopting green production technology, the diffusion process of wheat green production technology is divided into three stages: potential adoption, decisive adoption, and complete adoption, and each stage lasts for some time [34].

H2: The area where wheat is planted by professional planting cooperatives has reached a certain scale and remains unchanged for some time.

H3: The area where wheat is planted under the management of wheat farmers joining the cooperative is stable.

H4: Due to the influence of rural regional factors, the number of potential adopters of wheat green production technology remains unchanged.

H5: Family and price factors do not affect the absorption of green production technology by wheat farmers joining cooperatives.

H6: Leading agricultural enterprises drive the innovation and diffusion of wheat green production technology to maintain market competitiveness.

Construction of Causal Relationship Model of Wheat Green Production Technology Diffusion System

By analyzing the diffusion structure of the wheat green production technology system, the causality loop of the system was constructed based on the mainline behavior and interaction of each subject of technology diffusion (Fig. 2). The causal relationships of key variables were further sorted out using the "Causes Tree" and "Uses Tree" tools in Vensim. A comprehensive level of green production technology was used as an example to illustrate the causal feedback relationship, as shown in Figs 3 and 4.

Construction of Flow Chart Model of Wheat Green Production Technology Diffusion System

Based on the causal relationship model of the diffusion of wheat green production technology, five-level variables (the number of potential farmers adopting green production technology, the number of farmers deciding to adopt green production technology, the number of farmers completely adopting green production technology, the economic benefits of green production technology diffusion and the ecological benefits of green production technology diffusion), four rate variables (the adoption rate of green production technology, the absorption rate of green production technology, the improvement rate of ecological environment and the change rate of economic benefits), and 63 auxiliary variables, including the comprehensive level of green production technology and promotion service level of green production technology, were selected. The flow chart model showing the diffusion system of the wheat green production technology was constructed using Vensim (Fig. 5) by taking 2020-2024 as the research interval. Each parameter was assigned based on the field survey data of the main wheat-producing areas in Hebei province and statistical data sources such as "China Statistical Yearbook," "National Agricultural Product Cost-benefit Data Compilation," "Hebei Science and Technology Statistical Yearbook," "Hebei Economic Yearbook," etc. Arithmetic average,

Table 1. Composition and Key Variables of Wheat Green Production Technology Diffusion System.

Subsystem	Key Factor Variable
Technology Supply Subsystem	Comprehensive level of green production technology
Diffusion Intermediary Subsystem	Promotion service level of green production technology
Technology Adoption Subsystem	The capacity of farmers to absorb green production technology and information exchange among wheat farmers
Environmental Subsystem	Consumer purchase behavior of green wheat processing products, government investment in R&D of green production technology, agricultural technology promotion subsidies, government subsidies for technology adoption, R&D funding by financial institutions, and intellectual property protection.
Evaluation Feedback Subsystem	Economic and ecological benefits of green production technology diffusion.

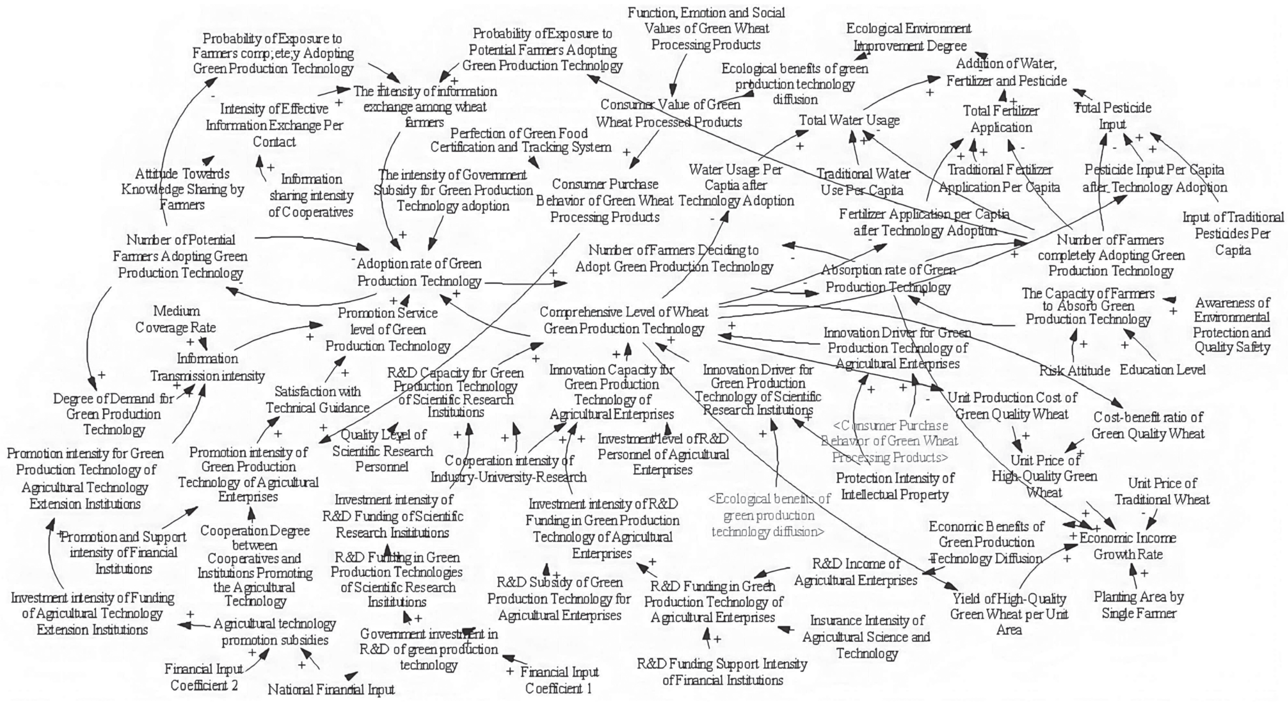

Fig. 2. Causal Relationship Model of Wheat Green Production Technology Diffusion System.

regression analysis, structural equation, and other methods were used to determine parameter assignment (Table 2) to establish the functional relationship equations of system variables. The main equations are as follows:

Number of potential farmers adopting green production technology = INTEG (adoption rate of green production technology, 150) (1)

Number of farmers deciding to adopt green production technology = INTEG (adoption rate of green production technology- technology absorption rate, 0) (2)

Number of farmers completely adopting green production technology = INTEG (absorption rate of green production technology, 0) (3)

Adoption rate of green production technology = Number of potential farmers adopting green production technology* (impact factor 2*comprehensive level of green production technology+ impact factor 1* promotion service level of green production technology + impact factor 3* information exchange intensity of farmers + the intensity of government subsidy for technology adoption *impact factor 4)/3 (4)

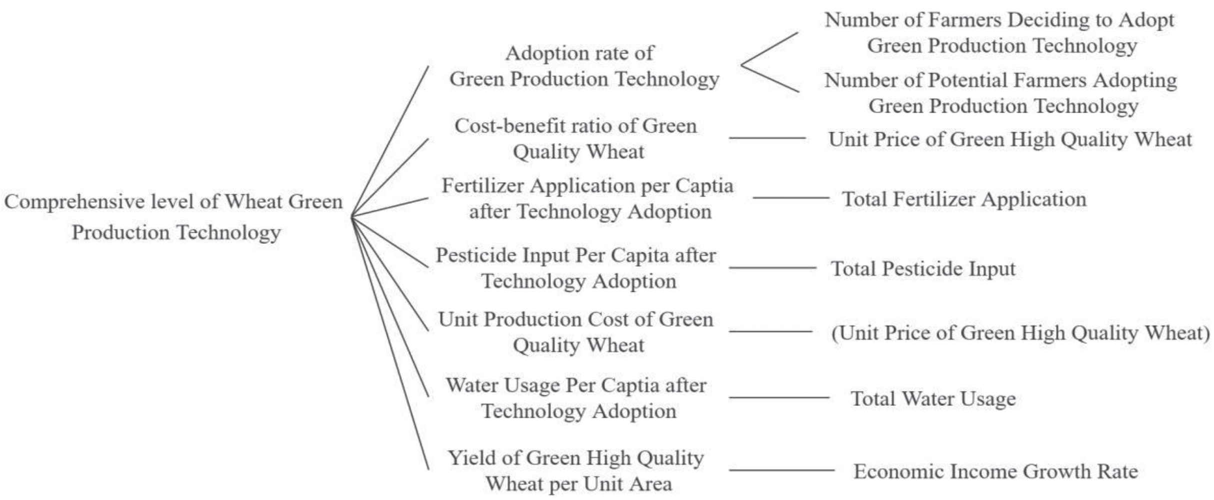

Fig. 3. Tree Diagram of Comprehensive Level of Green Production Technology.

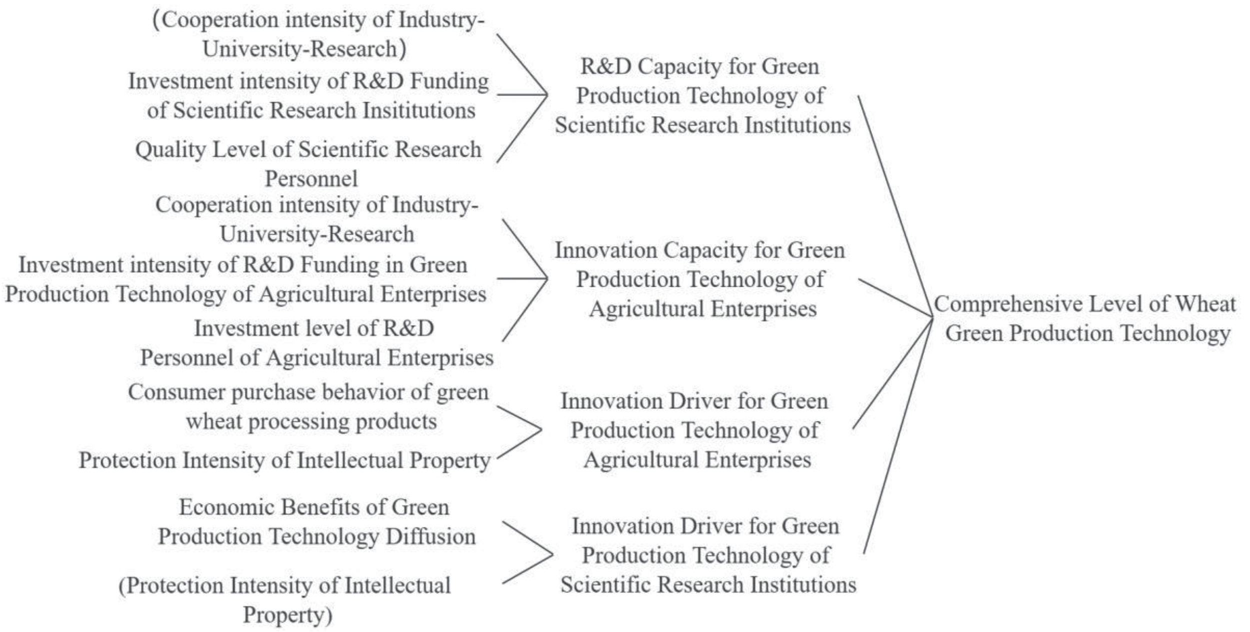

Fig. 4. Tree Diagram of Comprehensive Level of Green Production Technology.

Absorption rate of green production technology = the number of farmers deciding to adopt green production technology* green production technology absorption capacity of farmers*impact factor 5 (5)

Economic income growth rate = (unit price of high-quality green wheat- unit price of traditional wheat)*yield of high-quality green wheat per unit area*absorption rate of green production technology*planting area by a single farmer (6)

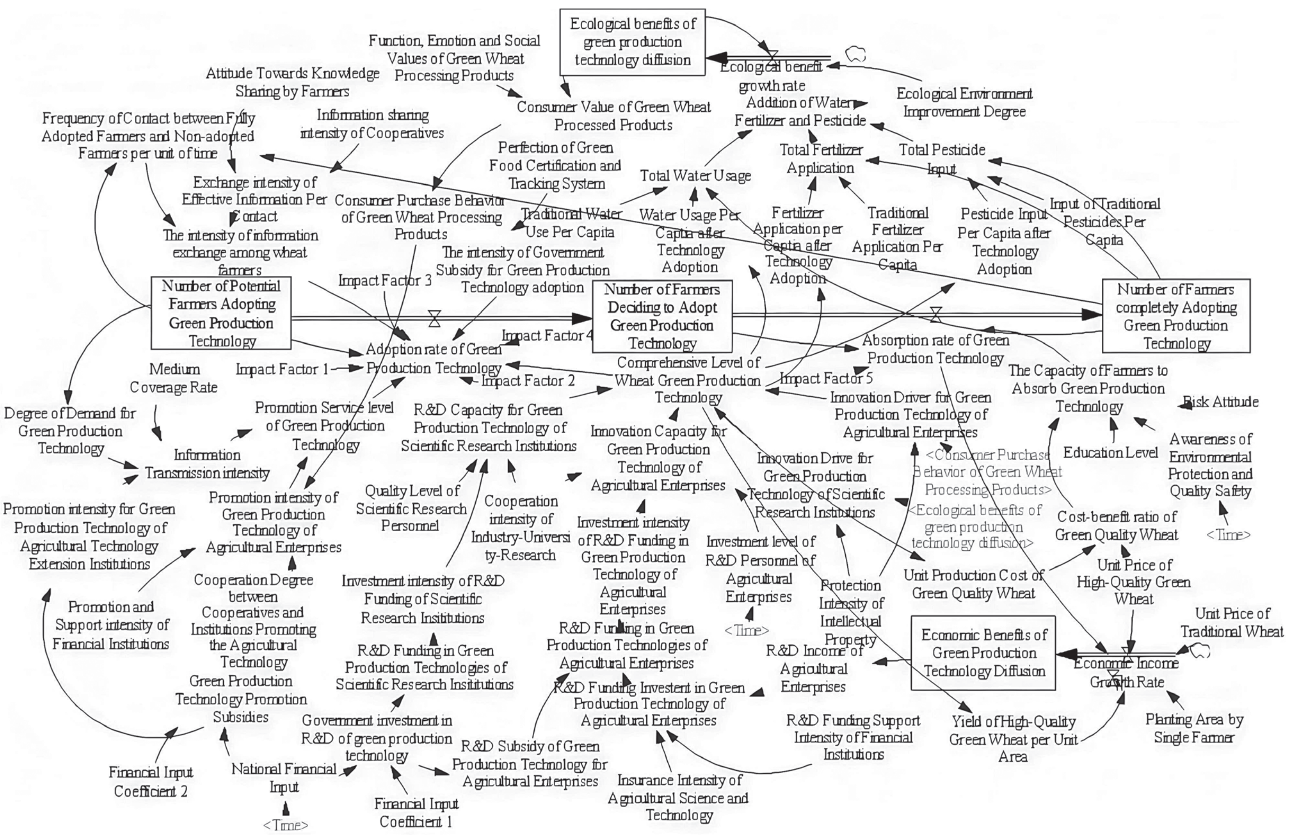

Fig. 5. Flow Chart Model of Wheat Green Production Technology Diffusion System.

Table 2. Constant Parameters of Diffusion System Model of Wheat Green Production Technology.

Variable Name	Parameter Value	Variable Name	Parameter Value
Financial Input Coefficient 1 (Dmnl)	0.00000016	Medium Coverage Rate(Dmnl)	0.7
Financial Input Coefficient 2 (Dmnl)	0.00000004	Insurance Intensity of Agricultural Science and Technology (Dmnl)	0.01
Protection intensity of Intellectual Property (Dmnl)	0.6	Attitude Towards Knowledge Sharing by Farmers(Dmnl)	1.2
The intensity of Government Subsidy for Technology Adoption (Dmnl)	0.1	Information sharing intensity of Cooperatives (Dmnl)	1.2
Green R&D Funding Support intensity of Financial Institutions (Dmnl)	0.02	Risk Attitude (Dmnl)	2.5
Quality Level of Scientific Research Personnel (Dmnl)	0.48	Education Level (Dmnl)	2.64
Cooperation Degree between Cooperatives and Institutions Promoting the Agricultural Technology (Dmnl)	0.3	Cooperation intensity of Industry-University-Research (Dmnl)	0.2
Promotion and Support intensity of Financial Institutions (Dmnl)	0.3	Planting Area by Single Farmer (mu/person)	410
Input of Traditional Pesticides Per Capita (Ton/Person)	0.2984	Unit Price of Traditional Wheat (RMB 10,000/Jin)	0.000113
Traditional Water Use Per Capita (Ton/Person)	143,500	Traditional Fertilizer Application Per Capita (Ton/Person)	9.91
Impact Factor 1 (Dmnl/Year)	0.5	Function, Emotion and Social Values of Green Wheat Processing Products (Dmnl)	0.6
Impact Factor 2 (Dmnl/Year)	0.6	Perfection of Green Food Certification and Tracking System (Dmnl)	0.7
Impact Factor 3 (Dmnl/Year)	0.2	Impact Factor 5 (Dmnl/Year)	0.9
Impact Factor 4 (Dmnl/Year)	0.4		

Economic benefits of green production technology diffusion = INTEG (economic income growth rate, 0) (7)

Ecological environment improvement degree = WITHLOOKUP (addition of water, fertilizer and pesticide, ([(1.8e + 07, 0) -(3e + 07,0.5)], (1.8e + 07, 0.45), (2e + 07,0.4), (2.1e + 07,0.3), (2.2e + 07,0.2),(2.4e + 07,0.15), (2.6e + 07,0.1), (2.8702e + 07,0))) (8)

Ecological benefit growth rate = ecological benefits of green production technology diffusion* ecological environment improvement degree (9)

Ecological benefits of green production technology diffusion = INTEG (ecological benefit growth rate, 0) (10)

Analysis of Empirical Results

Based on the structure of the diffusion system of wheat green production technology and the extraction of key variables, the effects of the diffusion of the technology in Hebei Province were simulated from five aspects, including the comprehensive level of the technology, the promotion service quality of the technology, the capacity of farmers to adopt the technology, and the support of government and financial institutions. The simulation was conducted to outline the internal mechanism and evolution law of the diffusion of wheat green production technology and identify the key driving variables of technology diffusion.

Comprehensive Level of Wheat Green Production Technology

The main indicators of the level of R&D of wheat green production technology are the investment level of R&D personnel in agricultural enterprises, cooperation between industry-university-research, and the quality of scientific research personnel. Assuming that other factors were constant, the above three indexes were adjusted to obtain Schemes 1, 2, and 3 (Table 3). Subsequently, a model simulation analysis was conducted on the three schemes. The results are shown in Fig. 6.

The comprehensive level of wheat green production technology has been significantly improved with

Table 3. Variation Scheme of Comprehensive Level Parameter of Wheat Green Production Technology.

Variables	Investment level of R&D Personnel in Agricultural Enterprises	Cooperation between of Industry-University-Research	Quality of Scientific Research Personnel
Scheme 1	Increase from 0.05 in 2020 to 0.9 in 2024	0.2	0.48
Scheme 2	Increase from 0.05 in 2020 to 0.9 in 2024	1	2.4
Scheme 3	Increase from 0.25 in 2020 to 4.5 in 2024	1	2.4

the continuous improvement in the cooperation between industry, university, and research institutions, the quality of scientific research personnel, and the investment level of R&D personnel in agricultural enterprises. This has accelerated the diffusion of wheat green production technology in Hebei Province, resulting in considerable economic benefits to green producers and improving the ecological environment. These results show that improving the efficiency of wheat green production technology enables farmers to obtain the relevant technical information accurately while reducing the complexity of the technology reduces the input of labor and capital, thus lowering the production costs. A comparison between schemes 2 and 3 shows that scheme 3 had a relatively limited improvement in the diffusion effect of green production technology in Hebei Province. Overall, these data showed that in the past five years, the R&D of wheat green production technology in Hebei Province focused on scientific research institutions as the main body, gradually encouraged agricultural enterprises to invest in basic technology of R&D, and strengthened the cooperation between industry, university, and research institutions.

Promotion Service Quality of Professional Service Organization

The promotion service quality of wheat green production technology is mainly affected by the competency of the promotion agencies, farmers' professional cooperatives, and other service organizations. Assuming that other factors are constant, three parameters which include cooperation degree between the cooperatives and institutions promoting the agricultural technology, the efficiency of information sharing by cooperatives, and perfection of green food certification and tracking system, were adjusted to obtain schemes 1, 2 and 3 (Table 4). Model simulation analysis was performed for the three schemes, and the results are shown in Fig. 7.

The diffusion of wheat green production technology in Hebei Province improved with the cooperation between cooperatives and institutions promoting agricultural technology, the increase in the intensity of information sharing by cooperatives, and the perfection of green food certification and tracking system. A comparison of schemes 1 and 2 shows that the cooperation between agricultural technology promotion

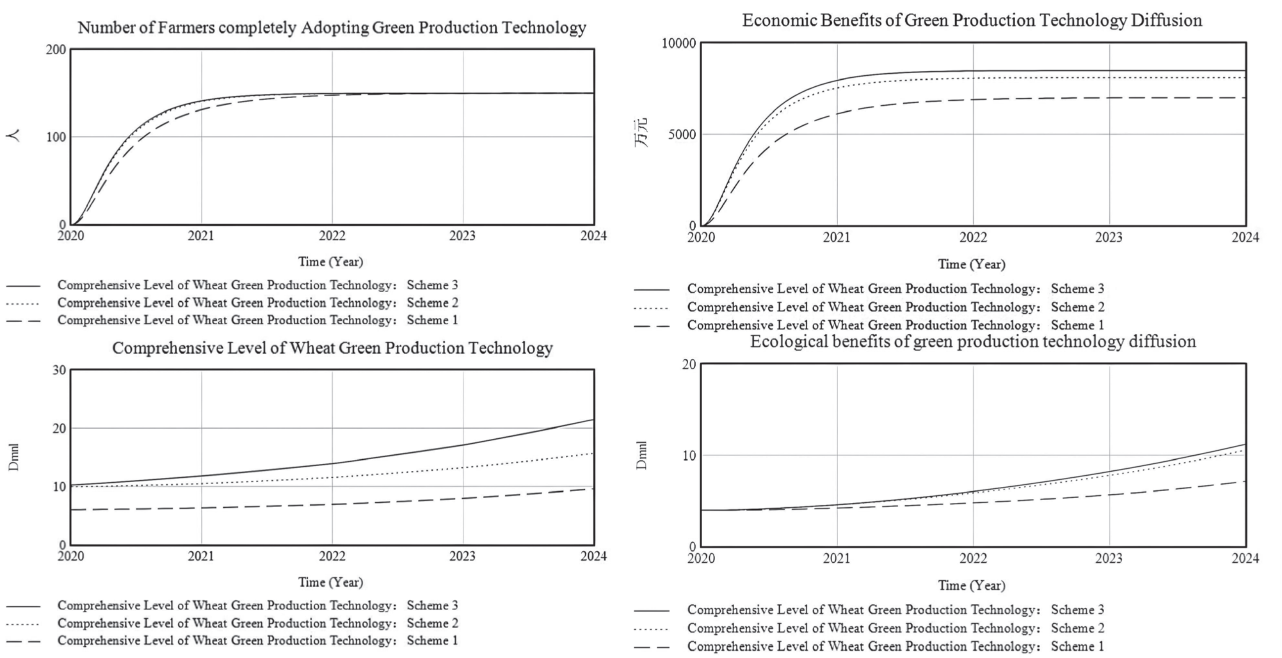

Fig. 6. Impact of Comprehensive Level of Wheat Green Production Technology on Technology Diffusion in Hebei Province.

Table 4. Variation Scheme of Technical Promotion Service Parameters of Professional Service Organizations.

Variables	Cooperation degree between cooperatives and institutions promoting the agricultural technology	Information sharing intensity of cooperatives	Perfection of green food certification and tracking system
Scheme 1	0.3	1.2	0.7
Scheme 2	1.5	6	0.7
Scheme 3	1.5	6	7

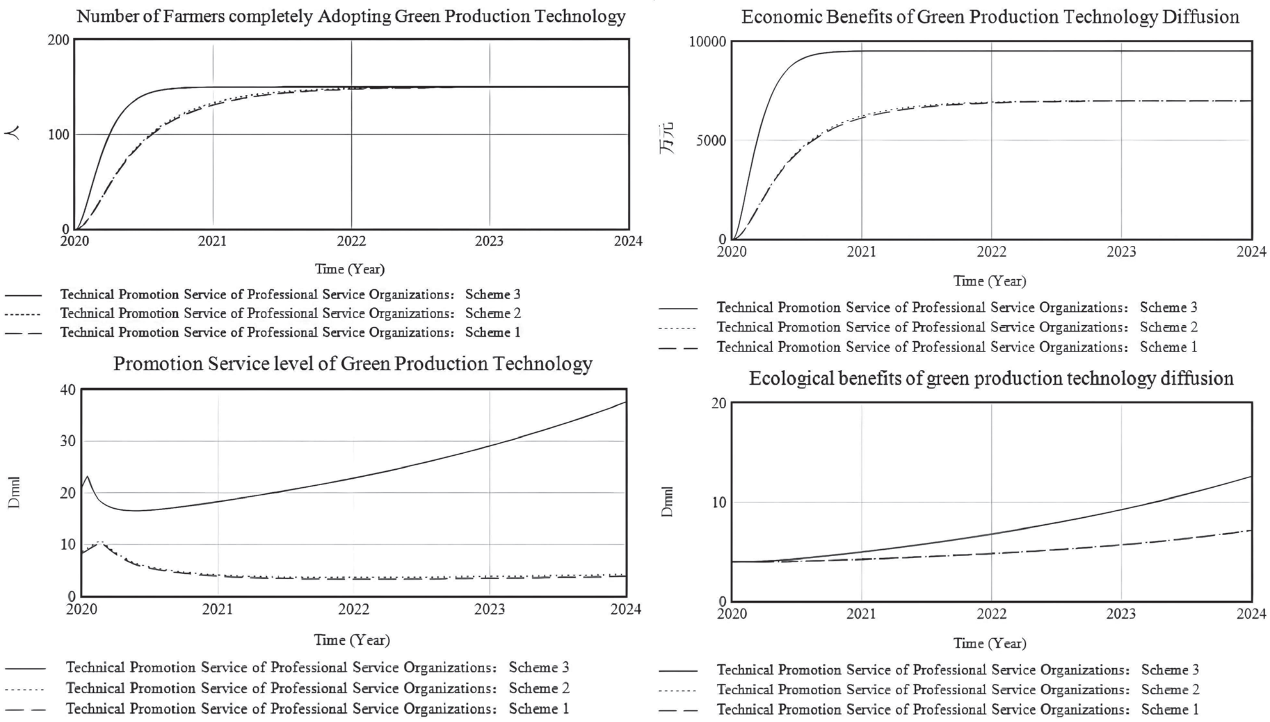

Fig. 7. Impact of Promotion Services Quality of Service Organisations on Technology Diffusion in Hebei Province.

institutions and cooperatives and the information sharing intensity of cooperatives had a very limited impact on the diffusion of wheat green production technology in Hebei Province. Notably, improving the information sharing intensity of cooperatives and the cooperation between cooperatives and institutions promoting agricultural technology resulted in a significant decline in the promotion of green production technology in Hebei Province in 2021. This could have been caused by multiple feedbacks of the diffusion system of the green production technology. Improving the efficiency of information exchange by farmers reduces the number of potential farmers adopting the technology, and decreases the demand for the technology, thus restraining the technology promotion service level. A comparison between schemes 2 and 3 shows that the perfection of green food certification and tracking system significantly improved the diffusion effect of wheat green production technology in Hebei Province. This indicates that professional service organizations monitor the wheat production behavior of farmers to guarantee the production of high-quality wheat, which is an important driving force for the diffusion of wheat green production technology.

Green Production Technology Adoption Capacity of Wheat Farmers

The ability of wheat farmers to adopt green production technology was mainly affected by their education level, risk attitude, awareness of environmental protection and quality safety, and information sharing attitude of green production technology drivers. The above four index parameters were adjusted to obtain Schemes 1, 2, 3, and 4 (Table 5) by assuming that other conditions remained unchanged. Model simulation analysis was performed for the four schemes, and the results are shown in Fig. 8.

Education level, awareness of environmental protection and agricultural product quality and safety, risk attitude, and information sharing attitude of wheat farmers affects their adoption behavior of green production technology. A comparison of schemes 1, 2, and 3 show that improving wheat farmers' awareness

Table 5. Variation Scheme of Wheat Farmer's Individual Endowment Parameters.

Variables	Education Level	Risk Attitude	Awareness of Environmental Protection and Quality Safety	Attitude Towards Knowledge Sharing by Farmers
Scheme 1	2.64	2.5	From 1.5 in 2020 to 5 in 2024	1.2
Scheme 2	2.64	2.5	From 7.5 in 2020 to 25 in 2024	6
Scheme 3	13.2	2.5	From 7.5 in 2020 to 25 in 2024	6
Scheme 4	13.2	8.35	From 7.5 in 2020 to 25 in 2024	6

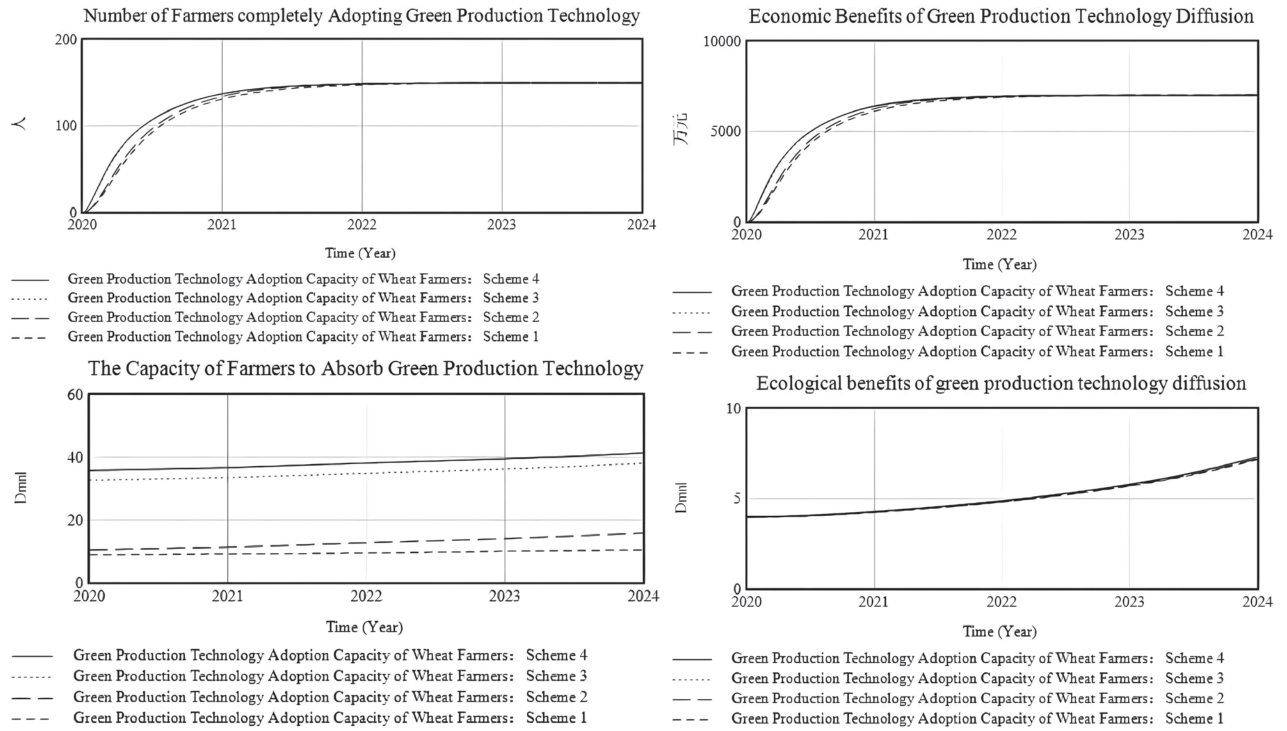

Fig. 8. Impact of Wheat Farmers' Adoption Capacity of Green Production Technology on Technology Diffusion in Hebei Province.

of environmental protection and quality safety and improving the knowledge-sharing attitude enhance the ability of farmers in Hebei Province to absorb green production technology. However, under the environmental conditions and parameters set in this study, the impact on the diffusion effect of green production technology was relatively limited. However, the educational level of wheat farmers significantly improved the economic and ecological benefits of diffusing wheat green production technology in Hebei Province. By comparing schemes 3 and 4, the risk attitude parameter of wheat farmers was adjusted by more than 2.5. Although it can improve the absorption capacity of green production technology of wheat in Hebei Province, the increase in risk preference of wheat farmers increases the number of early adopters of green production technology while gradually reducing the number of late adopters. This reduces the growth rate of economic benefits of green production technology diffusion and finally reduces the effect of the technology diffusion.

Support Intensity of Government Policy

The government support intensity refers to the funds and related support for the R&D provided by the government. In this case, the support is geared towards applying wheat green production technology. Assuming that other factors are constant, the governmental financial input coefficient, subsidy intensity of technology adoption, and protection intensity of intellectual property were adjusted to obtain schemes 1, 2, 3, and 4 (Table 6). Model simulation analysis was performed for the four schemes, and the results are shown in Fig. 9.

The diffusion effect of wheat green production technology in Hebei Province in scheme 4 was significantly stronger than in Scheme 1. Also, the variation range was very large, indicating that improvement of government policy support can strengthen the diffusion effect of wheat green production technology. A comparison of schemes 2 and 3 shows that the technology diffusion effect of scheme 2

Table 6. Variation Scheme of Government Policy Support Parameter.

Variables	Financial Input Coefficient 1	Financial Input Coefficient 2	Subsidy Intensity of Adoption	Protection Intensity of Intellectual Property
Scheme 1	0.00000016	0.00000004	0.1	0.6
Scheme 2	0.0000016	0.00000004	0.1	6
Scheme 3	0.00000016	0.0000016	6	0.6
Scheme 4	0.0000024	0.0000016	6	8

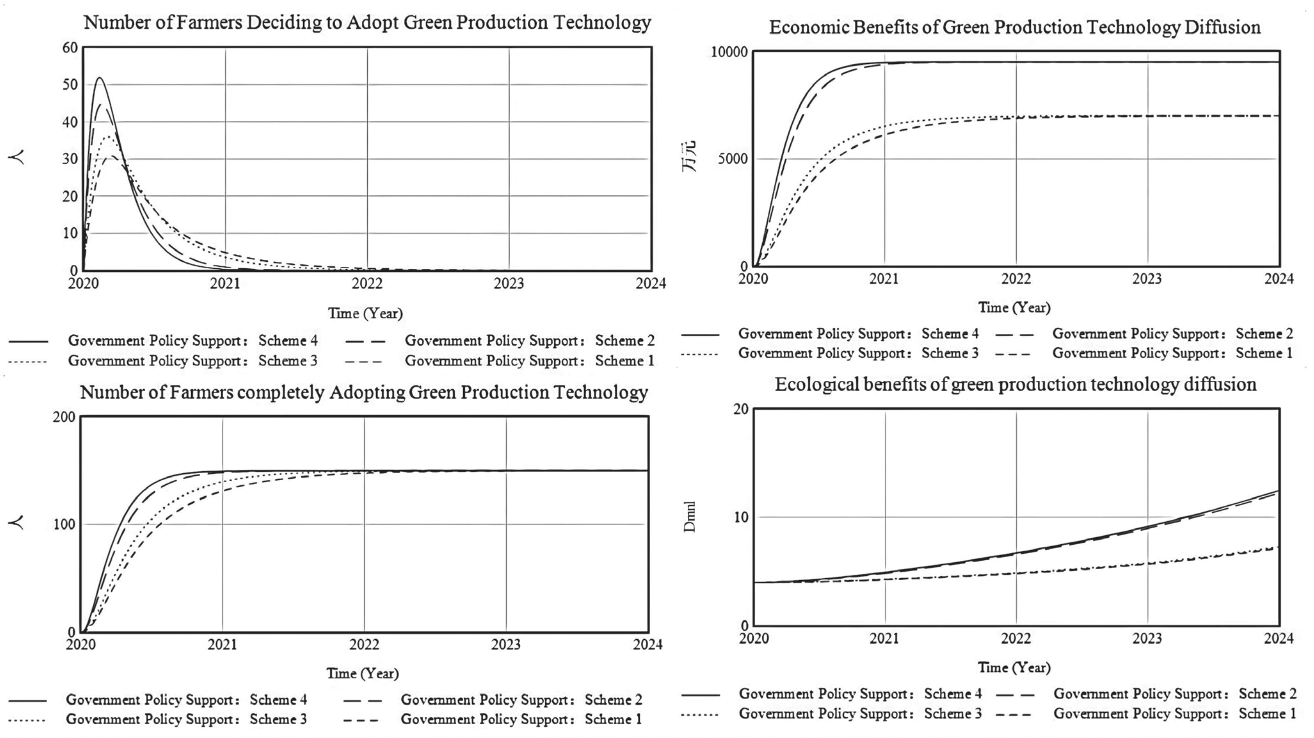

Fig. 9. Impact of Government Policy Support on Technology Diffusion in Hebei Province.

is significantly better than scheme 3, indicating that under the environment and parameters set in this study, Hebei Provincial government's subsidy and intellectual property protection for R&D can significantly improve the promotion of wheat green production technology and strengthen the diffusion effect of the green technology. Diversification of professional service organizations, agricultural enterprises, and other new business entities play an important role in technology promotion; thus, the role of government investment in agricultural technology promotion is relatively limited. Although the green production subsidies given by the Hebei Provincial government can reduce the cost of technology adoption by wheat farmers, there is a negative feedback loop in the system, reducing the absorption rate of the technology. This indicates that government subsidies for technology adoption by farmers cannot significantly improve the diffusion rate of green production technology.

Agricultural Support Intensity of Financial Institutions

Agricultural support intensity of financial institutions is mainly the financial support and risk guarantee for R&D. In this study, it applies to the support of wheat green production technology diffusion by financial institutions. Assuming that other conditions are constant, the insurance intensity of agricultural science and technology, green R&D funding support intensity of financial institutions, and the promotion funding support intensity of the agricultural technology of financial institutions were adjusted, and schemes 1, 2, and 3 were obtained (Table 7). Model simulation analysis was conducted for the three schemes, and the results are shown in Fig. 10.

Financial institutions can accelerate the diffusion of wheat green production technology in Hebei Province by increasing the number of loans given to agricultural enterprises and improving the technological R&D insurance of enterprises. A comparison of schemes 2

Table 7. Variation Scheme of Agricultural Support Intensity Parameters of Financial Institutions.

Variables	Insurance Intensity of Agricultural Science and Technology	Green R&D Funding Support Intensity of Financial Institutions	Agricultural Technology Promotion Funding Support Intensity of Financial Institutions
Scheme 1	0.01	0.02	0.3
Scheme 2	0.1	0.2	0.3
Scheme 3	0.1	0.2	3

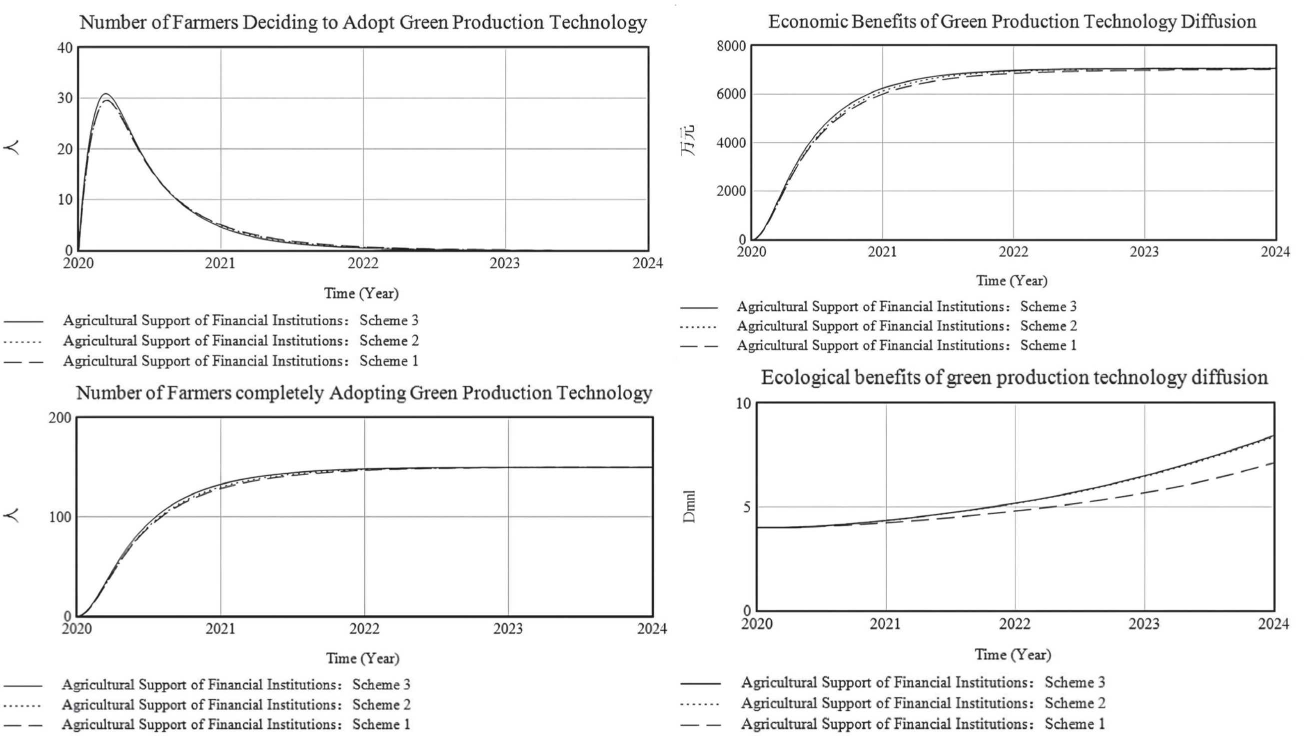

Fig. 10. Impact of Agricultural Support of Financial Institutions on Technology Diffusion in Hebei Province.

and 3 shows that compared with the financial support of financial institutions for enterprise technology promotion, increasing the insurance intensity of agricultural science and technology, as well as R&D funding support intensity of financial institutions, can significantly improve the diffusion effect of wheat green production technology in Hebei Province. This can be attributed to the continuous integration of digital technology and the internet into wheat green production. The multi-disciplinary and multi-field intersection of technology in R&D is bound to continuously strengthen the alliance among the leading agricultural enterprises, scientific research institutions, and universities, enabling agricultural enterprises to gradually conduct R&D of green production digital technology. However, due to the complexity and restraints of the external environment of green production technology, enterprises might suffer huge losses when R&D fails. Therefore, it is necessary for financial institutions to provide financial and insurance support for the R&D of wheat green production technology.

Mechanism Analysis

Accelerating the green development of the wheat industry and realizing "carbon peaking and carbon neutrality" goals have become important issues for improved wheat production. Hebei Province is the main wheat producing and selling area in China. Based on the simulated diffusion of the green production technology of wheat in Hebei Province, the diffusion driving mechanism has an important reference value for the sustainable development of the wheat industry. The simulation results show that multi-channel improvement of green production technology R&D support, strengthening professional organization service and stewardship, and improving production skills of wheat farmers can significantly accelerate the transformation of green production technology. Therefore, the mechanism driving the diffusion of wheat green production technology should be established through one system promotion and coordination of five links (Fig. 11).

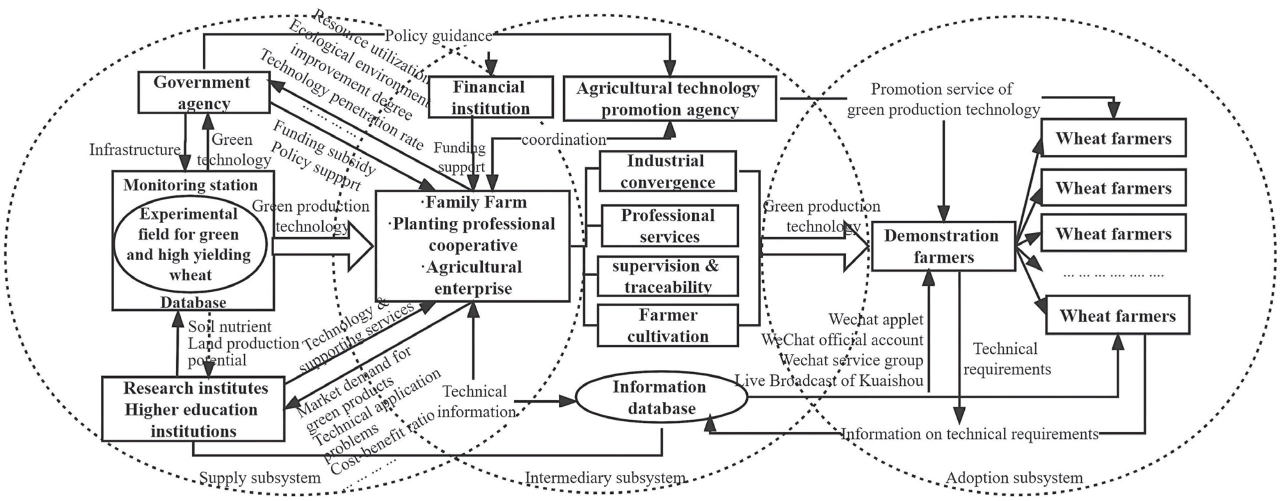

Fig. 11. Analysis of Mechanism Driving Diffusion of Wheat Green Production Technology.

One system promotion: diffusion of wheat green production technology is a complex system involving many stakeholders and comprising specific natural, social, market, and cultural environments. Organic integration of subsystems and optimization of factor structure can significantly improve the function of the wheat green production technology diffusion system. It is necessary to guide all service organizations to revitalize the resource elements, actively promote industrial integration, and innovate the technology promotion mode based on the region's resource endowment and cultural characteristics. This is crucial for establishing wheat green production technology diffusion ecosystem with factors gathering, one-majority-many-element, efficient mechanism, and complete system. Meanwhile, it is necessary to support the establishment of industrial wheat chains conforming to the local characteristics and encourage agricultural enterprises, farmers' professional cooperatives, agricultural technology promotion agencies, and research institutes along the industrial chain to synergistically participate in the R&D and promotion of wheat green production technologies. In addition, farmers' professional cooperatives and professional service companies should operate synergistically for the benefit of farmers. It is also important to actively explore the interest connection mechanism of multi-equity alliance to guarantee benefits for farmers who engage in wheat green production, which will encourage more wheat farmers to adopt green production technology.

Coordination of five links: the coordination of five links, including technology R&D, regulatory traceability, farmer cultivation, government support, and financial support for farmers, can maximize the diffusion of wheat green production technology. The improvement of the comprehensive level of green production technology has greatly accelerated the technology diffusion process. Regarding technology R&D, it is crucial to create technical innovation teams in the wheat industry, continuously update the knowledge gathered by scientific researchers on green production and facilitate the formation of human capital for the R&D of green production technology. Concerning the government and financial support for agriculture, there is a need to increase R&D investment intensity in green wheat production, build a "green financial service" channel to support technological innovation in green wheat production, and strengthen intellectual property protection policies, laws and regulations to improve competitive advantage of wheat green production technology. For example, a weak green food certification policy inhibits the diffusion of wheat green production technology. Thus, it is important to constantly improve the green production standard system of wheat pre-production, mid-production, and post-production. In addition, there is a need to establish the agricultural product quality supervision and traceability testing system covering food crops to promote the green purchasing behavior of consumers. Regarding the supervision and traceability link, there is a need to realize the high quality and favorable price of wheat and drive technology diffusion relying on the price mechanism. The education level of farmers has a higher potential of improving the diffusion effect of the green technology compared to other factors such as knowledge sharing attitude, risk preference, awareness of environmental protection, and health of wheat farmers. Concerning the farmer cultivation link, it is necessary to support link factors such as farmers' professional cooperatives and collective economic organizations to conduct training sessions related to green production of wheat, combine "theoretical self-study + field guidance", and use new media to strengthen the information exchange intensity of green production technology. These initiatives are likely to promote farmers' adoption and re-innovation of green production technology.

Conclusions

This study simulated the diffusion system of wheat green production technology in Hebei Province based on system analysis. Specifically, we analyzed the internal mechanism of wheat green production technology diffusion and constructed the driving mechanism of technology diffusion to provide policy recommendations for improving the diffusion level of wheat green production technology and accelerating the green transformation development of the wheat industry. The main findings of this study are as follows:

(1) The diffusion level of wheat green production technology can be enhanced significantly by improving the quality of scientific research personnel, industry-university research cooperation, and the investment intensity of agricultural enterprise R&D personnel. The R&D of green production technology should be led by government agencies. Also, agricultural enterprises should be gradually guided to invest in technology R&D.

(2) Improving the green food certification and tracking system and ensuring high quality and favorable price of wheat can significantly improve the promotion service level of wheat green production technology better than the cooperation between agricultural technology promotion agencies and cooperatives and the information sharing intensity of cooperatives.

(3) Education level, awareness of environmental protection and quality safety of agricultural products, risk attitude, and knowledge sharing attitude of farmers are conducive to the diffusion of wheat green production technology. Notably, the education level of wheat farmers has a higher potential of significantly improving the diffusion effect of green production technology compared with other factors. There is no need to significantly increase the proportion of farmers with risk preference, and the risk attitude parameter should be controlled between 1.5 and 2.5.

(4) Governments and financial institutions should provide more financial and policy support for R&D geared towards improving wheat green production technology. Improving capital investment, property protection, and risk assurance intensity in basic research of green wheat production can significantly accelerate the technology diffusion.

(5) There is a need to focus on one system (improving the diffusion system of wheat green production technology) and five links, including technology R&D, regulatory traceability, farmer cultivation, government support, and financial support for farmers to solve the "last mile" problem of green production technology diffusion.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. STRUIK P.C., KUYPER T.W. Sustainable intensification in agriculture: the richer shade of green. A review. Agronomy for Sustainable Development, **37** (5), 39, **2017**.
2. ADNAN N., NORDIN S.M., BAHRUDDIN M.A., TAREQ A.H. A state-of-the-art review on facilitating sustainable agriculture through green fertilizer technology adoption: Assessing farmers behavior. Trends in Food Science & Technology, **86** (4), 439, **2019**.
3. KANG Z.H., MU X.Z., ZHANG B., DUAN X.P. Hebei Blue Book: Hebei Agricultural and Rural Economic Development Report (2021). Social Science Literature Press: Beijing, China, 1, **2021**.
4. LI Y.Z., BAI J.J., WANG J., LIU F.Q. Analysis on influencing factors of promoting high-quality wheat green industry technology: Taking high-quality wheat producing area in Hebei Province as an example. Science and Technology Management Research, **40** (21), 240, **2020**.
5. WANG X., ZHANG J.B., HE K., HE P. . Influence of risk perception and public image appeal on the acceptability of farmers' green agricultural technology. Journal of China Agricultural University, **25** (7), 213, **2020**.
6. PAUDEL G.P., MCDONALD A.J., HARVEY D. Apparent Gains, Hidden Costs: Examining Adoption Drivers, Yield, and Profitability Outcomes of Rotavator Tillage in Wheat Systems in Nepal. Journal of Agricultural Economics, **71** (1), 199, **2020**.
7. XIONG Y., HE P. Impact factors and production performance of adoption of green control technology: An empirical analysis based on the survey data of rice farmers in Sichuan Province. Chinese Journal of Eco -Agriculture, **28** (1), 136, **2020**.
8. DANSO G.K., JEFFREY S.R., DRIDI C., VEEMAN T. Modeling irrigation technology adoption and crop choices: Gains from water trading with farmer heterogeneity in Southern Alberta, Canada. Agricultural Water Management, **253** (2), 106932, **2021**.
9. MARTE Y.E., ETWIRE P.M., MOCKSHELL J. Climate-smart cowpea adoption and welfare effects of comprehensive agricultural training programs. Technology in Society, **64** (1), 101546, **2021**.
10. GUO L., HOU J.Q., HUI R.R. Research on Diffusion Mechanism and Diffusion Model of Agricultural Watersaving Irrigation Technology. Research on Development, **30** (1), 43, **2021**.
11. CHEN M.F., HUANG J.H. The Eco-agricultural Technology Innovation Diffusion Mechanisms Under the Government Subsidies: Based on the Evolutionary Game Analysis of "Company+ Cooperative+ Ceasant

Household"Model. Science and Technology Management Research, **38** (4), 34, **2018**.
12. CHENG L.Y. Research on the technology diffusion mechanism of energy efficient ecological agriculture. Chinese Journal of Agricultural Resources and Regional Planning, **37** (4), 134, **2016**.
13. HAO X., YAN J., SHA J., KE W., ZHANG G. Exploring the synthetic optimal policies for solving problems of agricultural water use with a dynamic optimization simulation model. Journal of Cleaner Production, **287** (2), 125062, **2020**.
14. SHANG L., HECKELEI T., GERULLIS M.K., BRNER J., RASCH S. Adoption and diffusion of digital farming technologies integrating farm-level evidence and system interaction. Agricultural Systems, **190** (1), 103074, **2021**, .
15. CUI H., ZHAO T., TAO P. Evolutionary Game Study on the Development of Green Agriculture in China Based on Ambidexterity Theory Perspective. Polish Journal of Environmental Studies, **28** (3), 1093, **2018**.
16. LIU L., ZHU Y., GUO S. The Evolutionary Game Analysis of Multiple Stakeholders in the Low-Carbon Agricultural Innovation Diffusion. Complexity, **26** (1), 6309545, **2020**.
17. EGERER S., COTERA R.V., CELLIERS L., COSTA M.M. A leverage points analysis of a qualitative system dynamics model for climate change adaptation in agriculture. Agricultural Systems, **189** (4), 103052, **2021**.
18. SUNIK J., MASIA S., INDRIKSONE D., BREMERE I., VAMVAKERIDOU L.L. System dynamics modelling to explore the impacts of policies on the water-energy-food-land-climate nexus in Latvia. Science of The Total Environment, **775** (12), 145827, **2021**.
19. LU D., IQBAL A., ZAN F., LIU X., CHEN G. Life-Cycle-Based Greenhouse Gas, Energy, and Economic Analysis of Municipal Solid Waste Management Using System Dynamics Model. Sustainability, **13** (3), 1641, **2021**.
20. ABOAH J., WILSON M.M., BICKNELL K., RICH K.M. Ex-ante impact of on-farm diversification and forward integration on agricultural value chain resilience: A system dynamics approach. Agricultural Systems, **189** (2), 103043, **2021**.
21. WANG Z.Z., MA Y.H., ZHANG F. Study on Technology Innovation Diffusion Model and Simulation Based on System Dynamics. Science & Technology Progress and Policy, **32** (19), 13, **2015**.
22. WALTERS J.P., ARCHER D.W., SASSENRATH G.F., HENDRICKSON J.R., HANSON J.D., HALLORAN J.M. Exploring agricultural production systems and their fundamental components with system dynamics modelling. Ecological Modelling, **333** (15), 51, **2016**.
23. FAGERBERG J., VERSPAGEN B. Technology-gaps, innovation-diffusion and transformation: an evolutionary interpretation. Research Policy, **31** (4), 1291, **2002**.
24. MENARD C., SHIRLEY M.M. Handbook of new institutional economics. Springer US Press:New York, U.S.A., 515, **2008**.
25. RATKOVIC M., KRASULJA N., GARACA N. Customer relationship management strategy as an opportunity for improving the modern marketing concept. Kultura, **139** (2), 381, **2013**.
26. SUKI N.M., AZMAN N.S. Impacts of Corporate Social Responsibility on the Links Between Green Marketing Awareness and Consumer Purchase Intentions. Procedia Economics and Finance, **37** (3), 262, **2016**.
27. YU B. Industrial structure, technological innovation, and total-factor energy efficiency in China. Environmental Science and Pollution Research, **27** (8), 1, **2020**.
28. SCHULTZ T.W. Transforming traditional agriculture / Theodore W. Schultz. Journal of the American Statistical Association, **59** (308), 1308, **1964**.
29. HE Y., QI Y.B. Analysis of the risk cognition of excess fertlizer application and the adoption behavior of environment-friendly technology and its reson-base on the survey of 380 citrus grower in Sichuan province.Chinese Journal of Agricultural Resources and Regional Planning, **41** (5), 8, **2020**.
30. ZAMASIYA B., NYIKAHADZOI K., MUKAMURI B.B. Factors influencing smallholder farmers' behavioural intention towards adaptation to climate change in transitional climatic zones: A case study of Hwedza District in Zimbabwe. Journal of Environmental Management, **198** (16), 233, **2017**.
31. ABDULAI A.N., ABDUL-RAHAMAN A., ISSAHAKU G. Adoption and diffusion of conservation agriculture technology in Zambia: the role of social and institutional networks. Environmental Economics and Policy Studies, **23** (4), 761, **2021**.
32. CHEN W., DONG J., YAN C., DONG H., LIU P. What Causes Waterlogging?-Explore the Urban Waterlogging Control Scheme through System Dynamics Simulation. Sustainability, **13** (15), 8546, **2021**.
33. HAGERSTRAND T. Innovation Diffusion as a Spatial Process, by Torsten Hgerstrand. Geographical Analysis, **1** (4), 318, **2010**.
34. YANG G.Z., LIU M.C. Research on dualistic technology innovation diffusion based on system dynamics.Soft Science, **26** (8), 5, **2012**.