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Assessing the Impact of Digital Inclusive Finance on Agricultural Green Resilience: Evidence from China

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Abstract

Green and resilient agriculture can strike a balance between agricultural production and ecological conservation, ensuring a continuous and stable supply of food and agricultural products. Based on provincial panel data from 31 provinces in China during 2014–2023, this study constructs an evaluation system for agricultural green resilience and employs the fixed-effects model, mediation effect model, and spatial Durbin model to empirically examine the impact mechanism and spatial effects of digital inclusive finance on agricultural green resilience. The main findings are as follows: (1) Digital inclusive finance significantly enhances agricultural green resilience. (2) Agricultural technological innovation plays a mediating role in the relationship between digital inclusive finance and agricultural green resilience. (3) Digital inclusive finance generates significant positive spatial spillover effects on agricultural green resilience, not only improving local agricultural green resilience but also promoting coordinated development in neighboring regions. (4) Regional heterogeneity analysis indicates that the promoting effect is strongest in the central region, followed by the western region, while no significant effect is observed in the eastern region. From the perspective of different dimensions, the effect intensity follows the order of coverage breadth, depth of use, and degree of digitalization. These findings suggest that digital inclusive finance serves as an important driver of agricultural green resilience and sustainable agricultural transformation in China. Therefore, policymakers should further expand digital financial inclusion, strengthen support for agricultural technological innovation, and promote coordinated regional development to enhance agricultural green resilience.

Keywords: agricultural green resilience; digital financial inclusion; agricultural technological innovation; agricultural sustainability; mediation effect; spatial spillover effect

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1. Introduction

Ensuring a stable food supply while promoting environmentally sustainable agricultural growth has become an increasingly urgent global concern. This challenge has been intensified by ongoing climate-related disturbances, growing resource scarcity, and ecological pressures, which have heightened the vulnerability of agricultural systems and complicated efforts to achieve the Sustainable Development Goals [1,2]. China's Fourteenth Five-Year Plan explicitly calls for accelerating agricultural green transformation, improving resource-use efficiency, enhancing environmental sustainability, and strengthening agricultural green resilience. However, China's agricultural development still faces significant challenges, including tightening resource constraints, increasing environmental pressures, and the growing frequency of climate-related risks [3,4]. As agriculture faces mounting external pressures, enhancing its ability to respond to and recover from adverse shocks has emerged as a key prerequisite for achieving sustainable and environmentally friendly development. Therefore, efforts to strengthen agricultural green resilience and clarify its driving forces are critical for achieving a more efficient, sustainable, and modern agricultural sector.

The continuing digital transformation of the financial sector has altered the way financial resources are allocated and delivered. Digital inclusive finance refers to the integration of digital technologies, such as mobile internet, big data, and artificial intelligence, with traditional financial services to enhance the accessibility, affordability, and convenience of financial products, particularly for underserved groups and regions [5]. Compared with conventional financial services, digital inclusive finance reduces information asymmetry, lowers transaction costs, and expands the coverage of financial services through digital platforms, thereby improving the efficiency of financial resource allocation [6]. This evolution has improved the availability of financial services and offered fresh impetus for the green and sustainable development of agriculture [7]. Research undertaken in European and Asian contexts shows that improvements in digital financial inclusion help create favorable conditions for innovation within the renewable and green energy sectors [8,9]. In the agricultural sector, digital inclusive finance can alleviate financing constraints faced by farmers and agricultural enterprises, promote the adoption of green technologies, and facilitate the transformation of agricultural production toward more sustainable and resilient models. Digital financial inclusion, through digital platforms and big data technologies, helps governments monitor and track carbon emission sources in real time. It also facilitates information sharing among local governments and strengthens the coordination of cross-regional environmental policies, thereby effectively reducing transboundary pollutant emissions across provinces [10]. Therefore, digital inclusive finance can enhance agricultural green resilience by improving access to financial resources, promoting technological innovation, and facilitating green agricultural development.

The concept of resilience was originally proposed by Holling in ecological research, referring to the capacity of systems to absorb disturbances, adapt to environmental changes, and reorganize while maintaining their core functions [11]. This provides an important theoretical foundation for the study of agricultural green resilience. Subsequently, the concept of resilience was continuously extended and evolved into several related branches, including economic resilience [12], industrial chain resilience [13], and urban resilience [14]. Against the backdrop of increasing risks and uncertainties, green resilience become an important focus of recent research [15,16].

Building on the resilience framework, an increasing body of literature has examined agricultural green resilience from different perspectives, including its conceptualization, measurement, spatial characteristics, and influencing factors. These studies have gradually enriched the understanding of agricultural green resilience and provided an important foundation for exploring its determinants. Research on agricultural green resilience has identified several key influencing factors, Yan and Li highlighted the importance of technological and ecological factors in strengthening agricultural ecological resilience, showing that utility model patents and ecosystem service values were critical contributors to resilience improvement across China's provinces [17]. Chen and Li further revealed that the spatial heterogeneity of agricultural green resilience was mainly driven by innovation performance and the degree of marketization [18]. Tian et al. emphasized that regional characteristics, particularly disparities in socioeconomic development and digital infrastructure, determine the extent to which the digital economy can facilitate improvements in agricultural green resilience, thereby generating notable regional differences [19].

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Among these influencing factors, the role of digital financial development has attracted increasing scholarly attention due to its potential to reshape resource allocation and enhance the adaptive capacity of agricultural systems. Existing studies generally suggest that digital inclusive finance enhances agricultural sustainability by improving financial accessibility, optimizing the allocation of financial resources, and supporting green transformation and technological innovation in agriculture. Dong et al. suggested that technology-enabled financial services help ease financing difficulties in rural areas while facilitating a more efficient distribution of financial resources [20]. Gold and Tregenna suggested that greater access to digital inclusive financial services encourages technological progress, green investment, and modernization in agriculture, thereby facilitating its sustainable and green transition [21]. Liu et al. further pointed out that emerging financial instruments, such as digital insurance and green credit, can enhance the adaptive capacity of agricultural systems by providing risk-sharing and compensation support [22].

Overall, existing studies have substantially advanced the understanding of agricultural green resilience and the role of digital inclusive finance in promoting sustainable agricultural development. However, several important limitations remain in the existing literature, which warrant further investigation. First, although previous studies have demonstrated the positive role of digital inclusive finance in sustainable agricultural development, they have primarily focused on green agricultural transformation, financing efficiency, and environmental performance (Pei and Pei [23]; Satrovic et al. [24]). Consequently, limited attention has been paid to whether digital inclusive finance can enhance agricultural green resilience, which reflects the agricultural system's capacity to withstand, adapt to, and recover from external shocks while maintaining sustainable development. Second, most previous research has concentrated on the economic and environmental effects of digital inclusive finance, while paying limited attention to its spatial spillover effects. In particular, insufficient evidence exists on whether digital inclusive finance generates cross-regional impacts through technology diffusion, information sharing, and factor mobility, as well as on the underlying mechanisms of spatial transmission. To address these research gaps, this study examines the impact of digital inclusive finance on agricultural green resilience using provincial panel data from 31 provinces in China covering the period 2014–2023. Specifically, this study examines whether digital inclusive finance enhances agricultural green resilience, explores the mediating role of agricultural technological innovation, evaluates the spatial spillover effects, and analyzes regional heterogeneity in these relationships.

The contributions of this study are twofold. First, this study constructs a comprehensive evaluation index system for agricultural green resilience, which broadens the conceptual scope and measurement dimensions of agricultural green resilience and offers a novel theoretical framework for its evaluation and analysis. Second, this study links digital inclusive finance with agricultural green resilience in a comprehensive research setting and investigates the pathways through which digital inclusive finance supports agricultural green transformation from a resilience-oriented perspective. Particular emphasis is placed on the channeling effect of agricultural technological innovation, together with the cross-regional diffusion and regional variation in the effects of digital inclusive finance on agricultural green resilience.

The remainder of this paper is organized as follows. Section 2 presents the hypotheses development. Section 3 describes the research design. Section 4 presents the empirical results. Section 5 further examines the spatial spillover effects. Section 6 discusses the findings. Section 7 concludes the paper and provides policy implications.

2. Theoretical Analysis and Hypothesis Development

2.1. Direct Effect Analysis

Drawing on Schultz's classic theoretical framework for the restructuring of conventional farming sectors, the fundamental driving force behind rural agricultural growth resides in advancing the shift away from outdated agrarian modes toward contemporary agricultural systems via capital input, technical upgrades and institutional reform [25]. Digital inclusive finance is capable of breaking through the bottlenecks of conventional financial offerings, and provide critical support for enhancing agricultural green resilience through financing support, digital empowerment, and risk protection mechanisms [26] (Figure 1).

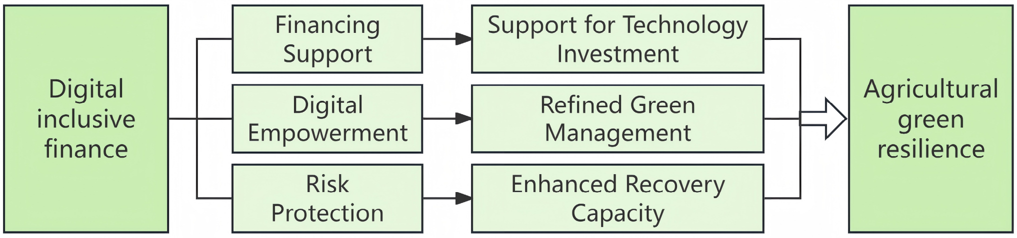

Figure 1. Schematic representation of direct effects. Source: Developed by the authors based on the theoretical analysis.

Improving agricultural green resilience often requires sustained financial investment [27]. The inclusiveness, accessibility, and efficiency of digital finance are more conducive to directing capital toward high value-added agricultural projects [28], thereby facilitating investment in agricultural innovation and accelerating the adoption and dissemination of environmentally friendly farming practices, including water-saving irrigation, green pest management, organic fertilizer substitution, and agricultural waste recycling.

By leveraging digital technologies, agricultural producers can obtain timely information on market dynamics, thereby optimizing production decisions and reducing resource waste and environmental pollution [29]. Meanwhile, smart agriculture enables the monitoring and regulation of key factors, such as field water availability, climatic conditions, and crop performance, through intelligent monitoring systems, thereby facilitating intelligent and refined management throughout the production process [30].

Digital inclusive finance enhances risk protection for agricultural producers by offering innovative financial products, including digital insurance, online credit, and supply chain finance, providing more diversified risk management channels [31]. When agricultural systems face external shocks, digital inclusive finance can provide timely risk-sharing mechanisms for agricultural operators, thereby strengthening their capacity to recover production and maintain sustainable development.

2.2. Indirect Effect Analysis

By improving the accessibility and efficiency of financial services, digital inclusive finance helps address funding shortages and creates a more supportive environment for the adoption and advancement of agricultural technologies, thereby advancing the generation, application, and dissemination of agricultural green technologies [32]. Digital inclusive finance can lower barriers to financial services, improve access to capital, boost the enthusiasm of innovators to engage in R&D activities, and promote the concentration of innovation resources in the field of green agriculture, which further promotes the continuous upgrading of green agricultural technological innovation [33].

Advances in agricultural technological innovation contribute to enhancing agricultural green resilience. Agricultural technological innovation contributes to the advancement and diffusion of green production technologies, which helps reduce the ecological pressures caused by agricultural production [34]. By optimizing factor allocation, developing stress-resistant varieties, and promoting advanced technologies, agricultural technological innovation can improve agricultural productivity and production stability [35], as well as enhance the ability of agricultural systems to withstand resource constraints, environmental pressures, and external shocks and to recover from them [36,37] (Figure 2).

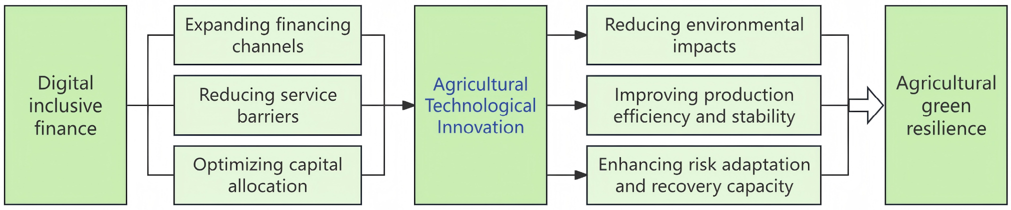

Figure 2. Schematic representation of indirect effects. Source: Developed by the authors based on the theoretical analysis.

2.3. Spatial Spillover Effect Analysis

With the advancement of financial technology, digital financial resources gradually diffuse from core cities to surrounding small and medium-sized cities, producing a trickle-down effect that helps narrow regional disparities in digital finance development [38]. Furthermore, digital finance platforms enable agricultural data to flow more efficiently across geographical boundaries and industrial fields, extend the reach of financial services while overcoming geographical and temporal constraints, thereby significantly improving financial access for long-tail users and underserved groups in financial markets [39]. From the perspective of the space of flows, public data openness facilitates the accelerated circulation of various factors across regions, fostering a high degree of interconnectedness and integration. It enables innovation actors to overcome geographical constraints and participate in cross-regional innovation collaboration, which supports the precise alignment of technological achievements with agricultural industry demands across spatial boundaries [40].

On the other hand, supported by the information dissemination mechanism enabled by digital networks, agricultural technological achievements can overcome the geographical and temporal constraints that traditionally hinder technology diffusion, thereby reducing the costs of spreading and applying green agricultural technologies across regions [41,42]. Agricultural producers in neighboring areas can more easily access advanced green production technologies and management experience, and absorb innovative achievements through channels such as technology imitation and talent mobility. This process improves green production efficiency and risk-response capacity, thereby enhancing the level of green resilience in regional agricultural systems. Such cross-regional technology diffusion and knowledge sharing ultimately generate spatial spillover effects on surrounding regions (Figure 3).

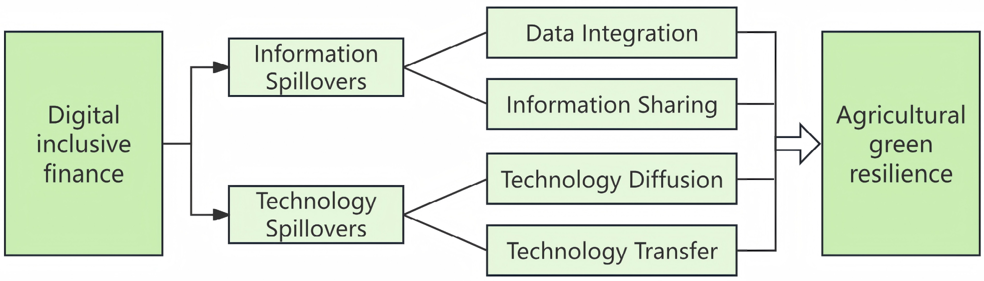

Figure 3. Schematic representation of spatial spillover effect. Source: Developed by the authors based on the theoretical analysis.

Based on the preceding discussion and the theoretical framework, this study formulates the following research hypotheses regarding the relationship between digital inclusive finance and agricultural green resilience:

H1. *Digital inclusive finance contributes positively to the enhancement of agricultural green resilience.*

H2. *Digital financial inclusion strengthens agricultural green resilience through fostering agricultural technological innovation.*

H3. *Digital financial inclusion generates positive spatial spillover effects on agricultural green resilience.*

3. Research Design

3.1. Research Area

This study uses panel data covering all 31 provincial-level administrative regions in mainland China, including provinces, autonomous regions, and municipalities directly under the central government. These regions were selected because they constitute the complete set of provincial-level administrative units in mainland China for which consistent panel data are available during the study period. Hong Kong, Macao, and Taiwan were excluded because of substantial data unavailability. The unit of analysis is the province-year observation, and the study population comprises all provincial-level administrative regions in mainland China. According to the regional classification standards of the National Bureau of Statistics of China, the 31 provincial-level regions are classified into three major geographical regions: eastern, central, and western China (Figure 4). This classification provides the basis for the subsequent regional heterogeneity analysis, allowing regional differences in the effects of digital inclusive finance on agricultural green resilience to be examined.

Figure 4. Spatial distribution of the study area. Note: The base map was produced using the standard map provided by the Ministry of Natural Resources of the People's Republic of China (Review No.GS(2024)0650), available from Tianditu (https://www.tianditu.gov.cn/). The base map has not been modified.

3.2. Model

3.2.1. Baseline Regression Model

Previous studies investigating the impact of digital finance and agricultural development have commonly employed two-way fixed-effects models to control for unobservable individual heterogeneity and time-specific shocks, thereby reducing potential estimation bias caused by omitted variables [43]. Following this approach, this study specifies a two-way fixed-effects model to examine the effect of digital inclusive finance on agricultural green resilience:

$$Y_{it} = a_0 + a_1 X_{it} + a_2 \text{Control}_{i,t} + u_i + v_t + \varepsilon_{it} \tag{1}$$

Y_{it} represents the level of agricultural green resilience. X_{it} represents the level of digital inclusive finance. "Control" represents a series of control variables. i represents the region, and t represents the year. u_i, v_t and ε_{it}, respectively, represent the individual fixed effect, the time fixed effect and the random disturbance term. If the regression coefficient a_1 is significantly positive, it indicates that digital inclusive finance has a significant positive effect on agricultural green resilience.

3.2.2. Mechanism Effect Model

To explore the mechanism through which digital inclusive finance affects agricultural green resilience, this study follows the mediation effect testing approach adopted by Liu et al. [44] and constructs a mediation effect model. This approach facilitates the identification of the transmission mechanism by assessing whether agricultural technological innovation mediates the relationship between digital inclusive finance and agricultural green resilience:

$$M_{it} = \mathrm{b}_0 + \mathrm{b}_1\ X_{it} + \mathrm{b}_2 \text{Control}_{i,t} + u_i + v_t + \varepsilon_{it} \tag{2}$$

$$Y_{it} = c_0 + c_1 X_{it} + c_2 M_{it} + c_3 \text{Control}_{i,t} + u_i + v_t + \varepsilon_{it} \tag{3}$$

M_{it} represents the level of agricultural technological innovation, b_1 represents the effect of the independent variable on the mediating variable, c_1 represents the direct effect of the independent variable on the dependent variable after controlling for the mediating variable, and c_2 represents the effect of the mediating variable on the dependent variable. The meanings of the remaining variables are consistent with those in Equation (1). If b_1 and c_2 are statistically significant and the absolute value of c_1 decreases compared with the benchmark regression coefficient, the mediating effect is confirmed.

3.2.3. Spatial Durbin Model

Tobler formulated the First Law of Geography, which emphasizes that spatial relationships tend to weaken as distance increases, meaning that geographically closer units are generally more strongly connected than those farther apart [45]. Building on this principle, this study incorporates spatial dependence into the analysis of the impact of digital inclusive finance on agricultural green resilience and employs the Spatial Durbin Model (SDM). This model can simultaneously capture the direct effects of digital inclusive finance on agricultural green resilience and its spatial spillover effects on neighboring regions, following established spatial econometric approaches [46]. The specific model is as follows:

$$Y_{it} = \alpha + \rho \sum_{j=1}^{n} w_{ij} Y_{jt} + \beta X_{it} + \varphi \sum_{j=1}^{n} w_{ij} X_{it} + \delta \text{Control}_{i,t} + \tau \sum_{j=1}^{n} w_{ij} \text{Control}_{i,t} + u_i + v_t + \varepsilon_{it} \tag{4}$$

W_{ij} is the spatial weight matrix. ρ is the coefficient of the spatial lag term. β is the column vector of the estimated coefficients of the independent variables. φ is the marginal impact of the digital financial inclusion of neighboring regions on the agricultural green resilience in the region. The meanings of other variables and parameters are the same as those in Equation (1).

3.3. Variable Selection

3.3.1. Dependent Variable (Agr)

Agricultural green resilience is the outcome variable. Drawing on the theoretical framework of agricultural green resilience and previous studies [17,47,48], this study establishes a comprehensive indicator system to assess the capability of agricultural systems to cope with external disturbances, restore normal functioning after shocks, and achieve adaptive development under changing conditions (Table 1). To measure regional differences in agricultural green resilience more objectively, the overall index is calculated through the entropy weighting method [49].

Table 1. Measurement system of agricultural green resilience.

First-Level Indicators	Secondary-Level Indicators	Interpretation of Indicators	Indicator Properties
Resistance capacity	Risk protection capacity	Agricultural insurance indemnity payments/gross output value of agriculture, forestry, animal husbandry, and fishery	+
	Fiscal support capacity	Expenditure on agriculture, forestry, and water affairs/General public budget expenditure × 100%	+
	Labor productivity	Gross output value of agriculture, forestry, animal husbandry, and fishery/number of employees in agriculture, forestry, animal husbandry, and fishery	+
	Production stability	Disaster-affected area/crop-sown area × 100%	−
Recovery capacity	Soil conservation	Area under soil and water erosion control	+
	Forest coverage rate	Forest area/total land area	+
	Cropland replanting index	Crop-sown area/cultivated land area	+
	Effective irrigation rate	Effectively irrigated area/crop-sown area × 100%	+
	Water resource use efficiency	Agricultural water consumption/Gross output value of agriculture, forestry, animal husbandry, and fishery	+
Transformation capacity	Vitality of green market entities	Number of green agricultural enterprises	+
	Green production certification level	Number of certified green food products	+
	Energy output efficiency	Gross output value of agriculture, forestry, animal husbandry, and fishery/rural electricity consumption	+
	Agricultural carbon emission intensity	Agricultural carbon emissions/cultivated land area	−

Note: The attribute "+" indicates a positive indicator, while "−" indicates a negative indicator.

Resistance capacity denotes the capability of an agricultural system to endure external shocks and various risk-related disturbances. It serves as the basic support for promoting green agricultural transformation and constitutes a fundamental component in assessing agricultural green resilience. Recovery capacity describes the ability of the agricultural sector to maintain normal functions and operational stability while adapting to tightening resource constraints and increasingly stringent environmental regulations, ultimately returning to an equilibrium development state. It reflects the system's capacity to restore normal operations and development levels after being impacted. Transformation captures the ability of the agricultural sector to reconstruct its development models and pathways through technological innovation, and to explore new development trajectories via industrial reorganization and adjustment. It is critical to China's shift from traditional to green agriculture and reflects the overall performance of agricultural green resilience.

This study employs the entropy method to measure the level of agricultural green resilience. The specific steps are as follows:

(1) Normalize the data for all indicators. To avoid zero values, negative values, or invalid results during the entropy calculation, a small constant of 0.0001 was added to the normalized data.

For positive indicators:

$$x'_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} + 0.0001 \tag{5}$$

For negative indicators:

$$x'_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)} + 0.0001 \tag{6}$$

(2) Calculate the proportion:

$$p_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{n} x'_{ij}} \tag{7}$$

(3) Calculate the entropy value:

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} p_{ij} \ln(p_{ij}) \tag{8}$$

(4) Calculate the coefficient of variation:

$$g_j = 1 - e_j \tag{9}$$

(5) Calculate the final weight:

$$w_j = \frac{g_j}{\sum_{j=1}^{m} g_j} \tag{10}$$

(6) Calculate the evaluation index:

$$S_i = \sum_{j=1}^{m} w_j \cdot x'_{ij} \tag{11}$$

3.3.2. Independent Variable (Dif)

The empirical analysis focuses on digital financial inclusion as the main variable of interest. To quantify regional variation in its development, the Digital Financial Inclusion Index is employed [50]. Specifically, this study adopts the Digital Financial Inclusion Index released by Peking University, which comprises three dimensions: coverage breadth, usage depth, and the level of digitalization. The indicator system evaluates regional differences in financial inclusion by considering the scope of service outreach, the extent of user engagement, and the advancement of digital technologies. Given its comprehensive measurement framework and widespread acceptance in empirical studies, the index has become a standard indicator for assessing digital inclusive finance and is therefore employed in this study [51]. To improve the comparability of the regression coefficients and reduce differences in variable magnitudes, the digital inclusive finance index and its sub-indices are divided by 100 before estimation [52]. This rescaling facilitates coefficient interpretation while preserving the underlying statistical relationships among the variables.

3.3.3. Intermediate Variable (Tech)

Agricultural technological innovation is incorporated into the empirical model as an intermediary factor to explore its potential role in linking digital inclusive finance and agricultural green resilience. By examining the mediating mechanism, the study seeks to find out whether improvements in technological innovation constitute an important channel through which digital finance contributes to sustainable agricultural development. Following previous studies [53,54], agricultural technological innovation is proxied by the quantity of granted green agricultural patents, and the corresponding values are transformed using the natural logarithm to reduce data dispersion.

3.3.4. Control Variables

Following previous studies [55–57], this study selects economic development, urbanization, government intervention, and human capital into the empirical model to reduce omitted-variable bias and improve estimation accuracy.

(1) Gdp: Economic development level, assessed using the natural logarithm of GDP per capita.
(2) Urb: Urbanization level, represented by the proportion of permanent urban residents to the overall population of the region.
(3) Gov: Government intervention, assessed using the proportion of local public budget spending in regional gross domestic product.
(4) Hum: Human capital, evaluated using the proportion of individuals enrolled in regular colleges and universities relative to the regional population.

3.3.5. Data Sources

This study employs a balanced panel dataset covering 31 provincial-level regions in China from 2014 to 2023 to examine the impact of digital financial inclusion on agricultural green resilience. The study period was selected to ensure the consistency and completeness of all variables included in the analysis. In addition, it captures a period during which digital inclusive finance in China experienced rapid development [58], making it suitable for examining its impact on agricultural green resilience. The year 2023 was selected as the endpoint because it was the most recent year with complete data available at the time of the study. The dataset was compiled from publicly available and authoritative sources, including the China Statistical Yearbook, the China Rural Statistical Yearbook, the Green Food Statistical Yearbook, various provincial statistical yearbooks, and the Peking University Digital Financial Inclusion Index. To minimize the influence of missing observations while maintaining data consistency, a small number of missing values were supplemented using interpolation methods.

4. Empirical Results

4.1. Spatial and Temporal Differentiation Characteristics

4.1.1. Temporal Evolution Characteristics

The trends presented in Figure 5 reveal a consistent rise in the levels of agricultural green resilience and digital financial inclusion across China during the years 2014–2023. Specifically, agricultural green resilience increased from 0.401 to 0.434, showing relatively steady growth and reflecting gradual improvements in the agricultural sector's capacity for sustainable development and shock adaptation. Digital inclusive finance rose from 1.797 to 3.937, with a more pronounced increase. Overall, the two variables display a certain degree of synchronous upward trend, providing preliminary empirical support for the subsequent analysis of their relationship.

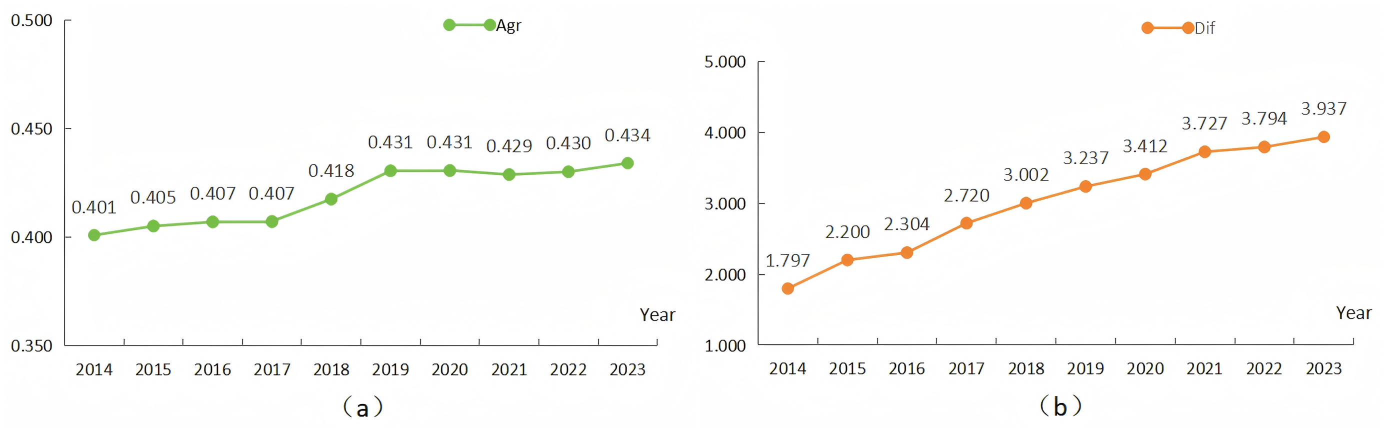

Figure 5. Temporal evolution of agricultural green resilience and digital inclusive finance from 2014 to 2023. (**a**) Agricultural green resilience. (**b**) Digital inclusive finance. Source: Compiled by the authors based on the agricultural green resilience index calculated using the entropy method and the Peking University Digital Financial Inclusion Index.

4.1.2. Spatial Evolution Characteristics

The Natural Breaks (Jenks) classification approach in ArcGIS Pro 3.6.0 is adopted to divide digital inclusive finance and agricultural green resilience into distinct categories, aiming to reveal their spatial distribution differences and evolutionary patterns. Based on this classification, spatial evolution maps are generated (Figure 6) to provide a more intuitive illustration of the spatiotemporal variations in the two indicators across different regions.

From Figure 6a–c, agricultural green resilience exhibits significant regional disparities across China. Overall, western regions such as Xinjiang and Tibet have consistently maintained relatively high levels, whereas some provinces in eastern and central China remain at comparatively lower levels. Over time, the spatial clustering of high-value regions has become increasingly pronounced, resulting in the formation of relatively stable high-value agglomerations. Meanwhile, a certain degree of low-value clustering persists in central China, indicating that some provinces still face challenges related to a weak foundation for green agricultural development and relatively limited capacity to withstand risks and external shocks. In general, the spatial distribution of agricultural green resilience displays a marked imbalance, with substantial regional disparities that continue to pose challenges for coordinated development.

In Figure 6d–f, the geographical distribution of digital financial inclusion presents a distinct east-to-west declining pattern. Provinces along the eastern coast, particularly Beijing, Shanghai, Jiangsu, Zhejiang, and Guangdong, consistently rank among the highest. These regions benefit from favorable economic conditions and highly developed digital infrastructure, which contribute substantially to the advancement of digital financial inclusion. In contrast, western regions generally remain at relatively lower levels, with considerable room for improvement in the coverage and depth of digital financial services. From the perspective of spatial evolution, digital inclusive finance displays a declining pattern from the eastern coastal areas toward the central and western regions, forming a pronounced "high in the east and low in the west" distribution pattern, while regional development imbalances continue to persist.

4.2. Descriptive Results

The descriptive statistics are presented in Table 2. The unit of analysis is the annual observation for each of the 31 provincial-level regions in China over the period 2014–2023, resulting in 310 panel observations (Obs). For all variables, the standard deviations are smaller than the corresponding mean values, indicating moderate variation across the sample and the absence of excessive dispersion.

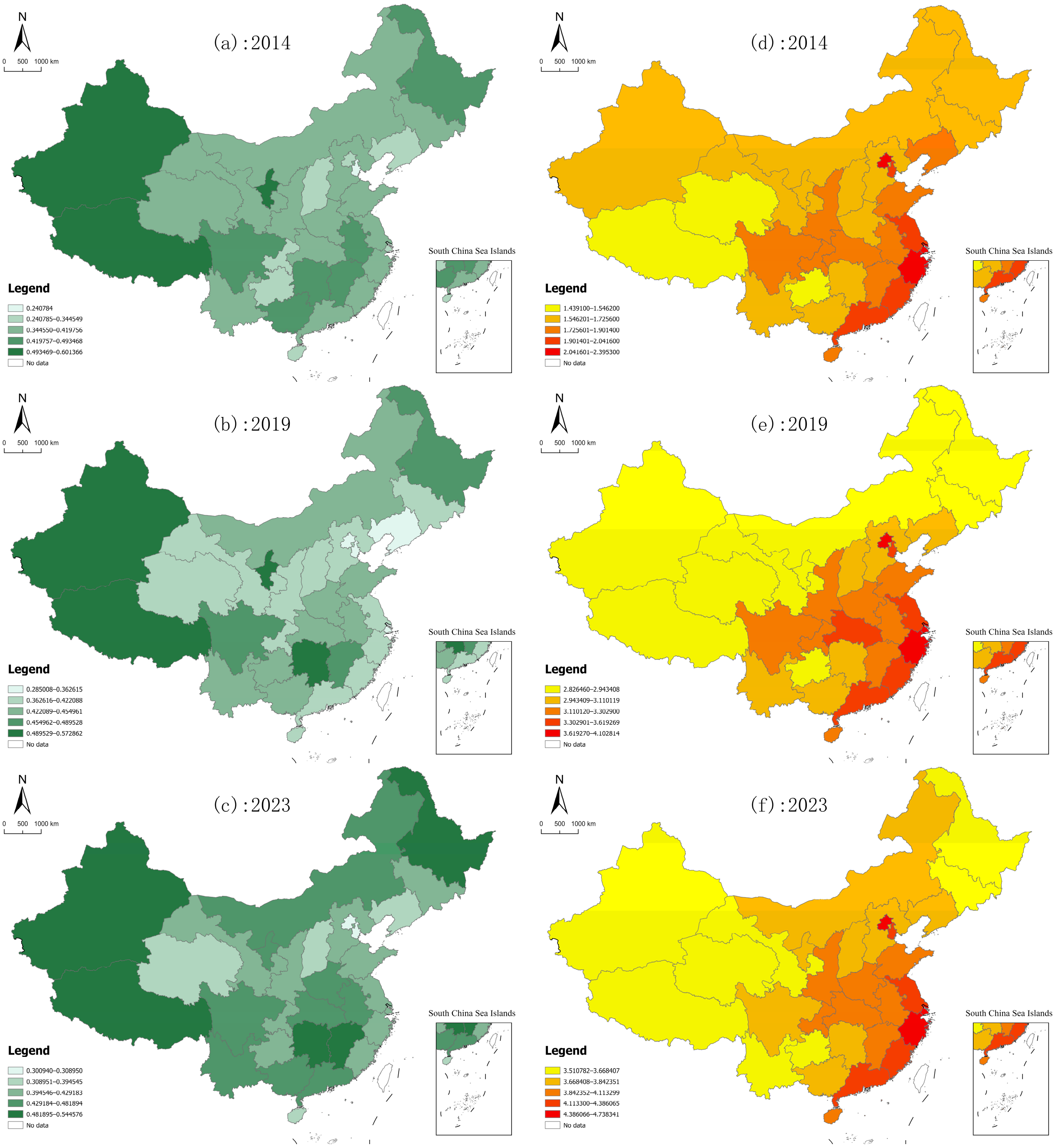

Figure 6. Spatial evolution of agricultural green resilience and digital inclusive finance. (**a**–**c**) Agricultural green resilience in 2014, 2019, and 2023, respectively. (**d**–**f**) Digital inclusive finance in 2014, 2019, and 2023, respectively. Source: Compiled by the authors based on the agricultural green resilience index calculated using the entropy method and the Peking University Digital Financial Inclusion Index.

Table 2. Descriptive statistics of the variables (n = 310).

Variables	Obs	Mean	SD	Min	Max
Agr	310	0.4193	0.0657	0.2408	0.6014
Dif	310	3.0132	0.7595	1.4391	4.7383
Tech	310	7.7774	1.4562	0.6931	10.7350
Gdp	310	10.9596	0.4410	10.0160	12.2400
Urb	310	0.6157	0.1194	0.2615	0.8947
Gov	310	0.2833	0.1969	0.0603	1.3262
Hum	310	0.2221	0.0622	0.0918	0.4441

4.3. Model Selection

Prior to the empirical estimation, an appropriate panel-data specification must be identified. Three types of models are considered: mixed-effects, random effects, and fixed effects. Accordingly, model selection is carried out using the F test, the LM test, and the Hausman test, with detailed results presented in Table 3. The evidence strongly favors the fixed-effects specification over the alternatives. Accordingly, the empirical investigation proceeds using the fixed-effects estimator.

Table 3. Panel data model selection results (n = 310).

Test Type	Statistic	p-Value	Model Selection
F test	82.00	0.0000	Fixed-effects model
LM test	1030.64	0.0000	Random effects model
Hausman test	67.77	0.0000	Fixed effects model

4.4. Benchmark Regression Analysis

Table 4 summarizes the benchmark estimation results. In the specification excluding control variables, digital financial inclusion shows a significantly positive effect on agricultural green resilience, with a coefficient estimate of 0.0748. When the control variables are introduced, the coefficient declines marginally to 0.0666 while retaining statistical significance. This evidence suggests that digital financial inclusion contributes to improvements in agricultural green resilience, providing empirical support for H1.

Regarding the control factors, economic development exhibits a positive coefficient that is statistically significant at the 10% threshold, suggesting that a higher level of economic development contributes to agricultural green resilience through increased financial investment, technological advancement, and improved infrastructure. Government intervention exhibits a positive coefficient that is statistically significant at the 1% threshold, indicating that instruments including agricultural support programs and ecological compensation schemes contribute to improving the ability of the agricultural sector to withstand risks and advance sustainable transformation. Human capital is observed at the 5% significance level, suggesting that a skilled workforce promotes the application of environmentally friendly production techniques while accelerating their dissemination, thereby enhancing agricultural green resilience. In comparison, urbanization exhibits a negative coefficient that is statistically significant at the 5% level. The result implies that the current urbanization process may reduce agricultural green resilience through labor migration away from farming activities.

Table 4. Benchmark regression results (n = 310).

Variables	(1)	(2)
	Agr	Agr
Dif	0.0748 ***	0.0666 ***
	(3.2200)	(3.0792)
Gdp		0.0206 *
		(1.8687)
Urb		−0.3567 **
		(−2.2145)
Gov		0.1571 ***
		(3.3274)
Hum		0.3450 **
		(2.1368)
Id fixed	YES	YES
Year fixed	YES	YES
Constant	0.2666 ***	0.1519
	(6.7682)	(0.9381)
R-squared	0.4178	0.5094
Observations	310	310

Note: Robust t-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.5. Robustness Tests

A series of robustness tests are conducted to validate the baseline findings, including winsorization, re-specification of the model, substitution of the dependent variable, and adjustments to the time sample. The results are reported in Table 5.

Table 5. Robustness test results (n = 310 for winsorization, replacement model, and replacement dependent variable; n = 279 for considering external shocks).

Variables	(1)	(2)	(3)	(4)
	Winsorization	Replacement Model	Replacement Dependent Variable	Considering External Shocks
Dif	0.0697 ***	0.0670 ***	0.0716 ***	0.0675 ***
	(2.8060)	(5.0053)	(3.1308)	(2.9527)
Controls	YES	YES	YES	YES
Id fixed	YES	YES	YES	YES
Year fixed	YES	YES	YES	YES
Constant	0.2287 *	0.0522	0.1196	0.1521
	(1.7680)	(0.3651)	(0.8107)	(0.9389)
R-squared	0.4798		0.3579	0.5094
Observations	310	310	310	279

Note: Robust t-statistics in parentheses, *** $p < 0.01$, * $p < 0.1$.

(1) Winsorization: All variables are winsorized at the 1% level on both ends to alleviate the influence of extreme observations while retaining all observations, thereby avoiding the potential loss of information associated with trimming. Panel regression is then re-estimated. The results in Column (1) of Table 5 show that the coefficient of digital inclusive finance remains positive and statistically significant at the 1% level, supporting the robustness of the main findings.

(2) Replacement model: A Tobit model is adopted as an alternative to the two-way fixed effects specification. According to Column (2) of Table 5, digital inclusive finance shows a significantly positive effect at the 1% level, which further validates the robustness of the baseline estimates.

(3) Replacement dependent variable: In the baseline regression, the agricultural green resilience index is calculated using the entropy method. To further verify the robustness of the findings, this study re-measures rural governance level using the entropy-weighted TOPSIS method and re-estimates the model. In Column (3) in Table 5, digital inclusive finance remains positively significant at the 1% level, confirming the robustness of the baseline findings.

(4) Considering external shocks: Considering the impact of the COVID-19 pandemic, the 2020 observations are removed from the sample and the model is re-estimated. Column (4) of Table 5 indicates a significantly positive effect of digital inclusive finance at the 1% level, reinforcing the robustness of the baseline findings.

4.6. Endogeneity Test

To address the potential endogeneity arising from reverse causality, the one-period lagged digital inclusive finance index is used as an instrumental variable, and the model is estimated using two-stage least squares (2SLS). The empirical results are summarized in Table 6. Columns (1) and (2) both show a significantly positive effect of digital inclusive finance. Furthermore, the Kleibergen-Paap rk LM statistic is significant at the 1% level, indicating that the model does not suffer from an underidentification problem. The Kleibergen-Paap rk Wald F statistic exceeds the Stock-Yogo critical value of 16.38 at the 10% significance level, suggesting that the instrumental variable is not weak. These results indicate that, even after accounting for endogeneity, digital inclusive finance still exerts a positive effect on agricultural green resilience, providing further empirical evidence consistent with H1.

Table 6. Endogeneity test results (n = 279).

Variables	(1)	(2)
	2sls_1	**2sls_2**
L1_Dif	0.7574 ***	
	(18.74)	
Dif		0.1138 ***
		(6.1356)
Controls	YES	YES
Id fixed	YES	YES
Year fixed	YES	YES
Constant	0.6697	0.0292
	(1.56)	(0.1929)
R-squared	0.9960	0.5100
Observations	279	279
Kleibergen-Paap rk LM	LM = 64.090, p = 0.000	
Kleibergen-Paap rk Wald F	2475.614	

Note: Robust t-statistics in parentheses, *** $p < 0.01$.

4.7. Mechanism Analysis

Table 7 shows the empirical results from the mediation effect analysis. Column (1) reports the digital inclusive finance has a significantly positive effect on agricultural technological innovation at the 1% level, implying that its development plays an important role in fostering innovation activities. In Column (2), technological innovation is shown to positively influence agricultural green resilience. Meanwhile, after incorporating agricultural technological innovation into the model, digital inclusive finance is still found to have a significantly positive effect, although its magnitude decreases compared to the baseline regression. Agricultural technological innovation is found to partially transmit the effect of digital inclusive finance on agricultural green resilience, suggesting the existence of a mediating channel in this relationship. Therefore, the results provide empirical support for H2.

Table 7. Mediation effect analysis results (n = 310).

Variables	(1)	(2)
	Tech	Agr
Dif	2.4685 ***	0.0478 **
	(3.3146)	(2.4154)
Tech		0.0084 **
		(2.2339)
Controls	YES	YES
Id fixed	YES	YES
Year fixed	YES	YES
Constant	−11.6190 **	0.3974 ***
	(−2.1737)	(4.3466)
R-squared	0.5825	0.5237
Observations	310	310

Note: Robust t-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$.

4.8. Heterogeneity Analysis

4.8.1. Regional Heterogeneity

Due to differences across geographical locations, historical development, and other factors, China's provinces show marked differences in terms of environmental conditions and economic development. To explore whether the effect of digital inclusive finance on agricultural green resilience varies across regions, the sample is divided into eastern, central, and western subsamples for separate estimations. To examine whether the impact of digital inclusive finance on agricultural green resilience varies across regions, this study follows the approach of Zeng and Gu by dividing the sample into three regional subsamples—eastern, central, and western China—for heterogeneity analysis [59]. This regional classification effectively captures differences in economic development, digital infrastructure, and agricultural development conditions across regions, thereby facilitating the identification of regional heterogeneity in the effects of digital inclusive finance and providing a basis for formulating region-specific policies to promote agricultural green development.

As shown in Table 8, digital inclusive finance exhibits a statistically significant positive effect at the 1% significance level in the central region, while its coefficient is only significant at the 10% level in the western region. However, no statistically meaningful relationship is observed in the eastern region. These regional differences suggest that the effectiveness of digital inclusive finance depends on regional development conditions. Specifically, digital inclusive finance appears to generate greater benefits in regions where conventional financial services are relatively less developed, whereas its marginal effect may be weaker in the eastern region, where financial systems and digital infrastructure are already more mature.

Table 8. Heterogeneity test results (1) (Eastern: n = 110; Central: n = 80; Western: n = 120).

Variables	(1)	(2)	(3)
	Eastern	Central	Western
Dif	−0.0044	0.1295 ***	0.1084 *
	(−0.1310)	(4.2454)	(1.8506)
Controls	YES	YES	YES
Id fixed	YES	YES	YES
Year fixed	YES	YES	YES
Constant	0.3241	1.0102 ***	0.2224
	(1.2357)	(3.5826)	(0.3340)
R-squared	0.7256	0.7788	0.4817
Observations	110	80	120

Note: Robust t-statistics in parentheses, *** $p < 0.01$, * $p < 0.1$.

4.8.2. Dimension Heterogeneity

Digital inclusive finance is commonly evaluated through three indicators, including its coverage breadth (cover), the intensity of its use (usage), and its level of digital development (dig) [60], these dimensions reflect different functional emphases and stages of development. Following the approach of Zhao et al. [61], each dimension was examined separately through regression analysis to further identify the heterogeneity within the internal structure of digital inclusive finance. Table 9 presents evidence that each dimension of digital inclusive finance significantly contributes to the outcome variable. Coverage breadth and depth of use are both significant at the 5% level, while the digitalization level is significant at the 10% level. Among these dimensions, coverage breadth exhibits a relatively stronger estimated effect than depth of use.

Table 9. Heterogeneity test results (2) (n = 310).

Variables	(1)	(2)	(3)
	Agr	Agr	Agr
Cover	0.0581 **		
	(2.0970)		
Usage		0.0479 **	
		(2.5754)	
Dig			0.0170 *
			(1.7567)
Controls	YES	YES	YES
Id fixed	YES	YES	YES
Year fixed	YES	YES	YES
Constant	0.2335	0.0497	0.4459 *
	(1.4297)	(0.2986)	(2.0114)
R-squared	0.4826	0.5175	0.4490
Observations	310	310	310

Note: Robust t-statistics in parentheses, ** $p < 0.05$, * $p < 0.1$.

Specifically, coverage breadth captures the accessibility of financial services. By extending service coverage and reducing market entry barriers, it can ease financing constraints and enhance risk management capacity. In contrast, depth of use focuses on user-side behavior, specifically the extent of engagement with financial products among existing users. This dimension tends to exhibit a relatively small marginal effect. Although the degree of digitalization helps improve service efficiency, its effectiveness is constrained by rural infrastructure and farmers' digital skills, resulting in a slower realization of its benefits and a relatively weaker impact.

5. Further Analysis: Spatial Spillover Effects

5.1. Spatial Correlation Test

Chinese provinces exhibit significant spatial linkages in terms of economic interactions and technology diffusion. Following the methodology adopted by Jiang and Bi [62], this study further investigates spatial dependence by employing the global Moran's I statistic, which is computed based on a contiguity-based spatial weight matrix (W1). The results are summarized in Table 10. Both variables show significantly positive spatial autocorrelation as indicated by the global Moran's I over time. In particular, digital inclusive finance shows an upward trend in Moran's I, increasing from 0.453 in 2014 to 0.578 in 2023, indicating a continuous strengthening of its spatial agglomeration characteristics. These findings suggest that both agricultural green resilience and digital inclusive finance exhibit significant positive spatial dependence.

Table 10. Global Moran index I (n = 310).

Year	Agr		Dif	
	Moran's I	**Z**	**Moran's I**	**Z**
2014	0.209 **	2.082	0.453 ***	4.166
2015	0.223 **	2.186	0.416 ***	3.853
2016	0.245 **	2.366	0.438 ***	4.055
2017	0.230 **	2.218	0.498 ***	4.575
2018	0.257 **	2.462	0.544 ***	4.934
2019	0.282 ***	2.687	0.545 ***	4.932
2020	0.262 **	2.520	0.563 ***	5.083
2021	0.244 **	2.361	0.573 ***	5.162
2022	0.261 **	2.512	0.594 ***	5.295
2023	0.224 **	2.191	0.578 ***	5.166

Note: *** $p < 0.01$, ** $p < 0.05$.

To further explore the spatial correlation characteristics between agricultural green resilience and digital inclusive finance, this study constructs a local Moran's scatter plot (Figure 7). According to the interpretation of the local Moran scatter plot proposed by Anselin [63], the first quadrant (High-High, HH) represents the spatial agglomeration of high-value regions surrounded by high-value neighboring regions, indicating positive spatial association. The third quadrant (Low-Low, LL) represents the clustering of low-value regions with low-value neighboring regions, also reflecting positive spatial association. The second quadrant (Low-High, LH) indicates that low-value regions are surrounded by high-value regions, while the fourth quadrant (High-Low, HL) indicates that high-value regions are surrounded by low-value regions. Both types represent negative spatial association.

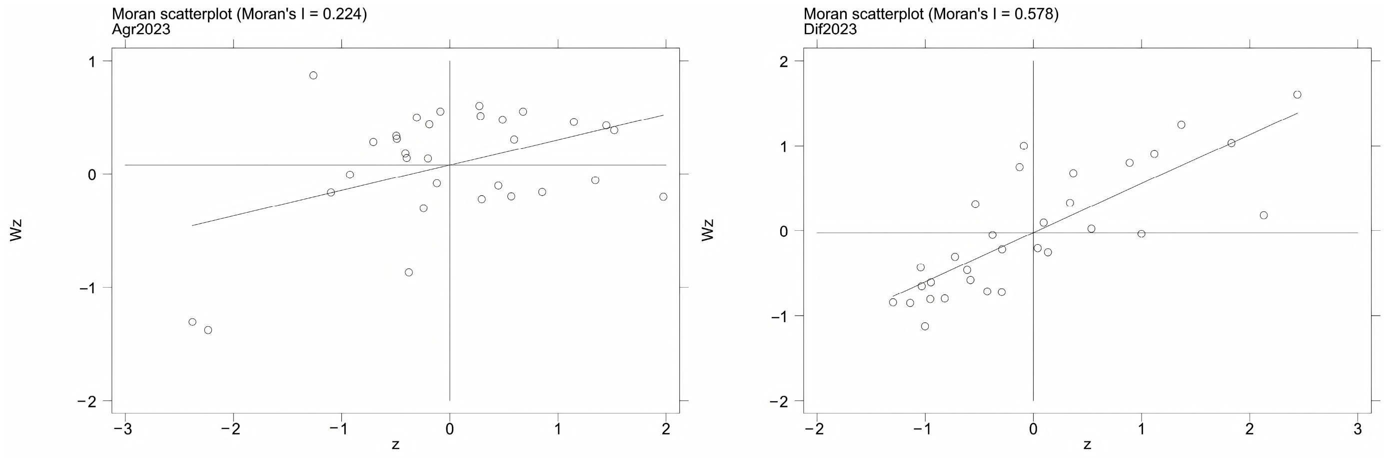

Figure 7. Local Moran scatter plot.

As shown in Figure 7, the observations of agricultural green resilience and digital inclusive finance are mainly distributed in the first and third quadrants, indicating significant positive spatial dependence between the two variables. Specifically, high-level regions tend to be adjacent to other high-level regions, while low-level regions tend to be surrounded by low-level regions. In contrast, relatively few observations are located in the second and fourth quadrants, suggesting that spatial heterogeneity and negative spatial associations are relatively limited. Overall, these results indicate a trend toward coordinated development between neighboring regions.

5.2. Spatial Econometric Model Selection

To select an appropriate spatial econometric specification, several diagnostic procedures were implemented and are summarized in Table 11. The LM test results indicate that both the spatial error and spatial lag effects are statistically significant at the 1% level, suggesting that the SDM is the preferred specification for spatial econometric analysis.

Table 11. Spatial econometric model diagnostic results (n = 310).

Type of Test	Test Results	p-Value
LMerr	14.129	0.000
Robust LMerr	22.894	0.000
LMlag	18.846	0.000
Robust LMlag	27.611	0.000
Wald	29.44	0.000
	46.23	0.000
LR	29.30	0.000
	47.01	0.000
Hausman	16.04	0.025

To verify whether the SDM can be simplified, Wald and LR tests are performed. The estimation results indicate rejection of the null hypotheses at the 1% level, confirming that the SDM cannot be reduced to either a SAR model or SEM model.

Since the Hausman test produces a statistically significant result at the 5% level, the fixed-effects model is considered more appropriate. On this basis, the study adopts a SDM with two-way fixed effects, which allows for a more precise examination of the spatial spillover effects of digital inclusive finance on agricultural green resilience.

5.3. Regression Results of Spatial Durbin Model

Using the adjacency weight matrix (W1) as the spatial weighting scheme, column (1) of Table 12 reports the corresponding estimation results. Significantly positive estimates are obtained for both the spatial autoregressive coefficient (ϱ) of agricultural green resilience and the spatial lag term of digital inclusive finance. The results suggest a dual effect of digital inclusive finance. It enhances agricultural green resilience at the local level and simultaneously produces significant spillover effects that benefit neighboring regions. Meanwhile, both results show that both types of effects—direct and indirect—are statistically significant and positive, suggesting that the digital finance development enhances local agricultural green resilience, but also breaks spatial and regional constraints, thereby promoting improvements in agricultural green resilience in adjacent areas. Therefore, H3 is supported.

As a robustness check, the analysis is repeated with two alternative spatial weighting specifications: W2 reflecting geographical proximity among regions and W3 capturing economic linkages across regions. Evidence from Columns (2) and (3) of Table 12 indicates that the positive relationship between digital inclusive finance and agricultural green resilience remains statistically significant after replacing the benchmark spatial weight matrix. This finding confirms the robustness of the positive spillover effect across different spatial specifications. Both the model specification and the empirical results are robust. Accordingly, policy efforts should extend beyond local digital advancement and place greater emphasis on collaborative regional governance. Facilitating the spread of benefits from digital financial inclusion can enhance agricultural system resilience. In addition, it supports sustainable agricultural development across regions.

Table 12. Spatial panel Durbin model estimation results (n = 310).

Variables	(1)	(2)	(3)
	W1	W2	W3
Dif	0.0742 ***	0.0409 **	0.0414 ***
	(2.8338)	(2.3031)	(2.7350)
Wx	0.0768 **	0.1722 *	0.2416 ***
	(2.1205)	(1.8419)	(3.2866)
Rho	0.2592 ***	0.4771 ***	0.3287 **
	(3.7817)	(3.3189)	(1.9778)
LR_Direct	0.0766 ***	0.0501 ***	0.0489 ***
	(2.7865)	(2.9452)	(3.1454)
LR_Indirect	0.0261 *	0.4018 *	0.4122 **
	(1.8050)	(1.6674)	(2.0353)
LR_Total	0.1027 ***	0.4520 *	0.4611 **
	(2.6111)	(1.8860)	(2.2563)
Id fixed	YES	YES	YES
Year fixed	YES	YES	YES
R-squared	0.6729	0.4257	0.3474
Observations	310	310	310

Note: z-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

6. Discussion

The findings demonstrate that digital inclusive finance should be understood not merely as a financial service innovation, but as an institutional mechanism that reshapes resource allocation and strengthens the adaptive capacity of agricultural systems. By improving financial accessibility and reducing constraints faced by agricultural actors, digital finance provides a new pathway for achieving sustainable agricultural transformation. This finding is consistent with previous studies suggesting that digital finance can improve the efficiency of resource allocation, alleviate financing constraints, and promote green development [64]. Compared with recent studies from ASEAN countries, which focuses on the contribution of digital inclusive finance to agricultural green development [65], this study extends the research perspective to agricultural green resilience, providing a more comprehensive understanding of the role of digital inclusive finance in promoting sustainable agricultural transformation.

From a mechanism perspective, this study reveals that technological innovation serves as a critical bridge linking digital financial development and agricultural green resilience. This finding extends existing discussions on digital finance beyond its traditional role in improving financing conditions and highlights its capacity to stimulate innovation-driven agricultural transformation. Similar evidence has been reported in previous international studies, which suggest that digital financial development facilitates green innovation by improving financing conditions and supporting technological progress [66,67].

The spatial analysis further reveals that digital inclusive finance generates significant spatial spillover effects, promoting agricultural green resilience not only within a province but also in neighboring regions. This may be because digital financial services facilitate the cross-regional diffusion of financial resources, technological knowledge, and green production practices, allowing neighboring regions to benefit from digital financial development. Meanwhile, the development of digital finance weakens geographical barriers and enhances interregional connectivity, making it easier for capital, information, and innovation resources to flow across provincial boundaries. As a result, neighboring regions can learn from successful development experiences, accelerate the adoption of green agricultural technologies, and optimize the allocation of agricultural resources, ultimately generating significant positive spillover effects on agricultural green resilience.

The heterogeneity analysis further demonstrates that the effects of digital inclusive finance vary across regions and different dimensions of digital inclusive finance. Stronger effects in the central and western regions suggest that digital finance generates greater benefits where traditional financial services are relatively underdeveloped, while the weaker effects in the eastern region may reflect diminishing marginal returns under more mature financial systems. In addition, coverage breadth exerts a stronger influence than usage depth and digitalization level, indicating that expanding access to digital financial services remains essential for enhancing agricultural green resilience.

Although this study focuses on China, its findings also provide broader implications for sustainable agricultural development in other developing countries facing challenges such as limited rural financial access and increasing environmental risks. The Chinese experience suggests that digital inclusive finance can improve financial inclusion, promote green technological progress, and enhance agricultural resilience. However, its effectiveness depends on supporting conditions, including adequate digital infrastructure and institutional support.

Overall, the results obtained from the baseline regression, mediation analysis, spatial econometric model, and heterogeneity analysis advance the understanding of digital financial development and agricultural sustainability. Together, these findings reveal three interconnected mechanisms: institutional support through financial inclusion, innovation-driven transformation through technological progress, and regional diffusion through spatial connectivity. Therefore, digital inclusive finance should be considered not only as a tool for expanding financial access but also as a broader governance mechanism that facilitates resilient and green agricultural development.

7. Conclusions and Recommendations

7.1. Conclusions

Focusing on 31 provincial regions in China during the 2014–2023 period, the study assesses the influence of digital financial inclusion on the capacity of agriculture to achieve sustainable and resilient development. The analyses are conducted from multiple perspectives, including spatiotemporal evolution characteristics, impact mechanisms, spatial spillover effects, and heterogeneous effects.

First, both agricultural green resilience and digital inclusive finance sustained growth during the sample period, Nevertheless, considerable regional disparities remain. Agricultural green resilience displays an uneven spatial distribution across provinces, whereas digital inclusive finance exhibits a pronounced regional disparity, with stronger development observed in coastal areas and weaker performance in the interior regions.

Second, Agricultural green resilience is significantly enhanced by the development of digital inclusive finance. The positive relationship remains stable after multiple robustness checks and endogeneity treatments, including tail trimming, replacement model, replacement dependent variable, considering external shocks, and the introduction of instrumental variables, the baseline findings remain robust. The results demonstrate that advances in digital inclusive finance are closely associated with higher levels of agricultural green resilience, underscoring its importance in the green transformation of agriculture.

Third, agricultural technological innovation serves as an important transmission channel. By broadening access to financial resources, reducing information asymmetry, and improving capital allocation efficiency, digital inclusive finance facilitates innovation activities and promotes the application of environmentally friendly technologies, which in turn improves the adaptive capacity of agricultural systems.

Fourth, significant heterogeneity exists in the effects of digital inclusive finance across different regions and dimensions. From a regional perspective, compared with other regions, the central region benefits the most from digital inclusive finance. The positive effect is also evident in the western region, but no significant influence is found in the eastern region. From a dimensional perspective, the strength of influence across different development dimensions is ranked as coverage breadth being the strongest, followed by usage depth, and digitalization level being the weakest, indicating that coverage breadth contributes more strongly to improvements in the greening and adaptive capacity of the agricultural sector than the other components of digital inclusive finance.

Finally, the spatial analysis results further indicate that both digital inclusive finance and agricultural green resilience exhibit significant positive spatial autocorrelation. Spatial Durbin Model estimates indicate significant local and cross-regional benefits associated with digital inclusive finance. Besides strengthening agricultural green resilience within a region, it also facilitates improvements in adjacent provinces through technology spillovers, information sharing, and resource reallocation.

7.2. Recommendations

First, accelerate the advancement of the digital inclusive finance system. To reduce regional disparities requires continuous investment in rural digital networks and wider availability of financial services across western regions such as Yunnan, Tibet, and Xinjiang, thereby narrowing the regional gap in digital financial development. Meanwhile, greater use of digital financial technologies in agricultural production should be encouraged, accompanied by improvements in the availability, especially those related to electronic payments and credit access. Promoting creativity in digital finance requires financial institutions to diversify product offerings and adopt more efficient service frameworks, develop more green financial products tailored to the characteristics of agricultural production, and lower the financing barriers and costs for agricultural operators.

Second, strengthen agricultural technological innovation capacity. Innovation efficiency can be enhanced through better-designed policy incentives, a more supportive innovation environment, and closer cooperation among enterprises, universities, research organizations, and agricultural producers. The wider diffusion of green technologies and their practical adoption should be promoted to strengthen resilience against resource limitations, environmental pressures, and various external disturbances.

Third, region-specific approaches should be adopted to address differences in local development conditions. Compared with eastern regions, central and western areas benefit more substantially from the development of digital inclusive finance. Therefore, greater efforts can be directed toward improving the utilization and distribution of digital financial resources in these regions to better support agricultural transformation and sustainable growth. Thereby creating stronger momentum for agricultural transformation and sustainable growth. By contrast, eastern regions can place greater attention on strengthening the interaction between digital finance and agricultural innovation, green industrial upgrading, and smart agriculture initiatives. Such efforts can improve the effectiveness of financial service delivery and provide stronger support for green agricultural modernization.

Fourth, enhance interregional collaboration and facilitate the diffusion of benefits generated by digital inclusive finance across neighboring areas. The government should establish cross-regional cooperation and information-sharing mechanisms in digital finance, and promote the interregional flow of digital resources, agricultural technologies, and innovation outcomes. By enhancing regional linkage development and experience exchange, the demonstration and spillover effects of more developed regions on less developed regions can be strengthened.

7.3. Limitations

Limited data availability confines the analysis to the provincial level, which prevents a comprehensive examination of the micro-level pathways through which digital inclusive finance influences agricultural green resilience, and the relevant causal pathways require further refinement and validation. Despite the empirical findings, concerns related to causal inference cannot be completely ruled out. The possibility that digital inclusive finance and agricultural green resilience may influence each other has not been thoroughly investigated, thereby weakening the credibility of causal interpretations derived from the estimates. Furthermore, the current analysis is primarily based on a linear framework and has not thoroughly explored potential nonlinear relationships or threshold effects among variables, leaving room for further expansion in depicting complex relationships.

7.4. Future Research

Future research could be extended in three aspects. First, more detailed micro-level and regional datasets could be incorporated to better understand the mechanisms underlying the relationship between digital inclusive finance and agricultural green resilience. For instance, household survey data could be used to examine how digital financial services affect farmers' access to credit, green technology adoption, and production decisions, while county-level panel data could further capture the influence of local agricultural conditions, digital infrastructure, and policy environments.

Second, more robust identification strategies could be adopted to improve causal inference. Future studies could employ instrumental variable approaches to address potential reverse causality and omitted variable bias, while difference-in-differences models could be used to evaluate the effects of specific digital finance-related policies or pilot programs on agricultural green resilience.

Third, future research could further explore the nonlinear and heterogeneous effects of digital inclusive finance. Threshold models could be applied to identify whether the impact of digital inclusive finance varies with different levels of digital infrastructure, agricultural modernization, or regional economic development. In addition, interaction models could be introduced to examine the moderating roles of factors such as technological innovation capacity, environmental regulation, and rural human capital, thereby providing a more comprehensive understanding of the conditions under which digital inclusive finance promotes agricultural green resilience.

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