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The impact of high-standard farmland construction on farmers' agricultural green production technologies adoption behavior

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High-standard farmland construction (HSFC) is crucial for advancing green agricultural development. Based on 1,350 rice farmers' research data in Jiangxi Province, this study uses a multivariate ordered probit model and mediation effect model to examine the impact of HSFC on farmers' agricultural green production technologies (AGPTs) adoption behavior and its influence mechanisms. The results show that: HSFC can substantially enhance the adoption of AGPTs among farmers. The mediation effect analysis results show that the socialized agricultural service and land transfer play a partly mediating role between the HSFC and the adoption behavior of AGPTs by farmers. Heterogeneity analysis shows that farmers with high education, high income and in plain areas are more inclined to embrace AGPTs after participating in HSFC. Therefore, the government needs to promote the active utilization of AGPTs among farmers by enhancing support for HSFC, improving the agricultural socialized service system and regulating the land transfer market.

KEYWORDS

high-standard farmland construction, agricultural green production technologies, agricultural socialization services, land transfer, rice farmers

1 Introduction

Against the backdrop of global sustainable development, the green transformation of agriculture has become a critical issue that needs urgent resolution (Zhang Q. et al., 2023). China's Green Agricultural Development Report 2023 shows that China's green agricultural development index rose to 77.90 in 2022, increasing by 2.71 and 0.37 compared with 2015 and 2021, respectively. However, the utilization efficiency of fertilizers and pesticides for rice, wheat, and corn (41.3, 41.8%) and the off-field utilization rate of straw (35.8%) in China still have considerable room for improvement. Agricultural green production technologies (AGPTs) are crucial for ensuring agricultural product quality, protecting the ecological environment, and improving agricultural economic benefits (Adnan et al., 2019; Asiedu-Ayeh et al., 2022). However, farmers have a low willingness to adopt these technologies due to constraints such as technical uncertainty, long return cycles, and capital endowment (Arhin et al., 2023; Mohankumar et al., 2023; Singh et al., 2023). In particular, the cultivated land quality endowment of farmers constrains their adoption of AGPTs (Shen and Wang, 2024). With the strengthening of state policy support, high-standard farmland construction (HSFC), through comprehensive renovation and transformation, has become a new engine for promoting green agricultural development (Zheng et al., 2025). By the end of 2023, China had cumulatively built over 1 billion mu of high-standard farmland, with the average grade of

cultivated land reaching 4.76. Therefore, exploring the impact of HSFC on farmers' adoption behavior of AGPTs is of great significance for promoting green agricultural development.

Existing studies have richly explored the elements affecting farmers' readiness and actions to use AGPTs. These include individual attributes such as gender (Dar et al., 2020), age (Adnan et al., 2019), and education level (Jabbar et al., 2022); household characteristics such as agricultural income share (Danso-Abbeam et al., 2020), labor force working outside the home (Li Y. et al., 2023), and social network (Kos et al., 2023); cognitive traits such as risk perception (Li et al., 2022) and ecological cognition (Xu et al., 2023); production and operation characteristics such as membership in cooperatives (Zhang Y. et al., 2023), agricultural insurance (Carter et al., 2016), scale of operation (Kolady et al., 2021), land fragmentation (Cholo et al., 2018) and other production and operation characteristics, as well as external environmental factors such as government subsidies (Koppmair et al., 2017) and environmental regulations (Xu et al., 2023).

Considering the key position of HSFC in the process of agricultural modernization, many scholars are increasingly focusing their research on the future development path of high-standard farmland and the multifaceted impacts it produces in the construction process. In terms of the development path, scholars assert that promoting HSFC should focus on solving the dilemmas of funding sources, organizational efficiency, and effectiveness of management and care (Yin et al., 2022). In terms of construction effects, scholars mainly focus on the significant impacts of HSFC on rural economic development (Peng et al., 2022), farm household income growth (Chen X. et al., 2024), food production capacity enhancement (Hao et al., 2024), agricultural land transfer (Chen L. et al., 2024), cropland abandonment (Zhang et al., 2024), and agricultural green development (Liu and Lin, 2024). Further analysis reveals that in the studies exploring the relationship between HSFC and agricultural green advancement, scholars mostly analyze from a macro perspective (Li L. et al., 2023; Zheng et al., 2025).

In summary, most of the previous research results focus on the influence of HSFC on the green advancement of agriculture from a macro perspective, and few studies have explored the impact of HSFC on farmers' utilization of AGPTs by based on a micro perspective. At the same time, the intrinsic influence mechanism between HSFC and AGPTs by farmers needs to be clarified. In addition, the heterogeneity of farm households has led to differences in the effect of HSFC on the utilization of AGPTs by farm households, warranting further study.

Given this, this study aims to comprehensively utilize the multivariate ordered probit model and mediation effect test method, utilizing data from farmers in Jiangxi Province in 2023, to explore the effect of HSFC on the utilization behavior of AGPTs by farmers. Analyzing the influence mechanism between the HSFC and the utilization of AGPTs by farmers from the perspectives of mechanization and scaling up. Meanwhile, this study will further delve into the diverse effects of HSFC on their technologies adoption behaviors under different conditions, aiming to provide practical reference for the enhancement of AGPTs adoption by farmers and the realization of the goal of high-quality agricultural development.

This study's contribution to the literature is reflected in the following points: first, this study explores the effect of HSFC on the utilization behavior of AGPTs from the micro perspective of farmers. Second, this study analyzes the mediating roles of agricultural socialization services and land transfers between HSFC and farmers' AGPTs usage behaviors from two perspectives: mechanization and scale. Third, it examines the varied effects of HSFC on farmers' AGPTs adoption behaviors under different human capital, economic capital, and natural capital conditions.

The subsequent sections of this study are organized as follows: Section 2 comprises the theoretical examination and formulation of research hypotheses. In Section 3, the materials and procedures are presented. The findings and discussion are presented in Section 4, while the conclusions and recommendations are provided in Section 5.

2 Theoretical analysis and research hypotheses

2.1 Impact of high-standard farmland construction on farmers' agricultural green production technologies adoption behavior

The implementation of HSFC has significantly contributed to advancing the green growth of agriculture (Zheng et al., 2025). On the one hand, HSFC optimizes farmland infrastructure (e.g., irrigation, field roads), providing a hardware foundation for AGPTs implementation and lowering farmers' technologies adoption barriers (Huang et al., 2024). On the other hand, advanced agricultural technologies and management modes are also introduced in the process of HSFC (Gong et al., 2023), which facilitates the process of agricultural modernization. In the process, farmers have the opportunity to be exposed to more AGPTs and management concepts, thus increasing their awareness of green production. In addition, there exists a deep emotional bond and a high degree of dependence between farmers and the land, and the high value attributes assigned to the land in the cognitive system of farmers make them present a cherished mentality towards the land (Yoshida et al., 2018). Based on the consideration of the long-term benefits of land, farmers will be more inclined to enhance the preservation of land after HSFC (Feng et al., 2024).

> *Hypothesis 1.* HSFC will induce farmers to adopt AGPTs.

2.2 Analysis of the impact mechanism of high-standard farmland construction on farmers' agricultural green production technologies adoption behavior

2.2.1 High-standard farmland construction, agricultural socialization services and farmers' agricultural green production technologies adoption behavior

HSFC has a vital role in advancing the development of agricultural socialized services (Zhang et al., 2024). On the one hand, HSFC creates more favorable conditions for agricultural machinery operation by optimizing land leveling and field road infrastructure. The continuous improvement of land quality has enabled large agricultural machines to plow more efficiently, reducing the downtime of machinery when operating in small-scale, irregular plots. The enhanced accessibility of field roads has ensured the smooth passage

of agricultural equipment, allowing it to reach the operation area more quickly and safely, thus improving agricultural machinery efficiency. On the other hand, factor substitution theory indicates that improving the quality of agricultural land triggers a shift in farmers' production factor input structure. Farmers will reduce investment in traditional agricultural factors and increase investment in modern agricultural technologies and machinery. Specifically, as HSFC has upgraded farmland infrastructure and arable land conditions, farmers' demand for specialized agricultural socialization services has grown.

And agricultural socialized services can stimulate farmers' motivation to use AGPTs (Drewry et al., 2022). First, socialized service organizations can minimize farmers' information search and procurement costs by centralized purchasing of green agricultural materials, by virtue of the scale effect. Simultaneously, socialized service organizations can also optimize the allocation of resources, improve the efficacy of resource use in the application of AGPTs, and further reduce production costs (Wang and Huan, 2023). Secondly, through organizing various training activities, carrying out field demonstrations and distributing technical information, social service organizations can accurately transfer the principles, operational points and advantages and benefits of technologies to farmers, which can help lower the threshold of farmers' knowledge of technologies, thus stimulating the intrinsic motivation of farmers to use AGPTs (Sáenz et al., 2024).

> *Hypothesis 2.* Agricultural socialization services play a mediating role between the effects of HSFC on farmers' AGPTs adoption behavior.

2.2.2 High-standard farmland construction, land transfer and farmers' agricultural green production technologies adoption behavior

HSFC has a vital role in facilitating the transfer of farmers' land (Chen L. et al., 2024). HSFC markedly enhances the quality of land through land remediation, soil improvement and other measures, while the enhancement of the quality of land enhances the production potential and output level of the land, which makes farmers more inclined to transfer to the land in order to expand the scale of operation. Simultaneously, HSFC significantly improves irrigation, drainage and other farmland water conservancy facilities and reduces the occurrence of natural disasters (Pu et al., 2019), which in turn promotes the transfer of farmers' land. Existing studies have shown that land transfer helps to expand the scale of land operation, which is the fundamental path to realizing the green agriculture (Nigussie et al., 2017). On the one hand, large-scale farmers have higher capital endowment than small farmers, and can bear and resist the costs and risks of adopting AGPTs, thus the higher possibility of adopting technologies (Nigussie et al., 2017); on the other hand, the enlargement of the scale of operation can help farmers to generate economies of scale in the use of AGPTs, thus reducing the production cost of agricultural products per unit. In addition, large-scale households usually prioritize improving the quality and market competitiveness of agricultural goods in order to realize higher economic returns. And the application of technologies can improve the quality of agricultural goods and satisfy the growing market demand for green agricultural goods (Valizadeh et al., 2023).

> *Hypothesis 3.* Land transfer plays a mediating role between the effects of HSFC on farmers' AGPTs adoption behavior.

According to the aforementioned theoretical analysis, this study constructs a theoretical analysis framework diagram of the effect of HSFC on farmers' AGPTs adoption behavior, as shown in Figure 1.

3 Materials and methods

3.1 Data sources

This study is based on data from a field survey actualized by the Jiangxi Agricultural University between June and July 2023. The survey adopted the stratified random sampling method, sorted the counties (cities, districts) in each region according to the per capita gross domestic product (GDP) of the counties, divided all counties (cities, districts) into three groups with high, medium and low economic development levels, and then randomly selected eight sample counties (cities, districts) from each group. The selected samples cover 11 prefecture-level cities in Jiangxi Province, including not only economically strong counties, but also counties with relatively backward economic development, as well as major grain-producing and non-grain-producing counties, and counties dominated by plains and mountains.

Townships in each sample county were randomly chosen based on nighttime light data. The townships were categorized into three groups—high, medium, and low economic development levels. One

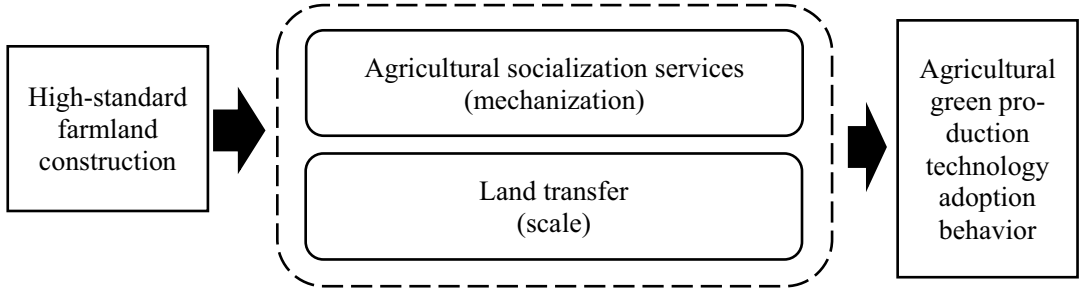

FIGURE 1
Theoretical analysis framework.

township was chosen from each group, yielding three townships per county. In each township, the stratified random selection technique was applied, selecting three villages and 10 farm households from each village. The survey focused on farm households and covered three levels—household, individual, and village. The questionnaire addressed five key areas: industrial success, ecological sustainability, rural culture, government efficiency, and lifestyle prosperity. A total of 2,160 questionnaires were distributed. According to the requirements of this study, after excluding samples from households that did not grow rice and those with missing key information, a total of 1,350 samples of rice-growing households were obtained (see Figure 2).

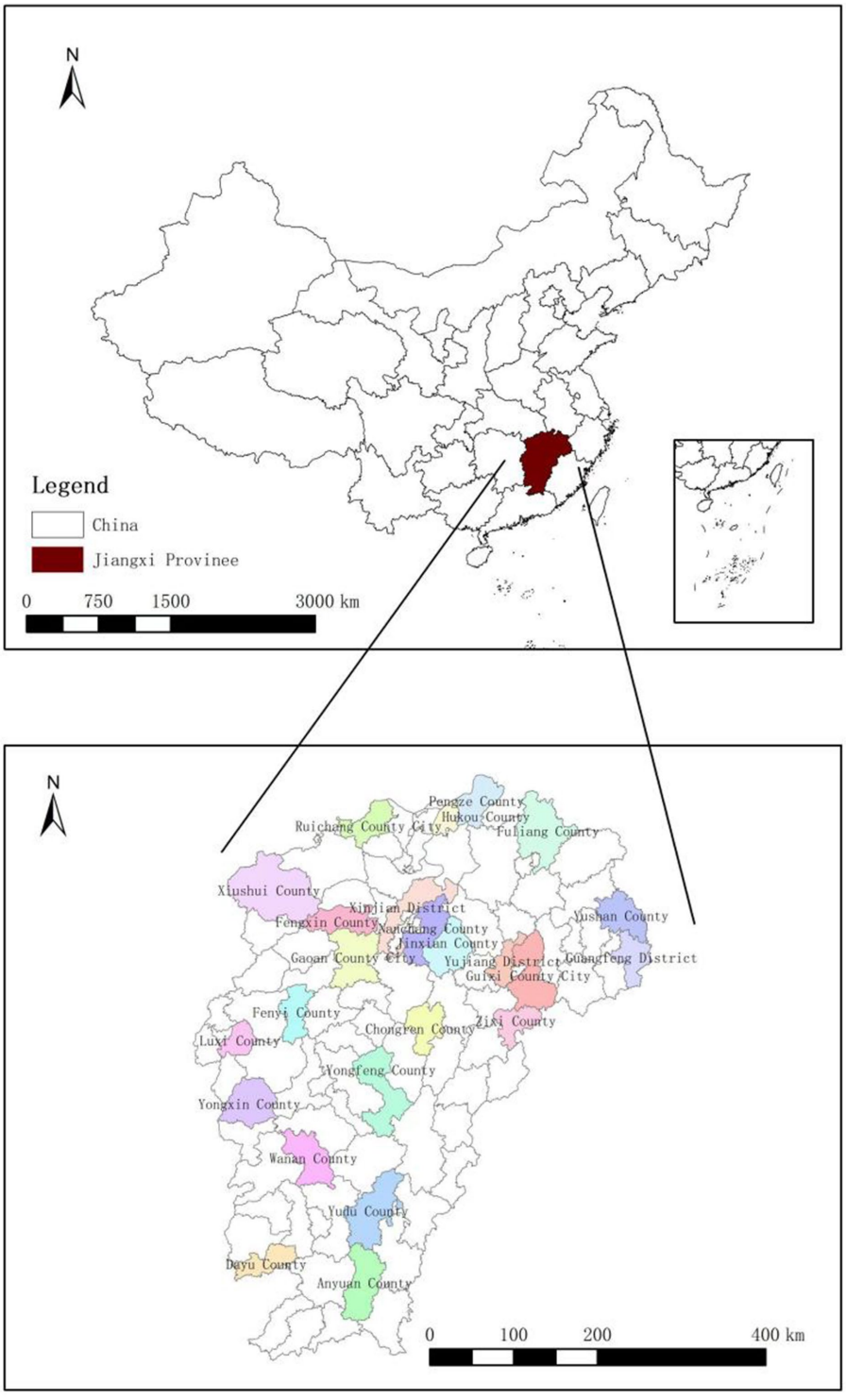

FIGURE 2
Study area.

3.2 Variable selection

3.2.1 Explained variables

The explained variable is AGPTs adoption behavior of farmers. These technologies are the general term for a collection of advanced technologies, competencies, instruments, and rule systems used in the agricultural production process to achieve the sustainable development goals of environmental protection, efficient use of resources, and safeguarding human health and safety (Chen Y. et al., 2024). Therefore, with reference to the content in the Technical Guidelines for Agricultural Green Development (2018–2030) and drawing on existing studies (Li et al., 2022; Zou et al., 2023), this study selected five AGPTs involving pre-production, mid-production and post-production soil testing and formula fertilization technology, organic fertilizer technology, pest and disease green prevention and control technology, recycling of agro-film and pesticide packaging, and straw crushing and returning to the field. Finally, the number of farmers' participation was used to characterize their AGPTs adoption behavior.

3.2.2 Core explanatory variables

The core explanatory variable is whether farmers have built high-standard farmland. As the foundation of agricultural output, farmland construction is essential for advancing the green development of agriculture. With the rapid development of China's agricultural modernization, HSFC not only pursues the improvement of yield, but also emphasizes the greening and sustainability of agricultural production. 0 indicates that farmers have not built high-standard farmland, and 1 indicates that farmers have built high-standard farmland.

3.2.3 Mediating variables

The mediating variables are agricultural socialization services and land transfer. Agricultural socialization services imply the diverse offerings given to agricultural producers (including farmers, family farms and farmers' cooperatives) throughout the pre-production, production and post-production processes in the course of agricultural production and management. These services are provided by a variety of institutions, organizations or individuals in society, with the aim of helping agricultural producers to better complete agricultural production activities, enhance the efficacy of agricultural production and the quality of agricultural goods, and promote the advancement of specialization, scale and modernization of agriculture. In this study, the quantity of agricultural socialized services adopted by farmers in the rice production process is chosen to characterize agricultural socialized services. Specifically, if farmers do not adopt, the variable is assigned a value of 0; otherwise, the variable takes a value greater than 0.

Land transfer in refers to the behavior of farmers or agricultural business entities (e.g., family farms, farmers' cooperatives, agribusinesses, etc.) who obtain land management rights from other land contract owners throughout the land transfer process. This study specifically characterizes the situation of land transfer from farm households by assigning a value of 0 if the land is not transferred, and vice versa, assigning a value of 1.

3.2.4 Control variables

Drawing on existing studies (Guo et al., 2022; Zhang Y. et al., 2023), this study incorporates respondents' individual, household, production and business, village, and regional characteristics into the model. Among them, individual characteristics include gender, age, educational level, health status, and village cadre status; household characteristics include the number of laborers and disposable income; production and operation characteristics include the degree of land fragmentation and paddy fertility status; village characteristics include topography; regional features include Ganbei, Ganzhong, and Gannan.

3.2.5 Instrumental variables

According to the study of Lin et al. (2022), this study chose "construction of high-standard farmland in the county" as an instrumental variable, and measures it by using the proportion of HSFC of farmers other than the farmer households in question within the county. High-standard farmland construction projects are promoted at the county level. If the completion rate of HSFC projects in the county where farmers are located is high, the probability that the cultivated land of the village group where farmers are located will be constructed into high-standard farmland increases, satisfying the relevance requirement of the instrumental variable. However, the HSFC of other farmers in the same county does not directly affect the adoption of AGPTs by this farmer, satisfying the exogeneity requirement of the instrumental variable. Based on the above analysis, this study concludes that the selection of instrumental variables is more reasonable.

The meaning of each variable and its descriptive statistics are presented in Table 1. The mean value of AGPTs adoption behavior of farmers is 1.171, indicating that the extent of technologies usage by farmers is low. The proportion of farmers participating in HSFC accounted for 62.7% of the total sample, indicating that the rate of HSFC by farmers was high. Among the mediating variables, the mean value of agricultural socialization services is 1.812, signifying that the adoption of agricultural socialization services by farm households is low; the proportion of farm households whose land is transferred accounts for 40.6% of the total sample, indicating that the transfer rate is low. Among the control variables, male respondents were predominant, with a mean age of about 58 years old, more primary and junior high school educated, and in good health, but fewer farm households had the status of village cadres; the mean value of the number of family laborers was slightly more than three, and the mean value of the household disposable income did not exceed 50,000 yuan; the paddy fields were more finely fragmented, but the overall fertility status was better; and the topography of the villages was predominantly mountainous and hilly.

Table 1 also reports the disparity in the mean values of the variables between the two types of farmers who participated in HSFC or not. The results show that farmers participating in HSFC have a higher probability of adopting AGPTs, which is 0.210 units higher than the probability of using AGPTs for farmers not participating in HSFC. From this, it is initially inferred that HSFC significantly contributes to the adoption of AGPTs by farmers. This lays an important foundation for the empirical research of this study. In terms of mediating variables, agricultural socialization services and land transfer of farmers participating in HSFC are 0.254 and 0.122 units higher than non-participants, respectively, signifying that farmers participating in HSFC are more predisposed to embrace agricultural socialization services and land transfer than non-participants. In terms of control variables, rural residents participating in HSFC are more likely to

TABLE 1 Descriptive statistics for each variable.

Variable type	Variable name	Variable definition and assignment	Average value	Standard deviation	No participation in HSFC	Participation in HSFC	Mean difference
Explained variable	Agricultural green production technologies adoption behavior	The number of adopted AGPTs: 0–5	1.171	1.047	1.040	1.249	−0.210***
Core explanatory variable	High-standard farmland construction	Not built = 0; built = 1	0.627	0.484	0	1	−1
Mediating variable	Agricultural socialization services	Number of agricultural production chain outsourcing	1.812	1.404	1.653	1.907	−0.254***
	Land transfers	Not transferred = 0; transferred = 1	0.406	0.491	0.329	0.452	−0.122***
Individual characteristic	Gender	Female = 0; male = 1	0.842	0.365	0.833	0.848	−0.014
	Age	Actual age of respondent, years	58.260	10.840	59.468	57.541	1.927***
	Educational level	Illiterate = 1; elementary school = 2; middle school = 3; high school/secondary school = 4; college and above = 5	2.843	0.955	2.843	2.843	0
	Health status	Very unhealthy = 1; less unhealthy = 2; fair = 3; more healthy = 4; very healthy = 5	3.853	0.984	3.736	3.922	−0.186***
	Village cadre status	No = 0; yes = 1	0.262	0.440	0.246	0.272	−0.026
Family characteristics	Number of family laborers	Number of family laborers, persons	3.061	1.869	2.867	3.176	−0.309***
	Household disposable income	Less than 30,000 RMB = 1; 30,000–50,000 RMB = 2; 50,000–80,000 RMB = 3; 100,000–120,000 RMB = 4; 120,000 RMB or more = 5	2.485	1.425	2.409	2.531	−0.122
Characteristics of production and operation	Degree of land fragmentation	Total number of family business plots/total business area, %	1.147	1.096	1.374	1.012	0.361***
	Fertility status of paddy fields	Very poor = 1; poorer = 2; fair = 3; better = 4; very good = 5	3.367	0.825	3.337	3.385	−0.048
Village characteristics	Village topography	Non-plain = 0; plain = 1	0.121	0.326	0.093	0.137	−0.044**
Area dummy variables	Ganzhong (Control group: Ganbei)	No = 0; yes = 1	0.235	0.424	0.220	0.243	−0.023
	Gannan (Control group: Ganbei)	No = 0; yes = 1	0.150	0.357	0.157	0.145	0.011
Instrumental variable	Construction of high standard farmland in the county	Percentage of high-standard farmland constructed by farmers other than this farmer in the county	0.627	0.241	0.481	0.714	−0.233***

,*Indicates significant at the 5 and 1% level, respectively.

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be male, younger, more educated mainly in primary and junior high school, in better health, have more village cadres, have a larger number of family laborers, have higher household disposable incomes, have less land fragmentation, have better paddy field fertility, and have more gently sloping village topography.

To further understand the differentiating characteristics of the data, Table 2 reports the difference in means between each variable and the explained variable. In this study, agricultural socialization services, educational level and household disposable income were classified into low and high value groups based on sample means. The results showed that in the high-value group, the AGPTs adoption behavior was substantially higher than that of the low-value group, indicating that the higher the adoption of agricultural socialization services, the higher the rate of land transfer, the higher the educational level, the higher the household disposable income, and the topography of the village as a plain, the higher the chances of the adoption of technologies in the farmers' households.

Further analysis found that the AGPTs adoption level of highly educated residents increased by 0.454 units after participating in HSFC, and the level of increase was 0.309 units higher than that of the low-education group; the level of adoption of technologies of farmers with higher household disposable income increased by 0.236 units after participating in HSFC, and the level of increase was 0.075 units higher than that of farmers with lower household disposable income. The level of usage of AGPTs by farmers whose village topography is plain increases by 0.405 units after participating in HSFC, and the level of increase is 0.224 units higher than that of farmers whose village topography is non-plain. This lays the foundation for the heterogeneity analysis later.

3.3 Model construction

3.3.1 Multivariate ordered probit models

The explained variable is farmers' AGPTs adoption behavior, which is a ordinal variable. In view of this, this study constructs a multivariate ordered probit model for estimation. The regression equation is:

$$Y_i = \lambda_1 + cF_i + g_1C + \varepsilon_1 \quad (1)$$

In Equation 1: Y_i is AGPTs adoption behavior, F_i is HSFC, C is the control variable, λ_1 is the constant term; $c, g_1$is the regression coefficients; ε_1 is the random disturbance term.

3.3.2 Mediation effect model

To further verify whether agricultural socialization services and land transfer have a mediating role between HSFC and farmers' AGPTs adoption behavior. This study draws on the method of Wen and Ye (2014) to test the influence mechanism of the mediating effect and constructs a mediating effect model as follows:

$$Y_i = \lambda_1 + cF_i + g_1C + \varepsilon_1 \quad (2)$$

$$M_i = \lambda_2 + aF_i + g_2C + \varepsilon_2 \quad (3)$$

$$Y_i = \lambda_3 + c'F_i + bM_i + g_3C + \varepsilon_3 \quad (4)$$

In Equations 2–4: M_i is the mediating variable, λ_2, λ_3 is the constant term; a, b, c', g_2, g_3 is the coefficient to be estimated; and $\varepsilon_2, \varepsilon_3$ is the random perturbation term.

4 Results and discussion

4.1 Regression analysis of the impact of high-standard farmland construction on farmers' agricultural green production technologies adoption behavior

In view of the possible covariance problem between the variables, this study carried out covariance diagnosis before regression analysis. The estimation results showed that the maximum variance inflation factor (VIF) value of each variable was 1.43, and the average VIF value was 1.14, and the VIF value of each variable was much less than 10, which indicated that there was no obvious multiple covariance problem between the variables. In this study, the Stata17 software was used to test the influence of HSFC on farmers' AGPTs adoption behavior using the multivariate ordered probit model, and the regression results are presented in Table 3.

As shown in Models 1 and 2, the coefficient of HSFC is positive and passes the test at 1 and 5% significant levels, suggesting that HSFC can substantially motivate farmers to actively adopt AGPTs. After replacing the benchmark regression model and re-running the regression using ordinary least squares (OLS), we found that the results remained robust (Model 3). These results align with the results of the studies by Duan et al. (2021), Xu et al. (2022), and Tang et al. (2024), and Hypothesis 1 is verified. This may be attributable to the enhancement of farmland infrastructure through HSFC, which provides better conditions for the implementation of AGPTs, thus diminishing the difficulty and expense of technologies adoption. Simultaneously, HSFC improves the quality and production capacity

TABLE 2 Analysis of differences in the means of the variables.

Variable name	Agricultural socialization services		Land transfers		Educational level		Household disposable income		Village topography	
	Low	High	No	Yes	Low	High	Low	High	Non-plain	Plains
Agricultural green production technologies adoption behavior	1.085	1.232	1.041	1.361	1.132	1.312	1.020	1.361	1.155	1.288

TABLE 3 Benchmark regression results.

Variable name	Model 1		Model 2		Model 3	
	Coefficient	Standard error of robustness	Coefficient	Standard error of robustness	Coefficient	Standard error of robustness
High-standard farmland construction	0.204***	(0.059)	0.147**	(0.061)	0.147***	(0.056)
Gender	—	—	0.089	(0.083)	0.079	(0.075)
Age	—	—	−0.003	(0.003)	−0.002	(0.003)
Educational level	—	—	0.078**	(0.037)	0.078**	(0.035)
Health status	—	—	0.034	(0.032)	0.030	(0.029)
Village cadre status	—	—	0.078	(0.070)	0.060	(0.069)
Number of family laborers	—	—	0.021	(0.016)	0.021	(0.015)
Household disposable income	—	—	0.115***	(0.022)	0.112***	(0.022)
Degree of land fragmentation	—	—	−0.071**	(0.029)	−0.064***	(0.024)
Fertility status of paddy fields	—	—	0.061*	(0.035)	0.049	(0.033)
Village topography	—	—	0.099	(0.091)	0.101	(0.088)
Area dummy variables	—	—	Controlled		Controlled	
Pseudo R^2	0.003		0.027		—	—
_Cons	—		—		0.305	(0.280)
Obs	1,350		1,350		1,350	

*,**,***Indicates significant at the 10, 5, and 1% levels, respectively.

of the land, so that farmers can further explore the potential of the land by adopting AGPTs, realize higher yields and quality, and increase economic benefits.

Among the control variables, educational level, household disposable income, degree of land fragmentation and land fertility status passed the significance test. Educational level positively affects farmers' technologies adoption behavior at a 5% significant level, and farmers with higher literacy not only have higher learning ability and knowledge level, but also have outstanding ability to access and apply AGPTs, and can recognize the role of technologies adoption in increasing agricultural income (Zou et al., 2023). Household disposable income significantly influences farmers' technologies adoption behavior, and in general, farmers with better household disposable income are more capable and inclined to invest in new technologies with a view to obtaining higher agricultural output and economic benefits (Prokopy et al., 2019). A greater degree of land fragmentation correlates with a reduced probability of farmers using AGPTs, which can be attributed to the reality that land fragmentation not only increases labor intensity, but also raises the expenses of technologies utilization, and may form a broken window effect in the minds of farmers, which inhibits the utilization of technologies by farmers (Zhang et al., 2022). Higher land fertility correlates with increased use of AGPTs by farmers, in order to maintain the land fertility at a high level to ensure the output of arable land, farmers will actively adopt AGPTs in actual production.

4.2 Robustness tests

4.2.1 Propensity score matching method

To enhance the reliability of the empirical results, the propensity score matching method (PSM) is chosen in this study to solve its self-selection problem. Table 4 shows the estimation results of the three classical methods of nearest neighbor matching, kernel matching, and caliper matching, whose matched ATT values are 0.171, 0.174, and 0.163, respectively, and all of them pass the significance test. This suggests that farmers participating in HSFC are more inclined to use AGPTs. The estimation results of propensity score matching are mostly congruent with the findings of the previous benchmark regression, suggesting that the outcomes of the previous study are reliable.

4.2.2 Conditional mixed process estimation methods

This study references the research idea of Mbudzya et al. (2022), the conditional mixed process estimation method (CMP) was chosen to further examine the impact of HSFC on the utilization behavior of AGPTs by farmers, and the outcomes are presented in Table 5. The endogeneity test parameter atanhrho_12 passed the significance test at the 10% level, signifying that the model has endogeneity issues. In the first-stage regression, the effect of instrumental variables on HSFC is considerably positive at the 1% significance level, which satisfies the correlation condition of instrumental variables; in the second-stage regression, HSFC positively affects the usage behavior of AGPTs of farmers at the 1% level, suggesting that after overcoming the potential endogeneity problem, HSFC can still facilitate the usage of AGPTs among farmers. The reliability of the previous estimation results is further verified.

4.3 Mediation effect analysis

The prior theoretical research indicates that agricultural socialization services and land transfer play a mediating role between

TABLE 4 PSM estimation results.

Matching method	Treated	Controls	ATT	Standard error	*T*-value
Nearest neighbor matching	1.250	1.079	0.171***	0.065	2.630
Kernel matching	1.250	1.076	0.174***	0.059	2.930
Caliper matching	1.250	1.087	0.163***	0.060	2.730

***Indicate significant at the 1% level.

TABLE 5 CMP model estimation results.

Variable name	Phase I	Phase II
	High-standard farmland construction	Agricultural green production technologies adoption behavior
County-level construction of high-standard farmland	2.793*** (0.180)	—
High-standard farmland construction	—	0.368*** (0.138)
Control variable	Controlled	Controlled
Atanhrho_12	−0.166* (0.095)	—
Obs	1,350	1,350

*,***Indicates significant at the 10 and 1% level, respectively.

TABLE 6 Mediation effect analysis results.

Variable name	Model 1	Model 2	Model 3	Model 4	Model 5
	Agricultural green production technologies adoption behavior	Agricultural socialization services	Agricultural green production technologies adoption behavior	Land transfers	Agricultural green production technologies adoption behavior
High-standard farmland construction	0.147** (0.061)	0.119** (0.060)	0.134** (0.062)	0.207*** (0.078)	0.130** (0.062)
Agricultural socialization services	—	—	0.074*** (0.024)	—	—
Land transfers	—	—	—	—	0.231*** (0.062)
Control variable	Controlled	Controlled	Controlled	Controlled	Controlled
Pseudo R^2	0.027	0.023	0.030	0.071	0.031
Obs	1,350	1,350	1,350	1,350	1,350

,*Indicates significant at the 5 and 1% level, respectively.

the effects of HSFC on farmers' AGPTs adoption behavior. This study employs the mediating effect method for additional examination. The specific outcomes are presented in Table 6.

The results of Models 1, 2, and 3 indicate that HSFC can not only substantially mobilize the enthusiasm of farmers to embrace AGPTs, but also promote their adoption of agricultural socialization services. Furthermore, the adoption of these services by farmers can markedly increase their adoption rate of AGPTs. Thus, agricultural socialization services play a mediating effect in the utilization of AGPTs by farmers via HSFC, and the Hypothesis 2 is further verified by Bootstrap test. From the perspective of the mediating effect of agricultural socialized services, HSFC reduces the threshold for agricultural machinery operations by optimizing farmland infrastructure, thereby promoting farmers' demand for professional services (Sun et al., 2024). Agricultural socialized services, in turn, reduce farmers' technical use costs, thereby enhancing their willingness to adopt AGPTs (Drewry et al., 2022).

As shown in Models 1 and 4, HSFC positively affects the adoption of AGPTs and land transfer behavior of farmers at the 5 and 1% significant levels. In Model 5, both HSFC and land transfer can significantly increase the likelihood of technologies adoption by farmers. In conclusion, land transfer plays a mediating effect in the AGPTs adoption behavior of farmers prompted by HSFC, and Hypothesis 3 is further verified by Bootstrap test. In terms of the land transfer mechanism, HSFC has improved the quality of cultivated land through measures such as land leveling, directly promoting the transfer of land to large-scale management entities (Xu et al., 2025). Endowed with higher capital endowments and risk-bearing capacities, large-scale management entities are more inclined to adopt AGPTs to achieve cost reduction and efficiency improvement (Nigussie et al., 2017).

4.4 Heterogeneity analysis

As a highly heterogeneous group, there may be some disparities in the utilization behavior of AGPTs by farmers with differing endowment characteristics as a result of HSFC. Given that educational level, household income and village topography can reflect the human, economic and natural capital of farm households to a certain extent, this study grouped the samples from the above three dimensions in order to derive more detailed research outcomes. The findings are presented in Table 7.

For educational level, HSFC is more likely to enhance the degree of adoption of technologies among highly educated farmers, this can be attributed to the highly educated farmers are able to more clearly recognize the economic benefits of HSFC and AGPTs, such as water, fertilizer, and medicines saving, which increases their incentives for the adoption of these technologies (Tan et al., 2022).

In terms of household income, HSFC has a significant influences on the extent of utilization of AGPTs by both low-income and high-income farmers. However, HSFC significantly influences the adoption of AGPTs among high-income farmers. The possible explanation is that high-income farmers generally have greater economic strength and risk-taking capacity, which makes them more able and willing to invest in AGPTs (Li H. et al., 2023).

For village topography, HSFC significantly influences the degree of AGPTs adoption by both non-plain and plain farmers. However, HSFC has a greater contribution to the technologies adoption behavior of non-plain farmers. The possible explanation is that farmland in the plains is more centralized and continuous, which makes it easier to form large-scale operations, diminishes the unit application expense of technologies, and enhances economic efficiency (Lampach et al., 2021).

5 Conclusions and recommendations

5.1 Conclusion

Based on 1,350 rice farmers' research data in Jiangxi Province, this study analyzed the effect of HSFC on farmers' AGPTs adoption behavior by using multivariate ordered probit model and mediation effect model, and came to the following conclusions in total: firstly, HSFC can substantially enhance the implementation of AGPTs among farmers, and the results still hold after passing the robustness test. Second, agricultural socialization services and land transfer play a partial mediating role between HSFC and farmers' technologies adoption behavior. Third, HSFC significantly influences the adoption of AGPTs by farmers with high education, high income and in the plains.

5.2 Recommendations

According to the above results, this study offers several recommendations.

Given that HSFC can markedly increase the enthusiasm of its AGPTs adoption, the government ought to further augment the financial input to HSFC projects, and broaden the source of funding channels to ensure that the construction project is widely carried out and high-quality promotion. In terms of construction planning, we should pay attention to local conditions, according to the topography, soil conditions and agricultural production characteristics of different regions, to develop a scientific and reasonable construction program, to ensure that the construction of farmland can adequately meet the needs of local farmers green production. Simultaneously, to establish a sound monitoring and evaluation mechanism for HSFC, regular inspection and acceptance of the construction results, to ensure that the quality of construction and the expected benefits, so as to encourage more farmers to participate in HSFC, and thus enhance the rate of utilization of AGPTs.

Given that agricultural socialization services and land transfer play a partly intermediary role in HSFC and the utilization of AGPTs by farmers, their importance cannot be ignored. In terms of agricultural socialized services, the government ought to enhance the development and support of agricultural socialized service organizations, and promote the development and growth of various types of socialized service entities through financial subsidies and other means. Promote the diversification and specialization of the content of agricultural socialized services, not only to provide the traditional supply of agricultural materials, agricultural machinery operation services, but also to expand to the AGPTs consulting and other areas. Create an agricultural socialized service information platform to realize the effective docking of service demand and supply, improve service efficiency and quality, decrease the expenses incurred by farmers for acquiring technologies services, and hence facilitating the utilization of AGPTs by farmers. In terms of land transfer, on the one hand, it is essential to enhance the land transfer service platform, ensure that the land transfer information is accurate, standardize the signing of the contract and the authority of the authentication process, so as to reduce the transaction costs of land transfer and enhance the convenience and stability of land transfer. On

TABLE 7 Results of heterogeneity analysis.

Variable name	Educational level		Household disposable income		Village topography	
	Low education	Highly educated	Lower income	High income	Non-plain	Plains
High-standard farmland construction	0.058 (0.070)	0.400*** (0.133)	0.125* (0.071)	0.270** (0.123)	0.121* (0.065)	0.405** (0.199)
Control variable	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Pseudo R^2	0.029	0.033	0.017	0.040	0.025	0.067
Obs	1,058	292	1,030	320	1,187	163

******Indicates significant at the 10, 5, and 1% levels, respectively.

the other hand, we should promote the expansion of new agricultural management disciplines by facilitating land transfer, realize the large-scale application and demonstration of AGPTs, drive small farmers to engage in sustainable agriculture practices, and facilitate the dissemination and application of AGPTs on a wider scale.

Given the disparities in the effects of HSFC on the utilization of technologies by farmers with varying characteristics, precise support policies should be implemented. First, highly educated farmers should be encouraged to carry out in-depth publicity and application demonstrations of technologies, and assume a leading role in knowledge to drive neighboring farmers to adopt AGPTs. Secondly, the government ought to provide more investment subsidies for AGPTs, and guide farmers to augment their investment in the purchase of green agricultural production equipment and the use of new types of agricultural materials, thereby further increase the scale and efficiency of green production. Thirdly, for farmers in non-plain areas facing more complex terrain conditions and agricultural production environments, support for the research of green production technologies that are characteristic of these areas should be increased, and relevant infrastructure should be strengthened to overcome geographical constraints and facilitate the extensive use of green technologies.

5.3 Limitations and perspectives of the study

Although this study verified that HSFC can facilitate the utilization of AGPTs by farmers, it still has the following limitations. On the one hand, this study used cross-sectional data to analyze and could not derive the causal relationship between the variables, and future studies may choose to analyze the farmer tracking data. On the other hand. This study just used the number of farmers' participation to characterize their AGPTs adoption behaviors, which may have overlooked the differences in regional applicability, functions, attributes, and effects of each technologies, and future studies could use more scientific methods to assess the extent of AGPTs usage by farmers.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

CC: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing. RP: Conceptualization, Formal analysis, Resources, Validation, Writing – review & editing. ZW: Data curation, Investigation, Resources, Writing – review & editing. FY: Data curation, Software, Supervision, Visualization, Writing – review & editing.

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Conflict of interest

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

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

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