frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 19 February 2025
DOI 10.3389/fsufs.2025.1534536

OPEN ACCESS

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RECEIVED 26 November 2024
ACCEPTED 27 January 2025
PUBLISHED 19 February 2025

CITATION
Zhang X, Zhang Y, Liu Y, Ye F and Liao W (2025) Impacts of organizational support on rice farmers' adoption of green production technologies—implications for food security and environmental sustainability.
Front. Sustain. Food Syst. 9:1534536.
doi: 10.3389/fsufs.2025.1534536

Impacts of organizational support on rice farmers' adoption of green production technologies—implications for food security and environmental sustainability

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Introduction: The relentless focus on maximizing production has exacerbated ecological challenges, including agricultural surface pollution, soil crusting, and farmland degradation, which increasingly threaten sustainable development. Agricultural green production technologies are essential for balancing food security with environmental sustainability.

Methods: This study examines the role of organizational support in fostering farmers' adoption of agricultural green production technologies, using survey data from 1,426 rice farmers in Jiangxi Province, China. Ordered logit and moderated mediation models reveal a robust positive effect of organizational support on agricultural green production technology adoption, even after addressing endogeneity concerns.

Results and discussion: The findings highlight that the effect of organizational support is more pronounced among farmers with agricultural insurance and those primarily engaged in farming. Mechanistic analysis shows that operation scale partially mediates the relationship between organizational support and agricultural green production technology adoption, accounting for 7.76% of the total effect. Furthermore, social capital acts as a positive moderator, amplifying the impact of organizational support on the operation scale and, subsequently, on agricultural green production technology adoption. These results underscore the need to enhance organizational support measures, promote moderate-scale farming, and cultivate social capital as critical strategies for advancing green agricultural practices.

KEYWORDS

organizational support, social capital, scale of operations, green production technologies, moderated mediation analysis, food security

1 Introduction

In recent years, China's agriculture has achieved significant progress, exemplified by rice production's unprecedented accomplishment of "twenty consecutive bumper harvests," ensuring national food security. However, traditional agricultural practices remain deeply entrenched, and resource utilization efficiency shows limited improvement. China's use of chemical pesticides per unit area is 2.5–5 times that of developed countries, but its utilization efficiency is only 30%. Fertilizer consumption accounts for more than 30% of the world's consumption, and its utilization efficiency is only 30–40% (Xie and Huang, 2021). The relentless focus on maximizing production has exacerbated ecological challenges, including agricultural surface pollution, soil crusting, and farmland degradation, which increasingly threaten sustainable development. To address these issues, China's agricultural sector urgently requires a transition toward green and modernized practices. Agricultural green production technologies (AGPTs) offer a balanced approach, addressing both economic and environmental demands and presenting advantages unmatched by traditional methods. Recognizing this potential, the Chinese government has prioritized AGPT adoption. The Ministry of Agriculture and Rural Development's "Technical Guidelines for Agricultural Green Development (2018–2030)" emphasized the establishment of a high-efficiency, low-carbon, and integrated technical system for green agriculture. Furthermore, the "14th Five-Year Plan" for National Agricultural Green Development (2021) underscored the importance of technological innovation and the widespread dissemination of green technologies. Notably, 98% of China's agricultural entities are still dominated by small farmers (Zou et al., 2023). AGPT has the characteristics of large investment, long cycle, and positive externalities, and small farmers are more cautious in choosing it, the adoption rate of AGPT is at a low level (Zhang T. et al., 2024; Mao et al., 2021; Xu et al., 2024). Addressing these barriers and enhancing AGPT adoption among farmers is thus a pressing challenge for China's agricultural modernization.

AGPTs exhibit the characteristics of public goods, offering significant potential to improve the agro-ecological environment. However, their adoption is hindered by high initial investments, substantial uncertainty in returns, and delayed efficacy (Xu et al., 2018). These factors conflict with farmers' time preferences and their goal of maximizing expected returns, resulting in low adoption rates. Government and industrial organizations, as primary suppliers of agricultural technologies and support systems, play a critical role in bridging the gap between smallholder farmers and modern agriculture (Liu et al., 2019). Government subsidies help mitigate farmers' discounted returns, while industrial organizations, such as professional cooperatives and agribusinesses, deliver essential production services, including agricultural procurement, technical training, and socialized services. These measures reduce transaction costs for smallholder farmers, providing them access to advanced technologies and modern management concepts, thereby catalyzing a shift from traditional to sustainable production methods. Consequently, investigating the role of organizational support (OS) in fostering farmers' adoption of AGPT holds significant practical importance.

Farmers, as the primary users of agricultural technology, make adoption decisions influenced by individual culture and values (Palis, 2006), risk attitudes (Barham et al., 2014), and time preferences (Mao et al., 2021). Among them, external incentives from the government and agricultural production organizations are conducive to changing farmers' input and risk perception (Paillé and Raineri, 2015), and are an important driving factor for farmers' adoption of new technologies (Nakano et al., 2018; Suvedi et al., 2017). However, some scholars have different conclusions. Giua et al.'s (2022) research shows that farmers' intention to use smart agricultural technology mainly depends on the performance expectations of the technology, the complexity of the technology, etc., and the impact of organizational support is not significant. In practice, individual behavioral decisions are inevitably shaped by personal and familial endowments (Tang et al., 2024). Existing studies have investigated the relationships among farmers' operational scales, social capital (SC), and technology adoption, but the findings remain inconclusive. Many researchers report a positive correlation between larger operational scales and higher technology adoption rates, as larger-scale farmers derive greater economic benefits from new technologies, enhancing their willingness to adopt (Ruzzante et al., 2021; Wang et al., 2022; Mao et al., 2021). However, Fischer (2016) argued that agricultural technologies introduced during Asia's Green Revolution were scale-neutral, yielding comparable results regardless of farm size. Ramirez (2013), Ren et al. (2022), and others verified the positive impact of social capital on agricultural technology adoption, but Mwaura (2014) showed that members of farmer groups were less likely to adopt inorganic fertilizers and new varieties than non-group members. Wang et al. (2020) believed that both social networks and extension services can improve the efficiency of farmers' agricultural technology adoption, but there is a competitive relationship between the two.

The existing literature forms a valuable theoretical foundation for this study but reveals key areas for further exploration. First, while prior research has examined the role of OS in farmers' technology adoption, it has not sufficiently addressed whether OS retains its incentive effect in the context of AGPTs, which possess distinctive positive externalities absent in other agricultural technologies. Second, although many studies have explored the influence of OS or SC on farmers' behavior, the potential synergistic effects of these factors on farmers' production decisions have not been comprehensively examined. Farmers' choices are shaped by a complex interplay of multiple influences, necessitating an integrative analytical approach. Third, the prevailing treatment of OS as a uniform measure overlooks the opportunity to tailor its components to meet the diverse needs of farmers with differing characteristics, limiting its efficacy and impact.

To address these gaps, this paper focuses on Jiangxi Province, a key rice-producing region in the Yangtze River Basin of China. It integrates OS, SC, and AGPT adoption into a unified analytical framework, drawing on micro-survey data from 1,426 rice farmers. By employing theoretical analysis, benchmark regression models, and a moderated mediation effect framework, the study investigates the impacts and mechanisms driving AGPT adoption. The findings aim to provide policymakers with a comprehensive understanding of the determinants of AGPT adoption, offering actionable insights for refining incentive mechanisms to effectively promote green agricultural technologies.

In contrast to existing studies, this paper deepens from the following two points. First, after empirically analyzing the impact of OS on farmers' adoption of AGPT, this paper also reveals the difference in the impact on farmers with different risk tolerance and different sources of income, which provides a scientific basis for the government to improve the way of OS, and to promote the adoption of AGPT by farmers through the differentiation strategy. Secondly, OS is only an external incentive, and the decision of farmers to adopt AGPT is subjective, so it is necessary to analyze the role of differences in operation characteristics and resource endowment. This paper explores the influence path of differences in operation scale and the interaction of SC in the influence path of OS and operation scale. It clarifies the internal logic of OS on the adoption of AGPT by farmers, which is of great theoretical value and practical significance for strengthening the actual effectiveness of the policy.

Abbreviations: AGPT, agricultural green production technology; OS, organizational support; SC, social capital.

2 Theoretical analysis

2.1 Impact of organizational support on farmers' agricultural green production technology adoption

Organizational support theory posits that OS reflects the extent to which members of an organization perceive that the organization values and supports them (Eisenberger et al., 1990). This perception fosters a sense of obligation, motivating members to assume greater responsibilities and reciprocate with behaviors that benefit the organization (Farh et al., 2007). In rural China, the entrenched smallholder economic model has instilled a short-term focus on profitability among farmers, making them less inclined to adopt AGPTs, which often lack immediate and stable returns. As an external incentive, OS plays a pivotal role in encouraging sustainable production decisions, acting as a critical driver for AGPT adoption (Paillé and Raineri, 2015).

First, government-provided agricultural extension services and technical training offset farmers' inherent resource and knowledge constraints. By enhancing farmers' understanding of AGPT, reducing information asymmetry, and offering direct technical guidance, these initiatives build farmers' trust in governmental support while addressing socio-emotional needs. This trust motivates farmers to align their practices with the government's green production goals, fostering greater adoption.

Second, socialized services from agricultural production cooperatives introduce new avenues for AGPT adoption. Given AGPT's "high-tech" nature, which raises the adoption threshold, cooperative interventions can directly integrate these technologies into farming practices, resolving technical challenges and enhancing adoption sustainability.

Third, the expansion of contract farming has strengthened the relationship between agricultural enterprises and farmers. Through unified production standards and centralized management practices, these enterprises have successfully embedded AGPT into farmers' operations, facilitating wider adoption.

Based on this analysis, the following hypothesis is proposed:

> *H1*: Organizational support has facilitated farmers' adoption of agricultural green production technologies.

2.2 Impact of organizational support on the adoption of agricultural green production technology by different groups of farmers

Farmer differentiation is a pervasive phenomenon in rural China (Zhang et al., 2023), and the impact of OS on the adoption of AGPTs may vary across farmers with differing endowment characteristics. The decision to adopt AGPT depends on the expected benefits, with AGPT characterized by high costs and significant risks. Smallholder farmers, often adopting "low security" agricultural production models, tend to avoid risks and adhere to traditional practices, even when supported by government and cooperative promotion efforts.

Agricultural insurance serves as an effective mechanism for mitigating agricultural risk shocks. By reducing the volatility of returns and stabilizing income expectations through risk diversification, insurance strengthens farmers' confidence in adopting new technologies, thereby promoting AGPT adoption. Concurrently, part-time farming has emerged as a significant trend in rural development, but it redistributes labor from agricultural to non-agricultural sectors, reducing the time and resources dedicated to farming. AGPT often demands higher time and labor investments, leading to prohibitive opportunity costs for part-time or non-farming households and weakening their willingness to adopt such technologies.

Conversely, farmers whose primary income derives from agricultural production and operations demonstrate a higher willingness to adopt AGPT. They are more inclined to invest resources to ensure the sustainability of their agricultural income, thereby driving demand for green technologies. As part-time employment intensifies, the adoption rate of AGPT among agricultural households is expected to decline.

Based on this analysis, the following research hypothesis is proposed:

> *H2*: Farmers who purchased agricultural insurance were likelier to adopt agricultural green production technologies than those who did not.
>
> *H3*: Pure farmers are more willing to adopt agricultural green production technologies than part-time farmers.

2.3 Mechanisms of the role of operation scale in the impact of organizational support on farmers' adoption of agricultural green production technology

Differences in production goals and factor input preferences among farmers with varying operation scales have made operation scale a critical determinant in shaping farmers' production behavior. AGPTs inherently require "intensive" and "scale-based" practices. Achieving sufficient operational scale is essential to distribute the costs of technology adoption, enabling the realization of economies of scale and creating the conditions for enhanced quality and efficiency. Larger-scale operations also facilitate continuous production and access to broader market opportunities, which are pivotal for maximizing the benefits of AGPTs.

Moreover, an increase in operation scale enhances farmers' SC, expanding their access to information and improving their understanding of AGPTs. Large-scale operators tend to exhibit a stronger commitment to sustainable production, greater resilience to potential risks, and a proactive approach to adopting and disseminating advanced green technologies, all of which promote AGPT adoption.

However, rural China's smallholder-dominated economic structure has limited the expansion of agricultural scale operations, underscoring the necessity of OS. Government land improvement policies, such as land leveling, plot consolidation, and tenure adjustments, have alleviated the issues of land fragmentation and insecure property rights, facilitated farmland transfers, and enabled scale expansion. Furthermore, cooperatives and agribusinesses play a vital role in supporting large-scale operations by addressing market disadvantages faced by smallholders. These organizations provide high-quality, cost-effective production services, reduce transaction costs, and ease land transfers, thereby empowering farmers to expand their operations and enhancing their bargaining power in agricultural markets.

Based on this analysis, the following hypothesis is proposed:

> *H4*: Operation scale mediates the path of organizational support on farmers' adoption of agricultural green production technologies.

2.4 Moderating role of social capital in the impact of organizational support on operation scale

Social capital (SC) encompasses the resources derived from social exchanges and relationships, which foster cooperation and mutual trust within a community (Adler and Kwon, 2002). In rural areas, the strength of SC plays a critical role in influencing operation scale.

First, the lack of efficient platforms for transferring production factors, such as land, necessitates reliance on interpersonal networks. Farmers with higher SC, who possess well-developed social relationship networks, exhibit stronger information acquisition capabilities, enabling them to identify appropriate transaction prices and potential counterparts at relatively lower costs. Moreover, the current farmland property rights system in rural areas remains underdeveloped, prompting farmers to transfer land to trusted individuals within their social circles. High SC facilitates trust-based negotiations, reduces transaction costs, and enhances the likelihood of reaching transfer agreements. Furthermore, farmers with high SC face greater reputational costs for breaching verbal agreements, leading to higher compliance rates and mitigating potential moral hazards in farmland transactions.

Second, SC influences financial accessibility. The SC of a farmer significantly affects the assessment of creditworthiness by banks and other financial institutions. Farmers with robust SC are perceived as having greater production capacity, operational competence, and reliability, increasing their likelihood of securing financial credit. This enhanced financial access alleviates capital constraints and supports the expansion of operational scale.

Based on this analysis, the following research hypothesis is proposed:

> *H5*: The higher the social capital, the greater the positive effect of organizational support on the operation scale, which promotes farmers' adoption of green production technologies.

3 Data and empirical analysis

3.1 Data sources

China is a major rice producer and consumer in the world, with rice planting area accounting for 20% of the world's total and output accounting for 33% of the world's total (Zhang M. et al., 2024). Jiangxi Province is one of China's 13 major grain-producing areas and a typical double-season rice area. In 2023, Jiangxi Province ranked third in rice production in China. In 2024, Jiangxi Province ranked second in early rice production in China. Jiangxi Province occupies an important position in China's rice production. Selecting Jiangxi Province as the research sample area is representative.

The data for this study were obtained from the "Double Hundred and Double Thousand" micro-research project conducted by Jiangxi Agricultural University between July and August 2023. The survey followed a stratified and random sampling approach. The 100 counties (cities/districts) in Jiangxi Province were categorized into three strata based on per capita GDP, and eight counties were randomly selected from each stratum. These included Anyuan County, Chongren County, Dayu County, Fengyi County, Fengxin County, Fouliang County, Gaoyan County, Guangfeng County, Guixi County, Hukou County, Jinxian County, Luxi County, Nanchang County, Pengze County, Ruijin County, Wan'an County, Xinxin County, Xiushui County, Yongfeng County, Yongxin County, Yudu County, Yu'an County, Jianxing County, Yujiang County, Yushan County, and Zixi County.

Within each selected county, three townships were randomly chosen, followed by the random selection of three administrative villages within each township. Subsequently, 10–12 farmers were randomly sampled from each administrative village, resulting in a total of 2,167 valid questionnaires. For this study, the sample was limited to rice-cultivating households. After excluding samples with missing key variables and extreme outliers, the final dataset comprised 1,426 valid responses from rice farmers.

3.2 Modeling

Benchmark regression. The dependent variable AGPT adoption is an ordered discrete choice variable, so the ordered choice model analyzes it; referring to D'Alberto et al. (2024) research, this paper constructs the Ordered Logit model to analyze the relationship between OS and farmers' adoption of AGPT, and the functional form is expressed as follows:

$$AGPT_i = \alpha_0 + \alpha_1 Osupport_i + \alpha_i Control_i + \mu_i, i = 0,1,2,3 \quad (1)$$

$$AGPT_i = \begin{cases} 0, AGPT_i < r_1 \\ 1, r_1 < AGPT_i \le r_2 \\ 2, r_2 < AGPT_i \le r_3 \\ 3, AGPT_i > r_3 \end{cases} \quad (2)$$

In Equation 1, $AGPT_i$ is the latent variable of AGPT adoption for the ith farmer, r_1, r_2, r_3 is the cutoff point that satisfies $r_1 < r_2 < r_3$, $Osupport_i$ is the level of OS received by the ith farmer, $Control_i$ is the control variables affecting the adoption of AGPT by the farmer, including the characteristics of the householder, operation characteristics, family characteristics, and village characteristics, and μ_i is the random error term.

In the Ordered Logit model, the probabilities of $AGPT_i = 0,1,2,3$ are respectively:

$$
\begin{aligned}
&P\left(AGPT_i = 0 \middle| Osupport_i\right) = P\begin{pmatrix} \alpha_1 Osupport_i \\ +\mu_1 < r_1 \middle| Osupport_i \end{pmatrix} \\
&= \Phi\left(r_1 - \alpha_1 Osupport_i\right) \\
&P\left(AGPT_i = 1 \middle| Osupport_i\right) = P\begin{pmatrix} r_1 < \alpha_1 Osupport_i \\ +\mu_1 < r_2 \middle| Osupport_i \end{pmatrix} \\
&= \Phi\left(r_2 - \alpha_1 Osupport_i\right) \\
&P\left(AGPT_i = 2 \middle| Osupport_i\right) = P\begin{pmatrix} r_2 < \alpha_1 Osupport_i \\ +\mu_1 < r_3 \middle| Osupport_i \end{pmatrix} \\
&= \Phi\left(r_3 - \alpha_1 Osupport_i\right) - \Phi\left(r_2 - \alpha_1 Osupport_i\right) \\
&P\left(Behavior_i = 3 \middle| Osupport_i\right) = P\begin{pmatrix} \alpha_1 Osupport_i \\ +\mu_1 > r_3 \middle| Osupport_i \end{pmatrix} \\
&= 1 - \ddot{O}\left(r_1 - \alpha_1 Osupport_i\right)
\end{aligned} \tag{3}
$$

The marginal effect of farmers' AGPT adoption was calculated as follows:

$$
\begin{aligned}
&\frac{\theta P\left(AGPT_i = 0\right)}{\theta Osupport_i} = -\phi\left(r_1 - \alpha_1 Osupport_i\right)\alpha_1 \\
&\frac{\theta P\left(AGPT_i = 1\right)}{\theta Osupport_i} = -\phi\left(r_2 - \alpha_1 Osupport_i\right)\alpha_1 \\
&\frac{\theta P\left(AGPT_i = 2\right)}{\theta Osupport_i} = -\phi\left(r_3 - \alpha_1 Osupport_i\right)\alpha_1 \\
&\frac{\theta P\left(AGPT_i = 3\right)}{\theta Osupport_i} = \phi\left(r_3 - \alpha_1 Osupport_i\right)\alpha_1
\end{aligned} \tag{4}
$$

In Equations 3, 4, $\phi(\cdot)$ is the standard normal distribution function, and $\varphi(\cdot)$ is the probability density function.

Robustness model - OLS. This paper focuses on examining the impact of OS on farmers' adoption of AGPT, and the OLS model is constructed as follows:

$$AGPT_i = \alpha_0 + \alpha_1 Osupport_i + \alpha_2 Control_i + \varepsilon_i \tag{5}$$

In Equation 5, $AGPT_i$ denotes the average AGPT adoption by the ith farmer; $Osupport_i$ denotes the OS received by the ith farmer; is the control variable; α_0 is the constant term; α_1, α_2 are the parameters to be estimated; ε_i is the random error term. Considering heteroskedasticity exists in the model, this paper directly corrects for heteroskedasticity through robust standard errors.

Mediating effect test. To test the mediating mechanism of operation scale, based on the examination of the total effect of OS on farmers' adoption of AGPT, the mediating effect model is constructed as follows with reference to the method of Wen and Ye (2014):

$$Agriscale_i = \beta_0 + \beta_1 Osupport_i + \beta_2 Control_i + \varepsilon_i \tag{6}$$

$$AGPT_i = \gamma_0 + \gamma_1 Osupport_i + \gamma_2 Agriscale_i + \gamma_3 Control_i + \theta_i \tag{7}$$

In Equations 6–7, $Agriscale_i$ is the mediating variable, which represents the operation scale of the ith farmer; β_0, γ_0 are constant terms; $\beta_1, \beta_2, \gamma_1, \gamma_2, \gamma_3$ are parameters to be estimated, and$\varepsilon_i, \vartheta_i$ are random error terms. Equation 5 tests the total effect of OS on farmers' AGPT adoption, Equation 6 tests the effect of OS on the mediating variable operation scale, the coefficient γ_2 in Equation 7 indicates the direct effect of operation scale on farmers' AGPT adoption, and substituting Equation 6 into Equation 7 further yields the mediating effect $\beta_1\gamma_2$, that is, the effect of OS on farmers' AGPT adoption through operation scale.

Bootstrap-based moderated mediation test. In order to examine the moderating role of SC in the first half of the path of farmers' AGPT adoption affected by OS through the operation scale, this paper utilizes the mediation effect test method based on Bootstrap with moderation proposed by Preacher and Hayes (2008), with reference to the study of Wen and Ye (2014), and the model is set as follows:

$$
\begin{aligned}
&Osupport_i = \delta_0 + \delta_1 AGPT_i + \delta_2 Agriscale_i + \delta_3 Scapital_i \\
&+\delta_4 Agriscale_i \times Scapital_i + \delta_5 Control_i + \mu_i
\end{aligned} \tag{8}
$$

In Equation 8, $Scapital_i$ denotes the SC of the farmer. In this paper, the significance of the coefficient δ_4 of the interaction term $Agriscale_i \times Scapital_i$ is used to determine whether the moderating effect exists.

3.3 Selection of variables and descriptive statistics

3.3.1 Explanatory variable

The explained variable in this paper is AGPT adoption. That is the number of AGPT rice farmers adopted in the production process. Measured by the questionnaire title "Which of the following green production technologies has your household adopted in the food production process?" Measurement. The options include water and fertilizer integration technology, green pest control technology, ecologically efficient farming technology, straw comprehensive utilization technology, recycling of agricultural film and pesticide packaging, water-saving irrigation such as sprinkler and drip irrigation, and deep plowing and fertilizer application, and straw crushing and returning to the field. Farmers who do not adopt the above technologies are assigned a value of 0, those who adopt one are assigned a value of 1, those who adopt two are assigned a value of 2, and those who adopt three or more are assigned a value of 3.

3.3.2 Core explanatory variable

The core explanatory variable in this paper is organizational support. Referring to the method of Zhang et al. (2023), this paper measures OS from three dimensions: cooperatives, agribusinesses, and government, and uses the entropy method to calculate the composite index score. The questionnaire questions measured the three dimensions: "Has your family acquired agricultural production technology by participating in farmers' cooperatives?" "In addition to the Internet, does your family obtain agricultural technology information through training organized by enterprises or large-scale farmers?" and "Does your household obtain agricultural technology information through training organized by the government?" Measurement. The range of composite indicator scores lies between 0 and 1.

3.3.3 Mediating variable

The mediating variable in this paper is the operation scale. Referring to the study by Zhu et al. (2018), the operation scale was measured by the questionnaire question, "How many hectares of paddy field will your household actually cultivate in 2022?"

TABLE 1 Variable description.

	Variable name	Variable description
Explained Variable	AGPT Adoption	0 = 0 adopted; 1 = 1 adopted; 2 = 2 adopted; 3 = 3 or more adopted.
Core Explanatory Variables	OS	Entropy method with variable score distribution 0–1.
Mediating Variable	Operation Scale	How many hectares of paddy land was your household actually cultivated in 2022?
Moderating Variable	SC	How many households of governmental and institutional workers do you have in your household?
Householder Characteristics	Age	Your age? (years)
	Education Level	What is your level of education? 1 = No schooling, 2 = Elementary school, 3 = Junior high school, 4 = High school (junior college), 5 = College and above
	Health Status	What is your health status? 1 = very unhealthy, 2 = quite unhealthy, 3 = fair, 4 = quite healthy, 5 = very healthy
	Whether a Village Cadre	Are you a village cadre? 0 = No, 1 = Yes
Household Characteristics	Proportion of Agricultural Operation Income	What percentage of your household income is from farming?
	Non-farm Employment Rate	Number of persons in the labor force engaged in non-agricultural work/number of persons in the household labor force
Operation Characteristics	Rice Insurance	Does your household have insurance for rice cultivation?0 = No, 1 = Yes
	Distance Between Plots	What is the furthest distance between plots of paddy land cultivated by your household? (kilometers)
	Size of the Land Transferred in	What is the total size of land transferred into your household? (hectares)
	Land Fertility	What is the fertility status of your own paddy fields? 1 = very poor, 2 = poor, 3 = fair, 4 = better, 5 = very good
Village Characteristics	Village Title	What honorary titles has your administrative village received? Famous Cultural Village; Civilized Village and Town; Demonstration Village of Democracy and the Rule of Law; Demonstration Village of Rural Governance; Ecological Village; Beautiful and Leisurely Village; Model Village of One Village and One Product; Other; 0 = None, 1 = 1 or more.
	Distance from County Town	How many kilometers is your village from the county town?
	Obs	1,426

3.3.4 Moderating variable

The moderating variable in this paper is social capital. Referring to the existing literature (Han et al., 2022), it was measured by the question in the questionnaire, "How many households of governmental and institutional workers do you have in your household?" to measure (Table 1).

3.3.5 Control variable

Referring to the studies of Zhang J. et al. (2024) and Zhang T. et al. (2024), the householder characteristics (age, education level, health status, and whether a village cadre or not), the household characteristics (share of income from agricultural operation, and the number of non-farm employment), the operation characteristics (rice insurance, distance between parcels, size of the land transferred to the land, and land fertility), and the village characteristics (title of the village, and distance from the county town) were selected as the control variables (Table 2).

4 Analysis of empirical results

4.1 Baseline regression

This study utilized Stata 17.0 software to estimate the direct effect of organizational support (OS) on farmers' adoption of agricultural green production technologies (AGPTs). The results of the Ordered Logit model are presented in Table 3, Model (1). The findings indicate that the coefficient of OS is 1.081, significant at the 1% level. Model (2), which includes control variables, shows that the coefficient of OS is 0.651 and remains significant at the 1% level. This suggests that a 10% increase in OS leads to a 6.51% increase in AGPT adoption among farmers, confirming the facilitating role of OS and verifying Hypothesis H1. These results align with prior studies demonstrating the positive relationship between OS and farmers' technology adoption (Mandari et al., 2017; Yang et al., 2021; Uddin and Dhar, 2018).

The analysis of control variables revealed several significant influences on AGPT adoption. Farmers' health status positively affects agricultural production and management, as good health is a prerequisite for effective labor. Larger distances between plots encourage AGPT adoption, as farmers utilize green technologies to mitigate labor constraints and improve inter-plot production. Similarly, increased land transfer sizes reduce fragmentation and promote contiguous operations, facilitating modernization and enhancing AGPT adoption. These findings are consistent with Ren et al. (2019), who demonstrated that larger farm sizes drive technology adoption.

High farmland fertility also positively influences AGPT adoption, as farmers are more motivated to protect fertile land and ensure

TABLE 2 Descriptive statistics.

	Variable name	Average value	Standard deviation	Minimum value	Maximum values
Explained Variable	AGPT Adoption	0.890	0.947	0	3
Core Explanatory Variables	OS	0.155	0.240	0	1
Mediating Variable	Operation Scale	2.185	9.055	0.017	166.667
Moderating Variable	SC	1.380	2.589	0	20
Householder Characteristics	Age	58.239	10.930	23	87
	Education Level	2.836	0.956	1	5
	Health Status	3.849	0.985	1	5
	Whether a Village Cadre	0.262	0.440	0	1
Household Characteristics	Proportion of Agricultural Operation Income	36.346	36.838	0	100
	Non-farm Employment Rate	28.542	23.751	0	100
Operation Characteristics	Rice Insurance	0.454	0.498	0	1
	Distance Between Plots	0.793	1.756	0	35
	Size of the Land Transferred in	2.310	10.382	0	166.667
	Land Fertility	3.335	0.853	1	5
Village Characteristics	Village Title	0.839	0.368	0	1
	Distance from County Town	29.792	21.758	0	150
	Obs	1,426			

sustainable production. Proximity to county towns was another positive factor, providing farmers greater access to technology dissemination and training opportunities, which increased awareness and adoption likelihood. Conversely, the non-farm employment ratio showed a significant negative effect on AGPT adoption. This outcome likely reflects labor shortages caused by part-time farming, where younger and more capable workers transition to non-agricultural sectors, leaving older and less skilled individuals less able to adopt advanced technologies.

4.2 Robustness tests

This paper replaces the regression model with an OLS model and PSM for a robustness test to ensure the reliability of the estimation results. The results are shown in Tables 4, 5.

First, referring to Lun et al. (2024) research, the baseline regression model was replaced with an OLS model, and model (3) in Table 3 shows the OLS results. The coefficient of OS is 0.418 and significant at the 1% level, indicating that OS facilitates farmers' adoption of AGPT. The estimation results of the remaining variables are basically consistent with the benchmark regression, indicating that the research results are relatively robust.

Secondly, referring to the study by Mukhametzyanov (2021), the entropy weight method was replaced with the CRITIC weight method to recalculate the independent variable OS. Table 3 (4) shows the results of the Ordered Logit model after changing the independent variables. The coefficient of OS is 0.569, which is significant at the 5% level, indicating that OS promotes farmers' adoption of AGPT. The estimated results of other variables are basically consistent with the baseline regression, indicating that the research results are relatively robust.

Third, considering that the baseline regression model does not control the impact of other observed variables on behavior when estimating the relationship between specific behaviors and outcomes, which may lead to biased results, we refer to the research of Deng et al. (2024) and use the PSM method for robustness testing. In order to ensure the robustness of the matching results, k-nearest neighbor matching, kernel matching, and local linear regression matching were performed on the samples, respectively. Table 4 shows the average treatment effect (ATT) of the three matching methods. From the ATT results, it can be seen that the mean value of the average treatment effect is 0.287, and all of them are positively significant at the 1% level, which again verifies the result that OS can enhance farmers' adoption of green production technologies.

4.3 Endogenous treatment

A potential endogeneity issue exists in the benchmark regression. On the one hand, farmers' adoption of agricultural green production technologies (AGPTs) may influence the level of organizational support (OS), as governments often prioritize technical guidance for demonstration households, creating reverse causality. On the other hand, the promotion of AGPTs is influenced by various factors that may simultaneously affect OS levels, such as regional economic development and whether the area is a major grain-producing county—potentially unobserved omitted variables.

To address this, "satisfaction with village cadres" was selected as an instrumental variable for OS. Village cadres act as key

TABLE 3 Benchmark regression.

Variable	Explained variable: AGPT adoption	
	Model (1)	Model (2)
OS	1.081*** (0.218)	0.651*** (0.226)
Householder characteristics		
Age		−0.004 (0.005)
Education level		0.118* (0.061)
Health status		0.119** (0.054)
Whether a village cadre		0.227* (0.117)
Household characteristics		
Proportion of agricultural operation income		0.003* (0.001)
Non-farm employment rate		−0.004** (0.002)
Operating characteristics		
Rice insurance		0.197* (0.106)
Distance between plots		0.068** (0.028)
Size of the land transferred in		0.026*** (0.006)
Land fertility		0.128** (0.059)
Village characteristics		
Village title		0.178 (0.137)
Distance from county town		0.007*** (0.002)
Prob> chi2	0.000	0.000
R2	0.007	0.037
Obs	1,426	1,426

*, **, ***Denote significance at the 10, 5, and 1% levels, respectively, with standard errors in parentheses.

TABLE 4 Robustness test results.

Variable	Explained variable: AGPT adoption	
	Model (3)	Model (4)
OS	0.418*** (0.123)	
OS(CRITIC)		0.569*** (0.194)
Householder characteristics		
Age	−0.002 (0.003)	−0.004 (0.005)
Education level	0.060** (0.029)	0.117* (0.061)
Health status	0.060** (0.024)	0.121** (0.054)
Whether a village cadre	0.086 (0.058)	0.225* (0.117)
Household characteristics		
Proportion of agricultural operation income	0.001** (0.001)	0.002* (0.001)
Non-farm employment rate	−0.002 (0.001)	−0.004** (0.002)
Operating characteristics		
Rice insurance	0.111** (0.051)	0.191* (0.106)
Distance between plots	0.040*** (0.014)	0.066** (0.028)
Size of the land transferred in	0.012*** (0.003)	0.026*** (0.006)
Land fertility	0.059** (0.029)	0.129** (0.059)
Village characteristics		
Village title	0.094 (0.064)	0.178 (0.137)
Distance from county town	0.003*** (0.001)	0.007*** (0.002)
Prob>F	0.000	0.000
R- squared	0.100	0.037
Obs	1,426	1,426

**, ***Denote significance at the 5 and 1% levels, respectively, with standard errors in parentheses.

intermediaries between the government and farmers, conveying policies and fostering trust. Since the quality of public services delivered by the government directly affects public trust, the relationship between village cadres and farmers is closely linked to the level of OS perceived by farmers. At the same time, this instrumental variable is not directly related to the dependent variable (AGPT adoption), making it a reasonable choice.

The study employed two-stage least squares (2SLS) estimation to address endogeneity, with results presented in Table 6. The weak instrumental variable test indicated that Shea's Partial R^2 was 0.031, and the F-statistic value was 90.279—well above the critical threshold of 10—rejecting the hypothesis of a weak instrument. The Durbin (score) test *p*-value of 0.072 and the Wu–Hausman test p-value of 0.074 confirmed OS as an endogenous explanatory variable at the 10% significance level, validating the necessity of 2SLS estimation.

First-stage regression results showed that satisfaction with village cadres significantly promotes farmers' adoption of AGPTs. The second-stage regression revealed a significantly positive coefficient for OS, with a larger absolute value than the corresponding coefficient in Model (1). This suggests that failing to account for the endogenous nature of OS may underestimate its facilitating effect on AGPT adoption. Additionally, the directions of the control variables remained consistent with the baseline regression results, reinforcing

TABLE 5 Estimated PSM results of organizational support on adoption of green production technologies by farmers.

Model (5)	Matching method	Experimental group/control group	ATT	*t*- value
AGPT Adoption	k nearest neighbor matching (k = 1)	571/855	0.305***	4.32
	Kernel matching	571/855	0.278***	4.97
	Local linear matching	571/855	0.279***	3.95
	Average value	–	0.287	–

***Indicates significance at the 1% level.

TABLE 6 Results of endogenous treatments.

Variable	Model (6): AGPT adoption	
	Phase I	Phase II
OS		1.457*** (0.564)
Tool Variables: Satisfaction with village cadres	0.023*** (0.002)	
Control variable	Controlled	
Shea's Partial R2	0.031	
Phase I *F*-value	90.279	
Durbin (score) test p-value	0.072	
Wu–Hausman test *p*-value	0.074	
Obs	1,426	

***Indicates significance at the 1% level.

the robustness and reliability of the findings after addressing endogeneity.

4.4 Heterogeneity analysis

4.4.1 Whether to purchase agricultural insurance

Agricultural insurance is essential for sharing the risk of farmers' grain cultivation (Guo and Ren, 2024). It plays a vital role in whether farmers adopt AGPT. In this paper, the sample is divided into two parts, according to whether or not he/she is a farmer who purchases rice planting insurance. Whether it is purchased or not is removed from the control variables; Table 7 reports the results of the Ordered Logit regression of farmers purchasing rice planting insurance and those who do not purchase rice planting insurance. The results of model (7) show that the regression coefficient of OS on the adoption of AGPT is not significant for farmers who did not purchase rice cultivation insurance. In contrast, model (8) results show that the regression coefficient of OS on the adoption of AGPT for farmers who purchased rice cultivation insurance is 0.941 and is positively significant at the 5% level. It shows that the promotion effect of OS on farmers' AGPT adoption is more evident in farmers who buy rice planting insurance, which verifies hypothesis H2. The study of Yao et al. (2024) verified the promotion effect of agricultural insurance on the adoption behavior of fertilizer reduction and efficiency technology among apple farmers, which is in line with the conclusion of this paper.

4.4.2 Part-time type differences

Referring to Weng et al.'s (2017) criteria for the division of farmers into different part-time types, the sample is divided into four levels by the share of agricultural income: pure farmers (agricultural income greater than 90%), I part-time farmers (agricultural income from 50 to 89%), II part-time farmers (agricultural income from 10 to 49%), and non-farming farmers (agricultural income less than 10%). The share of agricultural income is excluded from the control variables. The Ordered Logit model is estimated, and the regression coefficients of different part-time types of farmers are reported in Table 7 models (9)–(12). In terms of the differences in part-time types, the coefficients of OS for farmers' adoption of AGPT are positively significant at the 10% level for pure farmers and I part-time farmers, and the coefficients of OS for AGPT adoption by farmers are not significant for II part-time farmers and non-farming farmers. It shows that the promotion effect of OS on adopting AGPT is more evident in the farmers whose income is dominated by agricultural production and management income, which verifies hypothesis H3.

4.5 Mediation effect test results

To elucidate the mechanism by which organizational support (OS) facilitates farmers' adoption of agricultural green production technologies (AGPTs), a mediation effect test was conducted using operation scale as the mediating variable. The Sobel method results, presented in Table 8, support this analysis. In model (13), the coefficient of OS is 0.418, which is positive and significant at the 1% level, indicating that OS promotes the adoption of AGPT by farmers; in model (14), the coefficient of OS is 4.435, which is positive and significant at the 1% level, indicating that OS promotes farmers to expand their operation scale; Finally, Model (15) examines the simultaneous effects of OS and operation scale on AGPT adoption, showing that the regression coefficient of operation scale is positive and statistically significant at the 1% level. The coefficient for OS remains positive and significant at the 1% level, though its absolute value is smaller compared to Model (13), confirming the establishment of the mediation effect.

These findings verify Hypothesis H4, indicating that operation scale partially mediates the relationship between OS and AGPT adoption. The mediation effect accounts for approximately 7.76% of the total promotion effect of OS on AGPT adoption. Additionally, the robustness of the mediation effect was confirmed through three significance tests—Sobel, Goodman1, and Goodman2—performed using the Sgmediation command. All results satisfied the required statistical criteria, further validating the mediating role of the operation scale.

TABLE 7 Results of heterogeneity analysis.

Variable	Whether purchase rice insurance		Part-time type			
	(7) Not purchased	(8) Purchased	(9) Pure farmer	(10) I part-time farmers	(11) II part-time farmers	(12) Non-farming farmers
OS	0.329 (0.332)	0.941*** (0.311)	1.311** (0.641)	0.932* (0.522)	0.377 (0.382)	0.499 (0.421)
Control variable	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Prob>chi2	0.000	0.000	0.000	0.001	0.000	0.083
R-squared	0.020	0.064	0.078	0.057	0.029	0.021
Obs	778	648	273	231	489	433

*, **, and ***Indicate significance at 10, 5, and 1% levels, respectively.

4.6 Moderated mediation effect test results

To examine the moderating role of social capital (SC) in the first half of the mediation pathway—where "organizational support (OS) influences farmers' adoption of agricultural green production technologies (AGPTs) through expansion of operation scale"—this study employed the process plug-in procedure in SPSS27 software, following the methodology of Hayes (2013). The analysis used the Bootstrap method with 5,000 resamples, a 95% confidence interval, and Model 7. The results are presented in Tables 9, 10.

In Model (16), the coefficients of OS, operation scale, SC, and interaction terms are 5.155, 0.014, 0.613, and 2.545 respectively, and the positive impact on farmers' adoption of AGPT is significant at least at the 10% level. This indicates that SC positively moderates the mediating effect, meaning that higher levels of SC amplify the positive effect of OS on the operation scale, thereby promoting AGPT adoption. The conditional indirect effects further demonstrated that when SC was at low, average, and high levels, the indirect effects of OS through operation scale on AGPT adoption were 0.023, 0.073, and 0.167, respectively. The corresponding Bootstrap 95% confidence intervals were [0.004, 0.064], [0.020, 0.169], and [0.046, 0.391], none of which contained zero. These results confirm that the mediating role of operation scale is robust under different levels of SC and becomes stronger as SC increases. In summary, SC plays a significant moderating role in the mediation pathway of "OS → operation scale → AGPT adoption," validating Hypothesis H5.

TABLE 8 Results of Sobel's mediation effect test for business size.

	Model (13)	Model (14)	Model (15)
	AGPT Adoption	Operation scale	AGPT Adoption
OS	0.418*** (0.104)	4.435*** (0.575)	0.340*** (0.106)
Operation Scale			0.018*** (0.005)
Control variable	Controlled	Controlled	Controlled
Sobel	0.078*** (Z = -3.291)		
Goodman-1	0.078*** (Z = -3.269)		
Goodman-2	0.078*** (Z = -3.314)		
Percentage of intermediary effects	7.76%		

***Indicates significance at the 1% level.

TABLE 9 Results of the moderated mediation effect test.

Model (16)	Explained variable: AGPT adoption	
	coefficient	*t*- value
OS	5.155**	10.338
Operation Scale	0.014*	3.127
SC	0.613***	11.776
Operation scale * SC	2.545***	19.096
Control variable	Controlled	

*, **, and ***Indicate significance at 10, 5, and 1% levels, respectively.

5 Conclusion and discussion

AGPT offers both economic and ecological benefits; however, the actual adoption rates among farmers remain low, highlighting the urgent need for OS. In this paper, we analyze data from 1,426 rice farmers in Jiangxi Province, the main rice-producing area in the Yangtze River Basin. We employ baseline regression and moderated mediation effects models to investigate the impact of OS on farmers' adoption of AGPT, utilizing methods such as OLS, PSM, 2SLS, Sobel, and Bootstrap. Our findings indicate that, first, OS promotes farmers' adoption of AGPT, and this conclusion is still valid after the robustness test and endogeneity problem treatment. Second, the effect of OS on adopting AGPT varies widely across farmers. The positive impact of OS is particularly pronounced among those who purchase rice cultivation insurance and those whose income primarily derives from agricultural production and management.

The study by Ke et al. (2022) shows that part-time farmers are more inclined to adopt straw return technology than pure farmers, contrary to the findings of this paper, which may be attributed to the fact that straw return technology saves farmers' labor as it is mainly based on mechanically crushing straw and then returning it directly to farmland. In contrast, the AGPT explored in this paper involves a wide variety of technologies, most of which cannot be mechanically accomplished, and more labor is required, exacerbating the labor problems for part-time farmers. That exacerbates the scarcity of part-time farmers' labor. Third, the results of the mediating effect show that operation scale plays a partial mediating role in the path of OS affecting farmers' adoption

TABLE 10 Analysis of the moderating effect of social capital.

Model (17)		Conditional indirect effect				Moderated mediation			
Mediating variable	Condition	Effect		95% confidence interval		Index value	Standard error	95% confidence interval	
		Coefficient	Standard error	Lower limit	Upper limit			Lower limit	Upper limit
Operation Scale	Low SC	0.023	0.016	0.004	0.064	0.036	0.021	0.009	0.089
	Average	0.073	0.039	0.020	0.169				
	High SC	0.167	0.091	0.046	0.391				

of AGPT, with the mediating effect contributing 7.76% of the weight. The results of the moderated mediation effect showed that SC positively moderated the relationship between OS and operation scale, thus increasing the promotion effect of OS on farmers' AGPT adoption. Wan and Mu (2024) found that SC promotes farmers' organic fertilizer substitution behavior for chemical fertilizers, and the promotion effect is more pronounced among farmers with an average plot size of more than six mu, which is consistent with the findings of this paper.

Different types of policy tools have different effects on farmers' adoption of AGPT. Among them, the technical support of the government and agricultural industry organizations effectively reduces the technical barriers faced by farmers in technology adoption, thereby motivating farmers to adopt AGPT. Compared with existing studies, the results of this paper are somewhat correlated with the conclusions of Xie et al. (2024) and Hong et al. (2024). But it was deepened from the following two points. First, the factors affecting farmers' adoption of AGPT will change with the changes in social and economic development, and this study only used cross-sectional data, ignoring the influence of time factors; in future studies, panel data can be formed through tracking surveys to explore the multi-stage characteristics of the impact of OS on the adoption of AGPT by farmers. Second, the sample scope of this paper is limited, and it remains to be verified whether the study's conclusions based on Jiangxi Province apply to other rice-producing regions. In future studies, the sample area can be expanded to include China and countries with similar characteristics to increase the generalizability of the conclusions.

5.1 Policy implications

To establish a sustainable mechanism for promoting farmers' adoption of AGPTs, this study proposes several policy recommendations.

First, the level of OS should be continuously improved. Governments should increase the frequency of AGPT promotion and technical guidance and improve subsidy programs to support farmers' adoption. Agricultural enterprises should foster long-term cooperative relationships with farmers, guiding AGPT. Agricultural production cooperatives should expand advanced agricultural machinery to promote green production.

Second, OS should be dynamically adjusted to enhance the efficiency of incentives. Governments should widely promote agricultural insurance and other risk transfer tools, guiding farmers toward insurance participation through multi-channel publicity. At the same time, governments should ensure that farmers with non-agricultural income sources are not overlooked by offering training programs to build awareness of sustainable agriculture and green production practices.

Third, moderate-scale farming should be encouraged, and the cultivation of social capital (SC) should be prioritized to create a supportive environment for AGPT promotion. Local governments should establish effective channels for farmland transfer and reduce transaction costs. Additionally, technical exchanges, training sessions, and mutual aid programs should be organized to strengthen farmers' SC.

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/s.

Author contributions

XZ: Conceptualization, Formal analysis, Methodology, Resources, Software, Visualization, Writing – original draft. YZ: Conceptualization, Data curation, Formal analysis, Supervision, Validation, Writing – original draft. YL: Formal analysis, Supervision, Visualization, Writing – original draft. FY: Data curation, Investigation, Project administration, Writing – review & editing. WL: Funding acquisition, Project administration, Validation, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. The research is financially supported by the National Social Sciences Foundation of China (grant no. 71934003 and 72263017), Major Project of Social Sciences in Jiangxi Province (no. 23ZK07), and Humanities and Social Sciences Research Program for Universities in Jiangxi Province (no. JC23214).

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.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2025.1534536/full#supplementary-material

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