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Research on the impact of water-saving technologies on the agricultural production efficiency of high-quality farmers------taking Jiangxi province and Guangdong province in China as examples

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Based on the survey data of 1707 high-quality farmers in Guangdong and Jiangxi provinces in China, this article uses the DEA-tobit model and propensity score matching method to explore the impact of water-saving technology adoption on agricultural production efficiency from a micro perspective. The research results show that the adoption of water-saving technology by high-quality farmers can significantly improve agricultural production efficiency. By comparing the results with the baseline regression using propensity score matching method, the study findings are found to be robust. The mechanism and results of the study indicate that agricultural subsidy policies play a regulatory role between water-saving technology adoption and the agricultural production efficiency of high-quality farmers. Further analysis reveals that the impact of water-saving technology on the production efficiency of different types of high-quality farmers varies. Specifically, water-saving technology has a greater impact on the production efficiency of farmer cooperatives and agricultural enterprises compared to large-scale farming households and family farms. Therefore, policy recommendations are proposed to improve the water-saving agricultural technology system, among other aspects.

KEYWORDS

water-saving technology, high-quality farmers, production efficiency, agriculture, factors affecting

1 Introduction

The 20th National Congress of the Communist Party of China emphasized the need to improve total factor productivity and promote high-quality economic development. Among them, the high-quality development of agriculture is essential. The key to promoting high-quality development in agriculture lies in comprehensively improving agricultural production efficiency (Gao et al., 2022). High-quality agricultural development refers to the development concept that aims to ensure national food security, increase farmers' income, and improve the rural ecological environment. It achieves sustainable economic growth and development in agriculture by enhancing the overall factor productivity of agriculture, promoting agricultural modernization, upgrading agricultural industries, improving the quality and market competitiveness of agricultural products, all while ensuring the aforementioned goals are met. In 2023, the national grain yield per unit area is 5,845 kg per hectare (390 kg per mu), an increase of 43.6 kg per hectare (2.9 kg per mu) compared to 2022, with a growth rate of 0.8%. Among them, the grain yield per unit area is 6,419 kg per hectare (428 kg per mu), an increase of 40.0 kg per hectare (2.7 kg per mu) compared to 2022, with a growth rate of 0.6%. With the rapid development of our country's economy and the continuous increase in population, agricultural production is increasingly demanding water resources, while the supply of water resources is facing serious shortages and pollution. Therefore, how to improve the water resource utilization efficiency in agricultural production has become an urgent problem that needs to be solved.

China has a vast territory with diverse climates, terrains, soils, and water resource distributions, which have led to the development of various irrigation systems. The main irrigation systems in China include well-canal combined irrigation system, desert oasis agricultural irrigation system, water wheel pump irrigation system, well irrigation area, rainwater collection and storage utilization projects, and water-saving irrigation for forage fields. With the deepening of the concept of sustainable development, the development of agriculture in China is gradually shifting from extensive production and operation to green and high-quality development, taking into account resource conservation and environmental protection (Chang et al., 2023). The Central Document No. 1 in 2023 once again proposed to promote green development in agriculture, which cannot be achieved without the support of water-saving technologies. In 2019, the total water consumption in China was 602.12 billion cubic meters, with agricultural water consumption accounting for 368.23 billion cubic meters, industrial water consumption accounting for 121.76 billion cubic meters, domestic water consumption accounting for 87.17 billion cubic meters, and ecological water consumption accounting for 24.96 billion cubic meters. The proportion of agricultural water consumption is 61.2%. In the process of agricultural production, water resources and related technologies play an important role as production factors, and their importance cannot be ignored. However, in practice, China's agricultural water use faces serious shortages (Qian et al., 2022), mainly manifested in uneven regional distribution of water resources and low water resource utilization efficiency, which has seriously affected the high-quality development of agriculture. Therefore, exploring water-saving technologies is of great significance for improving agricultural production efficiency and achieving green and high-quality development in agriculture.

Scholars at home and abroad have conducted extensive research on the influencing factors of farmers' adoption of water-saving technologies. These factors include farmers' individual water-saving awareness (Valizadeh et al., 2021), farmers' perception of water-saving technologies (Zhang et al., 2019), government policy factors such as water-saving subsidies (Liu et al., 2018; Chen and Mu, 2022), and the social networks of farmers' families, all of which have important influences on farmers' adoption of water-saving technologies (Wang and Lu, 2015). In addition, there have been numerous studies on the impact of farmers' adoption of water-saving technologies on agricultural production. Kulkarni (2011) pointed out that the adoption of water-saving technologies by farmers can reduce the fragmentation of agricultural land and promote large-scale farming by farmers (Kulkarni, 2011). Chai et al. (2014) found that the adoption of water-saving technologies by farmers can increase the planting area of wheat and corn (Chai et al., 2014). Chathuranika et al. (2022) stated that the application of water-saving irrigation technology is beneficial for promoting the development of modern agriculture (Chathuranika et al., 2022).

It should be noted that there is limited literature on the impact of water-saving technologies on agricultural production efficiency, but there is more research on factors affecting agricultural production efficiency. One factor is the impact of natural factors on agricultural production efficiency. Natural factors mainly include climate, topography, and soil fertility (Reidsma et al., 2009; Scholten et al., 2017). Lu and Han (2019) used panel data from 15 major wheat-producing regions in China from 1991 to 2016 and found that overall wheat production efficiency has been continuously improving, but in provinces with inadequate irrigation, drought severely affects wheat production efficiency (Luan and Han, 2019). Another factor is the impact of agricultural resource endowment on production efficiency (Sibiko et al., 2013; Guth and Smędzik-Ambroży, 2020; Ma et al., 2021). Agricultural resource endowment mainly includes land, labor, and agricultural capita (Grzelak et al., 2019). Shao et al. (2020) pointed out that the lack of human capital is the fundamental constraint on improving the livelihoods of farmers in the loess hilly region, and financial capital and policy capital are the key factors causing differences in livelihood capital between poor and non-poor households (Shao et al., 2020). Gai et al. (2023) pointed out that land transfer can not only directly improve the efficiency of land allocation, but also indirectly improve agricultural total factor productivity by influencing farmers' employment choices and technology adoption (Gai et al., 2023). The third factor is the impact of policies on agricultural production efficiency. Implementing agricultural subsidy policies can enhance farmers' scale efficiency in planting (Li et al., 2022). The fourth factor is the impact of human capital on agricultural production efficiency. In economic growth models, the improvement of human capital can increase individual income, improve employment opportunities and social status, and promote economic growth (Lee and Lee, 2018). However, the impact of human capital on agricultural production efficiency exhibits a non-linear relationship in different land scales, and for human capital to exert productivity effects, it needs to be matched with a certain scale of operation (Zhou et al., 2018).

Although a significant amount of valuable research has been conducted in the academic community on water-saving technologies and agricultural production efficiency, there is a severe lack of research on the impact of water-saving technology adoption on the agricultural production efficiency of high-quality farmers. High-quality farmers play an important role in agricultural development. Among them, high-quality farmers refer to modern agricultural practitioners who specialize in agriculture, possess advanced professional skills, and earn a certain level of income mainly from agriculture. They mainly include three types: management and operation-oriented, professional production-oriented, and skill service-oriented. The characteristics of high-quality farmers are having cultural knowledge, understanding technology, being good at management, and skilled in operations. Therefore, this article aims to clarify the mechanism through which the adoption of water-saving technologies affects the agricultural production efficiency of high-quality farmers. Furthermore, it evaluates the actual impact of water-saving technology adoption on agricultural production efficiency based on addressing the self-selection problem of high-quality farmers adopting water-saving technologies. By conducting in-depth research on agricultural production efficiency, scientific evidence and policy recommendations can be provided for sustainable agricultural development.

2 Data sources, variable selection and model setting

2.1 Data sources

The data used in this study is from a 3-year survey conducted by the research team on high-quality farmers in Jiangxi and Guangdong provinces in China from 2019 to 2021. To ensure data quality, the research team distributed survey questionnaires to high-quality farmers participating in training programs using random sampling method based on the actual situation of each training site. A total of 1800 questionnaires were distributed, and 1750 were collected. After removing samples with outliers, a total of 1707 high-quality farmer samples were used for the study, with a questionnaire utilization rate of 97.54%.

Based on the research focus of this paper, the content of the questionnaire survey mainly includes: 1) village level characteristics of high quality farmers, such as the geographical environment where the village is located, the construction of high standard farmland, the distance from the town government and the geographical distance from the market; 2) individual characteristics of high quality farmers, such as age, gender, education level, employment experience and training experience; 3) the production and operation status of high quality farmers, such as the scale of agricultural production and operation, type of agricultural production and operation, hired labour and agricultural insurance, etc.; 4) the use of digital technology, such as whether and to what extent the Internet is used in the sale of agricultural products, and whether the Internet is used to purchase agricultural production materials.

2.2 Variables selection

2.2.1 Dependent variable

The productivity of high-quality farmers mainly refers to the maximization of output under the rational input of agricultural production factors, which is the input-output ratio formed by the optimal matching of agricultural production factors. Based on the research of Luo and Lei (2020), the comprehensive efficiency value is used as the proxy variable for the productivity of high-quality farmers in this study. The input indicators mainly include labor input, capital input, and agricultural land area; the output indicator mainly includes total agricultural output.

2.2.2 Core independent variable

According to the setting of the survey questionnaire, if high-quality farmers adopt water-saving technologies in the process of agricultural production and management, it is assigned a value of 1 (adopting water-saving technologies = 1); if they do not adopt water-saving technologies, it is assigned a value of 0 (not adopting water-saving technologies = 0).

2.2.3 Moderator variable

Policy support refers to the relevant policies or measures formulated by the government to stimulate high-quality farmers to engage in agricultural production and management activities. In this study, “whether to receive agricultural subsidy policy after engaging in agricultural production and management” is used as the proxy indicator for policy support, with a value of 1 for receiving policy support and 0 for not receiving.

2.2.4 Control variables

Variables are selected mainly from three aspects: individual, family, and village. Specifically, they include age, gender, education level, village geographical location, and other variables. Please refer to Table 1 for details.

2.3 Model setup

After obtaining the efficiency values of decision-making units using the DEA method, in order to further analyze and evaluate the factors that affect the efficiency values and their impact levels, if ordinary least squares regression is directly used, the parameter estimation values will be biased towards zero due to the efficiency values (dependent variable) determined by the DEA model being restricted between 0 and 1. To solve this problem, the Tobit model can be used. Therefore, this study primarily employs the Tobit model to investigate the impact of adopting water-saving technologies on the production efficiency of high-quality farmers. The model formula is shown as Eq. 1:

$$\begin{aligned} y^* &= \beta \chi \mathrm{i} + \varepsilon \\ yi &= yi^*, if\, y^* > 0 \\ yi &= 0, if\, y^* \leq 0 \end{aligned} \tag{1}$$

Here, εi: $N(0, \sigma 2)$,Y represents the production efficiency of high-quality farmers, X represents the variable of adopting water-saving technologies, β represents the estimated regression parameter coefficients, i represents different high-quality farmers, and ε represents the error term.

Additionally, since both the core independent variable (adopting water-saving technologies) and the moderating variable (agricultural subsidy policy) are categorical variables, a moderation effect model is used to empirically test the relationship between policy support and the adoption of water-saving technologies and the production efficiency of high-quality farmers. Based on this, we construct the following regulatory effect model as shown in Eq. 2.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_2 X_1 {}^* X_2 + +\beta_3 BDZi + \varepsilon \iota \tag{2}$$

TABLE 1 Variable definitions, assignments, and descriptive statistics results.

	Variable name	Variable meaning	Average	Standard deviation
Output Indicator	Agricultural Total Output	Family Annual Income (in ten thousand yuan)	572.38	152.578
Input Indicators	Labor Input	Self-employed labor + Hired labor	16.86	6.325
	Fund Input	Actual investment in agricultural production (in ten thousand yuan)	161.34	32.169
	Agricultural Operation Area	Actual operating area (in mu)	278.21	45.263
Dependent Variable	Production Efficiency	Specific calculated value	0.124	0.188
Key Independent Variable	Water-saving Technology	No = 0; Yes = 1	0.318	0.466
Moderating Variable	Agricultural Subsidies	No = 0; Yes = 1	0.529	0.499
Control Variables	Gender	Female = 1; Male = 2	1.707	0.455
	Age	Actual age (in years)	39.6	7.775
	Education Level	Primary school and below = 1; Secondary school or high school = 2; College or above = 3	2.344	0.687
	Village Cadres	No = 0; Yes = 1	0.262	0.440
	Years Engaged in Agricultural Production	Time (in years)	9.156	7.875
	Received Agricultural Training	No = 0; Yes = 1	0.605	0.489
	Total Household Population	Number of people (in individuals)	5.733	2.524
	Stable Agricultural Product Sales Channel	No = 0; Yes = 1	0.465	0.499
	Purchased Agricultural Insurance	No = 0; Yes = 1	0.320	0.467
	Number of Agricultural Machinery	Continuous variable (in units)	4.899	19.756
	Geographical Environment of the Village	Plain = 1; Hill = 2; Mountainous = 3	2.312	0.801
	Whether in Urban Suburbs	No = 0; Yes = 1	0.489	0.500
	Whether Connected to the Internet	No = 0; Yes = 1	0.917	0.276

TABLE 2 Statistical analysis results of production efficiency values for high-quality farmers.

Efficiency value interval	Overall efficiency		Technical efficiency		Scale efficiency	
	Number (units)	Percentage (%)	Number (units)	Percentage (%)	Number (units)	Percentage (%)
0 ≤ E < 0.4	1,496	87.64	1,171	68.60	1,099	64.34
0.4 ≤ E < 0.7	161	9.43	355	20.80	366	21.44
0.7 ≤ E < 0.9	35	2.05	48	2.81	145	8.49
0.9 ≤ E ≤ 1	15	0.88	133	7.79	97	5.68
Mean	0.124		0.323		0.345	

Here, Y represents the variable of agricultural production efficiency for high-quality farmers, X1 represents the variable of adopting water-saving technologies, X2 represents the variable of policy support, X1*X2 represents the interaction term between water-saving technologies and policy support, and X1*X3 represents the interaction term between water-saving technologies and industrial structure adjustment. If the coefficients β2 and β3 are significant, it indicates the presence of a moderation effect.

TABLE 3 Regression results of the impact of water-saving technologies on the productivity of high-quality farmers.

	I		II	
	Coefficient	Standard error	Coefficient	Standard error
	Tobit model		Tobit model	
Water-saving Technologies	0.063***	0.009	0.054***	0.009
Gender	---	---	0.003	0.009
Age	---	---	0.001	0.001
Education Level	---	---	0.017**	0.007
Village Cadres	---	---	0.004	0.010
Years of Agricultural Production	---	---	0.001*	0.0007
Agricultural Training	---	---	0.037***	0.009
Total Family Population	---	---	0.007***	0.001
Stable Agricultural Sales Channels	---	---	0.009	0.009
Purchase of Agricultural Insurance	---	---	0.021**	0.009
Number of Agricultural Machinery	---	---	0.0005**	0.0002
Geographical Environment of the Village	---	---	−0.013***	0.005
Urban or Suburban Area	---	---	0.019**	0.016
Internet Access	---	---	0.015	0.016
R^2	−0.0480		−0.1458	
Sample Size	1707		1707	

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

3 Empirical test results and discussion

3.1 Results of production efficiency measurement

Using DEAP2.1 software, the production efficiency of 1707 high-quality farmers was measured, as shown in Table 2. The comprehensive production efficiency of high-quality farmers is low, only 0.124, indicating a serious loss of comprehensive efficiency in their operations. However, this also indicates that there is a large potential for improvement. That is, while maintaining the current level of input and output, if we eliminate technical and managerial inefficiencies, the average input can be reduced by 87.6%. The pure technical efficiency is 0.323, also at a low level, indicating room for improvement in input and output. The scale efficiency is 0.345.

According to the statistical analysis results of the high-quality farmers' production efficiency values in Table 2, the following situations can be observed: Firstly, there are 1,496 high-quality farmers, accounting for 87.64% of the total, in the efficiency value range between 0 and 0.4. Among them, there are 1,171 with pure technical efficiency between 0 and 0.4, accounting for 68.60% of the total. There are 1,099 with scale efficiency between 0 and 0.4, accounting for 64.34% of the total. Secondly, there are 161 high-quality farmers, accounting for 9.43% of the total, in the efficiency value range between 0.4 and 0.7. Among them, there are 355 with pure technical efficiency between 0.4 and 0.7, accounting for 20.80% of the total. There are 366 with scale efficiency between 0.4 and 0.7, accounting for 21.44% of the total. Thirdly, there are 35 high-quality farmers, accounting for 2.05% of the total, in the efficiency value range between 0.7 and 0.9. Among them, there are 48 with pure technical efficiency between 0.7 and 0.9, accounting for 2.81% of the total. There are 145 with scale efficiency between 0.7 and 0.9, accounting for 8.49% of the total. Finally, there are 15 high-quality farmers, accounting for 0.88% of the total, in the efficiency value range between 0.9 and 1. Among them, there are 133 with pure technical efficiency between 0.9 and 1, accounting for 7.79% of the total. There are 97 with scale efficiency between 0.9 and 1, accounting for 5.68% of the total. In conclusion, the production efficiency of high-quality farmers needs to be improved, especially in terms of pure technical efficiency and scale efficiency. By improving technology and management, the overall efficiency of high-quality farmers can be further enhanced.

3.2 Benchmark regression results

Table 3 reports the benchmark regression results of the adoption of water-saving technologies on the production efficiency of high-quality farmers. The results show that the impact of water-saving technology adoption on the production efficiency of high-quality farmers is statistically significant at the 1% level when controlling for variables such as age, gender, and education level. This may be due to the fact that water-saving technologies play an important role in agricultural production as they can significantly improve production efficiency. Firstly, water-saving technologies can reduce the waste of irrigation water in farmland. Traditional irrigation methods often result in excessive water supply, leading to a significant waste of water resources. However, by adopting water-saving technologies such as drip irrigation and sprinkler irrigation, agricultural water usage can be precisely controlled, maximizing the utilization of water resources and improving irrigation efficiency. Secondly, water-saving technologies can reduce the loss of soil moisture through evaporation and leaching. Under traditional irrigation methods, excessive water supply often leads to excessive evaporation and leaching of soil moisture, resulting in the loss of soil moisture. However, by implementing water-saving technologies such as using coverings and soil improvement measures, the evaporation and leaching of soil moisture can be reduced, thereby improving the efficiency of soil moisture utilization (Valizadeh et al., 2018). Thirdly, water-saving technologies can also improve the water use efficiency of crops. Traditional irrigation methods often suffer from uneven water supply, resulting in insufficient water supply for some crops, which affects their growth and development. However, by adopting water-saving technologies, water usage and supply can be precisely controlled, ensuring even distribution of water, thus improving the water use efficiency of crops and ultimately enhancing agricultural production efficiency. In conclusion, water-saving technologies have a significant impact on the production efficiency of high-quality farmers. By mastering water-saving technologies, high-quality farmers can better utilize water resources, improve irrigation efficiency and soil fertility, thereby increasing agricultural production efficiency and farmers' income.

Among the control variables, education level, years of agricultural production, and the number of agricultural machinery have varying degrees of impact on the agricultural production efficiency of high-quality farmers, while the remaining control variables did not pass the significance test. Specifically, the education level of high-quality farmers is statistically significant at the 5% level, indicating that educational attainment contributes to improving individual agricultural production efficiency. By receiving education, high-quality farmers acquire more knowledge and skills, enabling them to better apply scientific and technological advancements and modern agricultural management methods to improve agricultural production efficiency. The variable of years of agricultural production is statistically significant at the 10% level, suggesting that with an increase in years of agricultural production, farmers accumulate more knowledge related to agricultural production, which is beneficial for improving agricultural production efficiency. The variable of agricultural training is statistically significant at the 1% level, indicating that agricultural training can enhance individual human capital, helping farmers improve their skill levels and better cope with challenges in agricultural production, thereby achieving sustainable agricultural development. The variable of total household population is statistically significant at the 1% level, suggesting that population size can increase the material and human capital stock of the household, leading to increased agricultural investment and improved agricultural production efficiency. Among the external environmental variables, the geographic location of the village is statistically significant at the 1% level, but with a negative direction, indicating that as the geographic type changes from plain areas to hilly and mountainous areas, the agricultural production efficiency of farmers decreases. In hilly and mountainous areas, agricultural production faces more challenges and difficulties due to changes in topography and soil conditions. In hilly mountainous areas, the variations in terrain and soil conditions can have an impact on agricultural production. Due to the higher elevation, the soil in hilly mountainous areas is usually more infertile, with limited supply of water and nutrients. This can restrict the growth of crops, and farmers need to put in more effort in soil improvement and water resource management to enhance agricultural productivity. Additionally, the variations in terrain in hilly mountainous areas also pose challenges to agricultural production. The changes in topography make the layout and management of farmland more complex, and farmers need to take appropriate measures to address issues related to slope agriculture, such as preventing soil erosion and utilizing water resources efficiently. Therefore, farmers in hilly mountainous areas need to face more challenges and difficulties, and they need to adopt suitable measures to improve agricultural productivity, such as selecting appropriate crop varieties, soil improvement, and rational utilization of water resources.

Therefore, measures need to be taken to improve the production efficiency of high-quality farmers, such as improving soil quality, introducing crop varieties adapted to mountainous environments, and strengthening agricultural technical training.

3.3 Robustness test

3.3.1 PSM method

Table 4 reports the results of the robustness test conducted using the PSM method, Including matching methods, experimental group, control group, ATT, standard error, and T-value. The matching methods include nearest neighbor matching, radius matching, and kernel matching. The results before and after matching are provided for each matching method. Due to data and variable limitations, and the fact that high-quality farmers' adoption of water-saving technologies in agricultural production activities does not meet random sampling but is the result of self-selection, the analysis process still faces sample selection bias. Based on this, this study will use the propensity score matching (PSM) method to construct a counterfactual framework for correction, to verify whether the positive effect of adopting water-saving technologies on the production efficiency of high-quality farmers is consistent and stable.

This study uses matching methods such as k-nearest neighbor matching, radius matching, and kernel matching to match the treatment group (adopting water-saving technologies) and the control group (not adopting water-saving technologies) based on propensity scores. The results show that the three matching results are similar, and all pass the significance test at the 1% level, with consistent effect direction and significance level. In addition, after matching using the three methods, the average treatment effect on the treated (ATT) is slightly reduced, with a small decrease in magnitude and consistent sign. Overall, adopting water-saving technologies can improve the production efficiency of high-quality farmers. That is, after using the propensity score matching method to address endogeneity issues, the impact of adopting water-saving

TABLE 4 PSM estimation results of water-saving technology on the production efficiency of high-quality farmers.

	Matching method		Experimental group	Control group	ATT	Standard error	T-value
Water-saving Technology	Nearest Neighbor Matching	Before Matching	0.141	0.097	0.035	0.009	3.78
		After Matching	0.135	0.106	0.027	0.100	2.76
	Radius Matching	Before Matching	0.141	0.097	0.035	0.009	3.78
		After Matching	0.133	0.104	0.029	0.010	2.91
	Kernel Matching	Before Matching	0.141	0.097	0.035	0.009	3.78
		After Matching	0.135	0.103	0.032	0.102	3.32

TABLE 5 Impact of water-saving technologies on agricultural production efficiency of high-quality farmers (substitution estimation method).

Variable	(1)	
	Coefficient	Standard Error
	OLS Model	
Water-saving Technologies	0.057***	0.216
Control Variables	Controlled	
cons	2.341	
Sample Size	1705	

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

technologies on the production efficiency of high-quality farmers still has a significant promoting effect. This also indicates that the research results obtained in this study have not changed due to different matching methods, verifying the robustness of the empirical results on the impact of adopting water-saving technologies on the production efficiency of high-quality farmers.

3.3.2 Replacement estimation method (OLS)

The Ordinary Least Squares (OLS) method is a commonly used statistical method for estimating the linear relationship between variables. It determines the best-fitting line by minimizing the difference between observed values and estimated values. In this study, we use the OLS method to re-estimate the impact of water-saving technology adoption on the agricultural production efficiency of high-quality farmers. Table 5 reports the results of robustness tests using the OLS method. The coefficient for water-saving technology is 0.057 with a standard error of 0.216. Control variables are controlled in the model, and the intercept is 2.341. The sample size is 1707. The choice of estimation method may also affect the research conclusions. To ensure the robustness of the research results, this study adopts the OLS model to re-estimate the impact of water-saving technology adoption on the agricultural production efficiency of high-quality farmers. The results show that both the direction of the effect and the significance level are consistent with the results in Table 3, indicating that the impact of water-saving technology adoption on the agricultural production efficiency of high-quality farmers is robust.

3.4 Mechanism verification

Based on the results in Table 6, we can draw the following conclusions: Firstly, water-saving technology has a significant positive impact on production efficiency. In Model I, the coefficient of water-saving technology is 0.042, with a standard error of 0.018, and a significance level of 1%. In Models II and III, the coefficients of water-saving technology are 0.021 and 0.024 respectively, with standard errors of 0.013 and 0.016. However, the impact of water-saving technology is not significant in these two models. Water-saving technologies still have a positive impact on production efficiency.

Secondly, policy support also has a significant positive impact on production efficiency. In Model I, the coefficient of policy support is 0.063, with a standard error of 0.029, and a significance level of 1%. In Model II, the coefficient of policy support is 0.056, with a standard error of 0.031, and a significance level of 5%. In Model III, the coefficient of policy support is 0.072, with a standard error of 0.034, and a significance level of 1%. This indicates that policy support is also crucial for improving productivity. Agricultural subsidies can provide financial support to help high-quality farmers purchase the necessary materials for agricultural production, such as seeds, fertilizers, and pesticides, thereby solving the problem of financial shortage and improving farmers' production capacity (Vitalis, 2007). As a result, high-quality farmers can invest better in agricultural production, increasing crop yield and quality. Secondly, the implementation of agricultural subsidies can also promote agricultural industrial structure adjustment and sustainable development. Through the guidance of subsidy policies, high-quality farmers can adjust their planting structure and choose crops that are suitable for local climate and soil conditions, thereby improving the competitiveness of the agricultural industry. At the same time, agricultural subsidies can also encourage high-quality farmers to adopt environmentally friendly agricultural production methods, reducing the use of pesticides and fertilizers and protecting the ecological environment of farmland. Thirdly, agricultural subsidies can help high-quality farmers cope with uncertainties in agricultural production. Agricultural production is influenced by factors such as weather, natural disasters, and market fluctuations, and high-quality farmers face the possibility of risks and losses. The subsidies provided by the government can help high-quality farmers reduce these risks and increase their confidence and enthusiasm in engaging in agricultural production.

Thirdly, the interaction between water-saving technology and policy support also has a significant positive impact on production efficiency. In

TABLE 6 Test results for regulatory effect mechanism.

Variable	I	II	III
	Productivity	Productivity	Productivity
	Tobit	Tobit	Tobit
	Coefficient (Standard error)	Coefficient (Standard error)	Coefficient (Standard error)
Water-saving technology	0.042**(0.018)	0.021 (0.013)	0.024 (0.016)
Policy support	0.063**(0.029)	0.056*(0.031)	---
Water-saving technology * Policy support	---	0.072**(0.034)	---
Control variables	Control	Control	Control
R^2	−0.172	−0.163	−0.168
Sample size	1707	1707	1707

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

TABLE 7 Regression results of the impact of water-saving technologies on the productivity of different types of high-quality farmers.

	I		II		III		IV	
	Large-scale farms		Family farms		Farmer cooperatives		Agricultural enterprises	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Water-saving Technologies	0.047**	0.023	0.036**	0.016	0.071***	0.030	0.069***	0.022
Control Variables	Control		Control		Control		Control	
R^2	−0.131		−0.143		−0.162		−0.675	
Sample Size	330		482		444		451	

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

Model II, the coefficient of the interaction between water-saving technology and policy support is 0.072, with a standard error of 0.034, and a significance level of 1%. With the intensification of global climate change and water scarcity, water conservation in agriculture has become a hot topic of global concern. In order to promote sustainable agricultural development, governments have implemented a series of policies to encourage farmers to adopt water-saving technologies. Agricultural subsidies play an important role in promoting the adoption of high-quality water-saving technologies by farmers. The regulatory role of agricultural subsidies can stimulate farmers to adopt high-quality water-saving technologies by providing economic incentives. Firstly, agricultural subsidies can provide economic support and reduce the cost of adopting water-saving technologies for high-quality farmers. The introduction and application of water-saving technologies require certain investments, including the purchase of water-saving equipment and the renovation of irrigation systems, etc., Agricultural subsidies can help farmers alleviate these cost pressures and encourage them to adopt water-saving technologies. Secondly, agricultural subsidies can provide market protection and increase the motivation for high-quality farmers to adopt water-saving technologies. High-quality farmers usually have strong market awareness and marketing capabilities, making it easier for them to apply adopted water-saving technologies to agricultural production and obtain better economic benefits through market sales. Agricultural subsidies can provide market support and sales channels to help high-quality farmers better promote and sell water-saving agricultural products, further motivating them to adopt water-saving technologies. In this way, high-quality farmers can not only save water but also increase income and improve economic efficiency when adopting water-saving technologies.

Overall, water-saving technology, policy support, and the interaction between water-saving technology and policy support all have a positive impact on production efficiency. These results indicate that adopting water-saving technology and receiving policy support can improve production efficiency.

3.5 Further analysis

As analyzed earlier, overall, water-saving technologies are beneficial for improving the production efficiency of high-quality farmers. However, is there a difference in the impact of water-saving technologies on different types of high-quality farmers? Based on this, this section explores the impact of water-saving technologies on the production efficiency of different types of high-quality farmers. Based on the definition of high-quality farmers, the types of high-quality farmers are further divided, and the impact of water-saving technologies on the production efficiency of different types of high-quality farmers is explored. The research subjects in columns I to IV are large-scale farmers, family farms, farmer cooperatives, and agricultural enterprises, respectively. Table 7 reports the regression results of the impact of water-saving technologies on the production efficiency of different types of high-quality farmers.

The impact of water-saving technologies on the production efficiency of different types of high-quality farmers varies. Firstly, the impact of water-saving technologies on the production efficiency of large-scale farmers is significant at the 5% level, with a coefficient of 0.047. Secondly, the impact of water-saving technologies on the production efficiency of family farms is significant at the 5% level, with a coefficient of 0.036. Thirdly, the impact of water-saving technologies on the production efficiency of farmer cooperatives is significant at the 1% level, with a coefficient of 0.071. Finally, the impact of water-saving technologies on the production efficiency of agricultural enterprises is significant at the 1% level, with a coefficient of 0.069. This indicates that the impact of water-saving technologies on the production efficiency of farmer cooperatives and agricultural enterprises is higher than that of large-scale farmers and family farms. This research result demonstrates that the adoption of water-saving technologies can effectively improve the production efficiency of farmers and is of great significance for sustainable agricultural development.

4 Conclusion and implications

Based on the survey data of 1707 high-quality farmers from Guangdong and Jiangxi provinces, this study used the DEA-tobit model to explore the impact of water-saving technology adoption on agricultural production efficiency from a micro perspective. The following conclusions were drawn. Firstly, the adoption of water-saving technology by high-quality farmers can improve agricultural production efficiency. Even after controlling for other variables, this impact remains significant. Secondly, robustness tests using propensity score matching (PSM) and substitution estimation models show that the promotion of water-saving technology adoption among high-quality farmers is robust in improving agricultural production efficiency. Thirdly, the results of the mechanism study indicate that government policies can further strengthen farmers' adoption of water-saving technology, thereby enhancing agricultural production efficiency. Finally, the analysis of the impact of water-saving technology on the production efficiency of different types of high-quality farmers reveals differences. According to the significance level, the impact of water-saving technology on the production efficiency of farmer cooperatives and agricultural enterprises is higher than that of large-scale farming households and family farms. Based on these findings, the following implications can be drawn: continuously improve the water-saving agricultural technology system. Firstly, enhance the research and development and promotion of water-saving agricultural technology. Increase investment in the research and development of water-saving agricultural technology, promote collaboration between research institutions, agricultural enterprises, and farmers in the research and experimentation of water-saving agricultural technology. At the same time, strengthen the publicity and promotion of water-saving agricultural technology, improve farmers' awareness and acceptance of water-saving agricultural technology. Secondly, strengthen the construction of farmland water conservancy facilities. Improve farmland water conservancy facilities, including irrigation systems and water conservancy projects, to improve the efficiency of water resource utilization. Finally, promote efficient water-saving agricultural technologies such as precision irrigation, mulching cultivation, and straw returning. Through scientific and reasonable irrigation management, reduce irrigation water volume and improve irrigation water utilization efficiency. Mulching cultivation can reduce soil water evaporation and improve soil water retention capacity. Strengthen policy support and incentive mechanism construction. Firstly, formulate relevant policies to encourage and support farmers in adopting water-saving agricultural technology. For example, provide financial subsidies for the research, promotion, and application of water-saving equipment and technology, reduce the economic burden on enterprises and individuals, and promote the popularization and application of water-saving technology. Secondly, establish incentive mechanisms to provide rewards and subsidies to farmers who adopt water-saving agricultural technology. At the same time, strengthen the supervision and evaluation of water-saving agricultural technology to ensure the effective implementation and promotion of the technology.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the [patients/ participants OR patients/participants legal guardian/ next of kin] was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

XL: Conceptualization, Writing–original draft. DY: Data curation, Formal Analysis, Writing–review and 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.

Publisher's note

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