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Original Research

From Technology Adoption to Scientific Application: Can Agricultural Extension Services Effectively Promote Farmers' Scientific Fertilization?

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Abstract

Farmers in China generally have unreasonable fertilization behavior. Agricultural extension services are not only related to popularizing scientific fertilization technology but also affect farmers' subsequent technology use behavior to a great extent, which is a critical factor in promoting farmers' scientific fertilization. This study aims to clarify whether there are differences in the impact of agricultural extension services provided by different organizations on farmers' fertilization behavior, and to explore the feasible path of agricultural extension services to promote farmers' scientific fertilization. This study used the survey data of 1262 farmers in the main rice-producing areas of Hubei Province to empirically analyze the impact and mechanism of agricultural extension services on farmers' scientific fertilization behavior. The study finds that agricultural extension services have a significant positive impact on farmers' scientific fertilization behavior. Moreover, the impact of different agricultural extension service providers on farmers' scientific fertilization behavior varies. Specifically, the public sector and farmers' organizations have a more significant impact on farmers' scientific fertilization behavior than the private sector. The public and private sectors promote farmers' scientific fertilization behavior by increasing their value perception. These findings help clarify the influencing factors of farmers' fertilization behavior, clarify the path of agricultural technology extension services, and provide practical policy guidance for developing countries to reduce fertilizer effectively.

Keywords: agricultural extension services, scientific fertilization, value perception, China

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Introduction

As an essential input for soil fertilization and grain production, chemical fertilizer is crucial to developing agricultural economies in various countries. In order to understand the application of agricultural chemical fertilizers in China, based on the data from 'China Statistical Yearbook' and 'China Rural Statistical Yearbook' from 1990 to 2022, this study sorted out the changes in agricultural chemical fertilizer application amount and fertilization intensity (agricultural chemical fertilizer application amount/crop planting area), as shown in Fig. 1. According to the data, China's current fertilizer reduction and efficiency have achieved specific results. However, the amount and intensity of agricultural fertilizer application are still high, and further efforts are needed. To this end, the 'Action Plan for Fertilizer Reduction by 2025' proposes accelerating the construction of a modern scientific fertilization technology system and promoting the use of new fertilizer products and technologies.

Scientific fertilization technology prioritizes high yield, high quality, economy, and environmental protection in fertilization. It features adopting new fertilizer products, such as commercial organic fertilizers and slow-release fertilizers, and high-efficiency fertilization technologies, such as soil testing and formulated fertilization technology (STFFT) and water and fertilizer integration [1]. It is critical to achieving the dual goals of fertilizer reduction, efficiency, and ecological environment protection. However, in reality, farmers still generally use traditional fertilization methods and promoting scientific fertilization technology is less effective than expected. Micro-empirical studies indicate that only 32% of sampled farmers adopt new fertilizer products like slow-release fertilizers and commercial organic fertilizers, and even fewer farmers adopt efficient fertilization technology like water-fertilizer integration and soil-measurement fertilization [1]. Therefore, how to quickly and effectively promote and apply scientific fertilization technology and change farmers' fertilization behavior remains an urgent issue.

It is generally accepted that changes in farmers' fertilization behavior are influenced not only by their demographic, psychological, household, and production and business characteristics [2-4], but also by external incentives and government regulation [3-5]. For farmers, transitioning from traditional fertilization methods to scientific fertilization methods is a complex decision-making process to decide whether to adopt new technologies and new products, often relying on multiple information channels to help make decisions [6]. Studies have shown that farmers learn the agricultural knowledge and technologies they need from peers, extension services, farmers' organizations, agricultural dealers and the news media [7, 8]. Among these, extension services are an important way to facilitate the implementation of new agricultural technologies and changes in farmers' production behavior, and they are also critical factors in changing farmers' fertilizer use [9]. Scholars have pointed out that agricultural extension services can lead to direct or indirect changes in production behavior by changing farmers' perceptions, increasing technology accessibility and spillover effects [10]. However, at present, agricultural extension services in China still have imperfect systems, low service levels and "one-size-fits-all" extension models [11]. If the current situation of agricultural extension services in China is not clarified, and the mechanism of the influence of agricultural extension services on farmers' behavior is not understood, it will continue to lead to problems such as low efficiency of agricultural extension services and unscientific adoption of technologies by farmers.

China's agricultural extension services have formed a pattern in which public welfare and business exist, and diversified subjects participate extensively. The main subjects of agricultural extension services can be summarized into three categories: first, the public sector, represented by government departments such as extension stations and soil fertilizer stations [8, 12, 13]; second, the private sector, represented by agricultural enterprises and private consultants [14-16]; and third, farmers' organizations represented by farmers' cooperatives, agricultural chambers of commerce, and industry associations [16-18]. They are funded from different sources, are based in different social sectors, and operate at different levels of governance [19]. However, there needs to be more debate about the effectiveness of technical training provided by different extension agents. Some scholars argue that the public sector is more binding, credible and appealing, well-funded and effective in training [9, 20]. Other scholars believe the private sector is more autonomous and targeted and can provide farmers with more needed knowledge and skills [21-23]. Others argue that technical training by farmers' organizations can help change farmers' perceptions and significantly increase their willingness to produce green [24, 25].

At the same time, scholars have noted that the impact of agricultural extension services on farmers' fertilizer use remains to be determined. For example, Lin et al. [9] found that receiving public agricultural extension services increased farmers' total fertilizer use, nitrogen fertilizer use and fertilizer expenditure in rice production. Rahman et al. [15] noted that farmers who received private sector extension services did not reduce urea fertilization. Qiao et al. [26] found that agricultural extension services significantly increased farmers' willingness to apply organic fertilizer. At this stage, scientific fertilization technology has been widely promoted in rural China but has yet to achieve sound fertilizer reduction and efficiency. One of the possible reasons for the unsatisfactory promotion effect is that farmers do not correctly understand the value of scientific fertilization technology. Farmers still rely excessively on production habits and experience

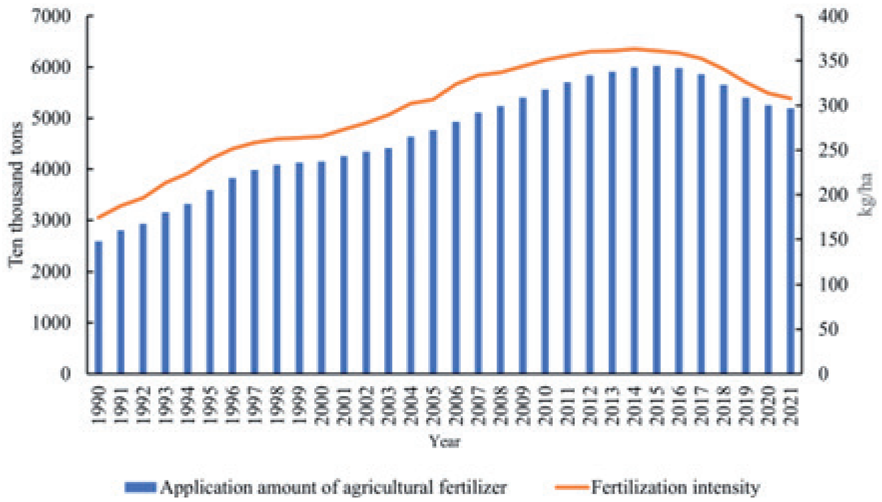

Fig. 1. The amount and intensity of agricultural chemical fertilization in China from 1990 to 2021.

in agricultural production, resulting in a "two-sided" situation between technology adoption and scientific application [27]. Therefore, in the current market environment, it is necessary to further investigate whether agricultural extension services have honestly and effectively promoted farmers' adoption and scientific application of fertilizer technology.

The existing literature discusses the relationship between agricultural extension services and farmers' fertilization behavior. First, the impact of agricultural extension services on farmers' fertilization behavior is analyzed at the level of farmers' behavior. Existing studies have mostly analyzed whether agricultural extension services have influenced farmers' adoption of certain technologies or products, without considering whether farmers have used them correctly according to technical specifications and product requirements. This approach does not comprehensively and deeply reflect the scientific nature of farmers' fertilization behavior. To judge whether the agricultural extension service can effectively promote the scientific fertilization behavior of farmers, we should pay more attention to whether farmers are scientifically applied. Second, the influence of extension agents and extension methods on farmers' fertilization behavior is analyzed at the level of extension service supply. Current research has focused on examining the impact of a single extension service provider on farmers' fertilizer use, while comparatively less attention has been given to analyzing the multiple impacts of different extension service providers on farmers' fertilization behavior.

Therefore, taking agricultural extension services as the entry point, this study empirically analyzed the impact and pathways of agricultural extension services on farmers' scientific fertilization behavior using data from a survey of farmers in the main rice-producing areas of Hubei Province in 2022 and compared the differences in the impact of different agricultural extension service providers. We aim to answer, "Do agricultural extension services effectively promote farmers' scientific application behavior, rather than just their technology adoption behavior? How can the effectiveness of agricultural extension services in promoting scientific fertilization be effectively enhanced?". Our research can also provide some theoretical and practical basis for the continued promotion of fertilizer reduction and efficiency and for achieving the goal of green agricultural development.

Theoretical Analysis and Research Hypotheses

Impact of Agricultural Extension Services on Farmers' Scientific Fertilization Behavior

The scientific application of fertilizer by farmers is not simply a matter of adopting scientific fertilizer technology, but whether farmers adopt fertilizer technology and then apply fertilizer scientifically according to technical specifications and product requirements is the key to scientific fertilization by farmers. Therefore, access to scientific fertilizer information and the correct use of fertilizer technology or fertilizer products are prerequisites for scientific fertilization by farmers. However, scientific fertilization is highly professional and technical, beyond most farmers' perception and learning capacity, and requires more guidance and support from external information. As an important bridge between science and technology and agricultural productivity, agricultural extension services can provide farmers with information on new products and technologies and help them understand and master their use. Effective agricultural extension services can influence farmers' technology adoption decisions [26], assist them in correctly applying fertilization technology and fertilizer products, and thus promote scientific fertilization practices. Farmers generally receive extension services from public, private, and farmers' organizations. Interaction between different service organizations and interest groups results in a diversity of extension services [19].

There are still conflicting views on the impact on farmers of diversifying agricultural extension services. Some scholars believe diversifying agricultural extension service providers can help meet farmers' individual needs and reduce the cost of accessing services [28, 29]. It can promote technology adoption, help farmers solve problems in technology adoption, and regulate their technology use behavior, thus ensuring effective technology implementation. Another group of scholars argues that disadvantaged groups, such as smallholders, face service exclusion in the context of diversified agricultural extension services, and that the fragmentation of agricultural services and the differentiation of technology content increase the cost of agricultural production, thus exacerbating farmers' technology access dilemma [23]. The lack of scientific and timely technical information is a fundamental reason for the irrational fertilization of farmers in China [9, 30]. Agricultural extension services are critical in improving agricultural productivity and changing farmers' use of fertilizers. Although diversified agricultural extension models have been developing at this stage, and the agricultural extension service system has gradually changed from a single subject to a plurality of subjects, there still needs to be more compelling evidence on its role in constructing a scientific fertilization system. Based on this, we propose the following hypothesis:

Hypothesis 1: Agricultural extension service has a significant positive effect on farmers' scientific fertilization behavior, and the effect of different agricultural extension service subjects on farmers' scientific fertilization behavior is different.

The Mediating Role of Value Perception

Farmers' value perception is their weighing of costs and benefits before making behavioral decisions [31, 32]. Farmers' adoption of new technologies is related to how the technology is disseminated and their value perceptions of the new technology [33]. As "rational economic people", farmers tend to adopt technologies that are beneficial to them [34]. The valuable information that farmers obtain from agricultural extension services will be transformed into value perceptions through a series of thinking activities such as perceptions and representations. In the context of encouraging farmers to apply fertilizer scientifically, agricultural extension services will influence farmers' value perceptions of scientific fertilization through knowledge and technology diffusion, influencing their behavior. Farmers who receive extension services tend to be more aware of the positive effects of scientific fertilizer application on improving soil fertility, increasing crop yields, and protecting the ecological environment than those who do not [26]. Consequently, they are more likely to adopt these technologies or products. In addition, different agricultural extension service providers have different emphases when promoting technologies, which may lead to differences in farmers' perceptions of the value of the technologies and thus have a differential impact on farmers' behavior. Therefore, we propose the following hypothesis:

Hypothesis 2: Value perception intermediates the agricultural extension service and farmers' scientific fertilization behavior.

A diagram of the research framework is shown in Fig. 2.

Materials and Methods

Survey Data

The data used in this paper come from a questionnaire survey conducted by the research team between July and August 2022 among rice growers in Hubei Province, China. The main reasons for selecting Hubei Province for the study are: Firstly, Hubei province is one of China's major grain production regions, and rice is the province's largest grain crop. In 2021, Hubei Province will account for 7.60% of the country's rice sown area and 8.85% of total production. Secondly, the promotion of scientific fertilization in Hubei Province has been effective. According to statistics, as of 2020, the coverage rate of STFFT for major crops in Hubei Province had increased to 95%, the utilization rate of chemical fertilizers had risen to 40%, and the total amount of chemical fertilizers applied had been reduced to 2.735 million tons (pure), with the province experiencing negative growth in the total amount of chemical fertilizers applied for seven consecutive years.

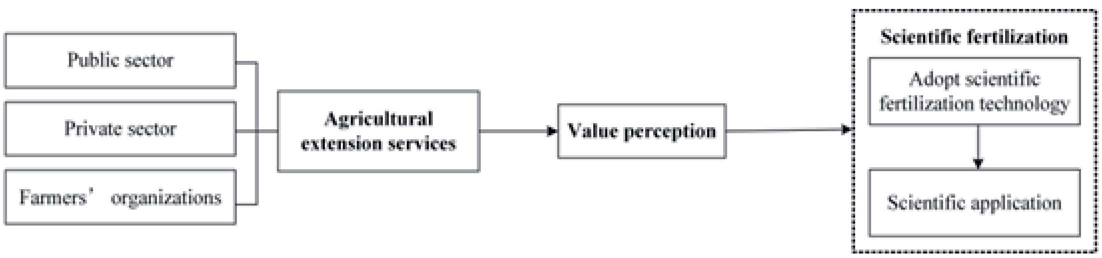

Fig. 2. Research framework.

The survey utilized a multi-stage random sampling method. Firstly, Hubei Province was chosen as the research area, and based on the research's feasibility, Tianmen, Xiantao, Zhijiang, Yunmeng, Songzi, and Zhongxiang were ultimately selected as the sample collection areas (Fig. 3). Secondly, 2-4 towns were randomly selected from the sample cities/counties. Then, 2-4 administrative villages were selected in each township. Finally, 15-20 farming households were randomly chosen in each sample village as survey subjects. The survey mainly covers the essential characteristics of individual farmers and their families, the status of agricultural production and operation, the adoption of scientific fertilization technology, agricultural extension services and the essential characteristics of villages. Given that rice farmers are generally middle-aged and elderly and have a low level of education, the survey was conducted in the form of one-to-one questionnaire interviews. The researchers were postgraduate and undergraduate students who had attended training sessions. The researcher filled in the questionnaire based on clear responses from the farmers. According to the needs of the study, poor quality questionnaires with too much missing essential information, contradictory answers and outliers were eliminated, resulting in 1262 valid questionnaires.

Model

Baseline Regression Model

Farmers' decisions on scientific fertilization are not single but are typically gradual on technology adoption [27]. Specifically, farmers first have to decide whether to adopt scientific fertilization technologies. Then those who choose to adopt scientific fertilization technologies must decide whether to apply them scientifically according to technical specifications. Therefore, the Bivariate Probit model was chosen for estimation in this paper concerning previous studies, and the model was set as follows:

$$Y_1^* = \beta_1 X + \varepsilon_1$$
$$Y_2^* = \beta_2 X + \varepsilon_2 \tag{1}$$

In Equation (1), Y_1^* and Y_2^* represent the latent variables for the adoption of Y_1 and the scientific application of Y_2 by farmers' fertilization technology, respectively. represents agricultural extension services. β_1 and β_2 are coefficients to be estimated. ε_1 and ε_2 are random error terms and are assumed to follow a normal joint distribution of $N(0,0,1,1, \rho)$, and ρ is the correlation coefficient between them. The specific relationship of Y_1^*, Y_1, Y_2^*, Y_2 are as follows:

$$Y_1 = \begin{cases} 1 & Y_1^* > 0 \\ 0 & Y_1^* \le 0 \end{cases} \quad Y_2 = \begin{cases} 1 & Y_2^* > 0 \text{ and } Y_1^* > 0 \\ 0 & Y_2^* \le 0 \text{ and } Y_1^* > 0 \end{cases} \tag{2}$$

First, farmers have to decide whether to adopt scientific fertilization technology (Y_1 = 0 or 1). When farmers adopt the scientific fertilization technology (Y_1^*>0), they then decide whether to apply it scientifically (Y_2 = 0 or 1). Thus, farmers' scientific fertilization decisions can be expressed formally as:

$$Y_1 = 0\text{:}\ \ Prob(Y_1 = 0) = \Phi(-\beta_1 X) \tag{3}$$

$$Y_1 = 1, Y_2 = 1\text{:}\ \ Prob(Y_1 = 1, Y_2 = 1) = \Phi_2(\beta_1 X, \beta_2 X, \rho) \tag{4}$$

$$Y_1 = 1, Y_2 = 0\text{:}\ \ Prob(Y_1 = 1, Y_2 = 0) = \Phi_2(\beta_1 X, -\beta_2 X, -\rho) \tag{5}$$

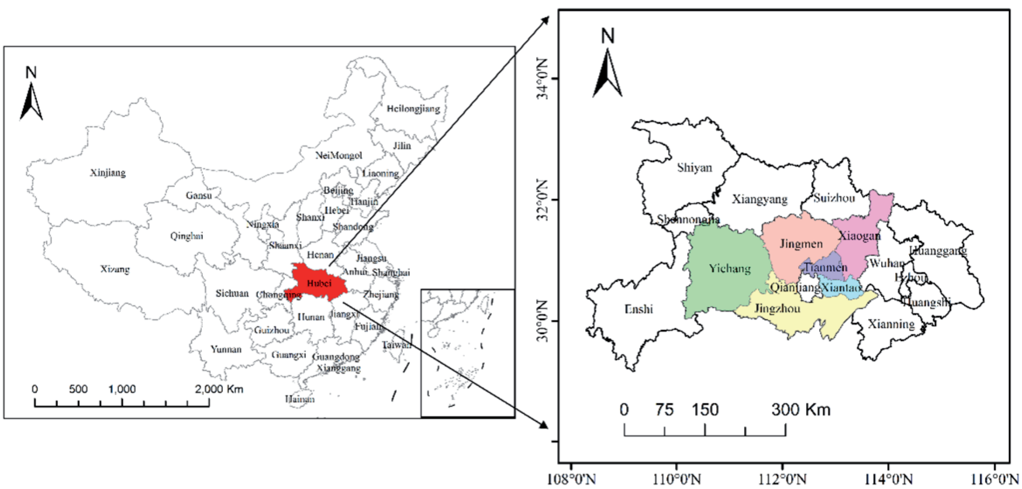

Fig. 3. Distribution of study area.
Note: Different colors represent the geographic locations where samples are obtained, and only up to the city (county) level are indicated here.

Variables

Dependent Variables

The dependent variable is the adoption behavior and scientific application of scientific fertilization technology. We believe that simply adopting scientific fertilization technology does not reflect whether farmers' fertilization behavior is scientific, and the technical specifications corresponding to each fertilization technology are different. In order to better clarify the impact of agricultural technology extension services on farmers' scientific fertilization behavior, we select soil testing and formulated fertilization technology (STFFT) as the research object. We define the "adoption behavior" of scientific fertilization technology as "whether farmers adopt STFFT in the process of rice planting", and define "scientific application" as "whether farmers fertilize strictly according to local technical specifications and product descriptions".

The reasons for selecting STFFT are as follows: Firstly, STFFT has been promoted in China since 2005 and has been promoted for a long time. The analysis of the current situation of farmers' adoption of STFFT can better reflect the long-term impact of agricultural extension services and has important practical significance for promoting fertilizer reduction and efficiency technology. Secondly, STFFT has precise requirements on the quantity and application of varieties of base and follow-up fertilizers applied by farmers at different periods, which can better reflect the connotation of scientific fertilization technology [27]. Therefore, clarifying whether farmers apply fertilizer according to the requirements of technical specifications after adopting STFFT can better evaluate whether the technology has been effectively promoted and applied. This has essential reference significance for the promotion of other scientific fertilization technologies.

Independent Variables

Agricultural extension services mainly include the participation of farmers in agricultural extension services and the participation in extension services provided by subjects of different natures. The mediating variable "value perception" is measured by farmers' recognition that "Using scientific fertilization technology and new fertilizer products can protect the ecological environment and improve cultivated land quality". In order to eliminate potential confounding variables, we controlled for individual characteristics, family characteristics, production and operational characteristics, and village characteristics of the respondents, in line with existing research [9, 11, 13, 27]. The definitions and descriptive statistics for each variable are detailed in Table 1.

Table 1. Definition and description of variables.

Variables	Definition and assignment	Mean		Diff.
		Yes	No	
Dependent Variable				
Adoption behavior	Whether the STFFT was adopted during rice planting: yes = 1, no = 0	0.000	1.000	
Scientific application	Whether fertilization was strictly carried out according to the requirements of local technical specifications and product descriptions: yes = 1, no = 0	0.000	0.933	-0.933***
Independent Variable				
Agricultural extension services	Whether to accept the technical training of STFFT: yes = 1, no = 0	0.611	0.941	-0.330***
Public sector	Whether to participate in the training of STFFT provided by public sector such as agricultural technology stations: yes = 1, no = 0	0.326	0.749	-0.422***
Private sector	Whether to participate in the training of STFFT provided by private sector such as agricultural materials stores: yes = 1, no = 0	0.012	0.050	-0.038***
Farmers' organizations	Whether to participate in the training of STFFT provided by farmers' organization such as cooperatives: yes = 1, no = 0	0.010	0.092	-0.082***
Mediating Variable				
Value perception	Interviewee's response to the statement "Using scientific fertilization technology and new fertilizer products can protect the ecological environment and improve cultivated land quality": very disagree = 1, disagree = 2, neutral = 3, agree = 4, very agree = 5	3.459	3.962	-0.503***
Control Variable				
Gender	Male = 1; Female = 0	0.937	0.954	-0.017
Age	Respondent's actual age (years)	60.297	57.238	3.059***

Table 1. Continued.

Education	Respondents' years of education (years)	7.897	9.117	-1.220***
Health	Respondents' physical condition self-assessment: very poor = 1, relatively poor = 2, general = 3, good = 4, very good = 5	4.020	4.201	-0.181***
Experience	Number of years respondents have been farming	37.016	34.460	2.555**
Agricultural labor	Number of laborers engaged in agricultural production in the household	1.810	1.900	-0.089
Demonstration	Demonstration household: yes = 1, no = 0	0.066	0.146	-0.080***
Proportion	Share of farm income of total household income	0.361	0.372	-0.011
Purpose	Household consumption = 1, sales = 2, both = 3	2.555	2.749	-0.194***
Plots	Number of plots planted with rice	7.839	10.619	-2.780*
Scale	Logarithm of actual planting area (mu) of rice, 1 mu = 1/15 hectare	2.239	2.553	-0.314***
Concentration	Concentration of plots: very poor = 1, relatively poor = 2, general = 3, good = 4, very good = 5	3.206	3.305	-0.099
Fertility	Soil fertility: very poor = 1, relatively poor = 2, general = 3, good = 4, very good = 5	3.393	3.515	-0.122*
Cooperatives	The village has a cooperative: yes = 1; no = 0	0.901	0.937	-0.036*
Enterprises	The village has agricultural enterprises: yes = 1, no = 0	0.312	0.264	0.048
Tianmen	Tianmen = 1, others = 0	0.229	0.159	0.070**
Yunmeng	Yunmeng = 1, others = 0	0.140	0.033	0.106***
Xiantao	Xiantao = 1, others = 0	0.141	0.050	0.091***
Zhongxiang	Zhongxiang = 1, others = 0	0.154	0.351	-0.197***
Zhijiang	Zhijiang = 1, others = 0	0.181	0.222	-0.041
Songzi	Songzi = 1, others = 0	0.155	0.184	-0.029

Note: The last column shows the results of the t-test of sample means for the non-adopted (No) and adopted (Yes) groups of the STFFT. ***, ** and * are significant at the 1, 5 and 10% levels, respectively.

Results and Discussion

Estimation of the Impact of Agricultural Extension Services on Farmers' Scientific Fertilization Behavior

Baseline Regression Results

Since farmers may receive multiple extension services simultaneously in actual agricultural production, considering only a single extension service may lead to bias in the regression results. Therefore, we considered the scenario of farmers receiving multiple extension services simultaneously, and the model estimation results are presented in Table 2. Both Athrho and Wald test values were significant at the 1% statistical level, indicating that the residuals of farmers' adoption behavior and scientific application were correlated and that applying the Bivariate Probit model was reasonable. To test the robustness of the estimates, the results of the Probit model tests are also reported in Table 2. The coefficients and significance of the variables

Table 2. Estimation results of the baseline regression model.

Variables	Bivariate Probit		Probit	
	Adoption behavior	Scientific application	Adoption behavior	Scientific application
Agricultural extension services	0.231*** (0.072)		1.009*** (0.152)	
Public sector		0.176*** (0.064)		0.811*** (0.104)
Private sector		0.049 (0.077)		1.246*** (0.260)

Table 2. Continued.

Farmers' organizations		0.100** (0.046)		0.510* (0.291)
Gender	0.124 (0.194)	0.190 (0.200)	0.119 (0.205)	0.104 (0.207)
Age	-0.007 (0.006)	-0.006 (0.006)	-0.008 (0.006)	-0.004 (0.007)
Education	0.042** (0.016)	0.047*** (0.016)	0.043** (0.017)	0.047** (0.018)
Health	0.067 (0.053)	0.086 (0.054)	0.059 (0.055)	0.106* (0.062)
Experience	0.005 (0.004)	0.004 (0.004)	0.006 (0.005)	0.005 (0.005)
Agricultural labor	-0.050 (0.056)	-0.003 (0.053)	-0.040 (0.054)	0.012 (0.054)
Demonstration	0.353** (0.151)	0.383** (0.151)	0.311** (0.152)	0.431*** (0.158)
Proportion	-0.194 (0.164)	-0.174 (0.166)	-0.214 (0.172)	-0.140 (0.175)
Purpose	0.173** (0.080)	0.212*** (0.080)	0.143* (0.082)	0.215** (0.085)
Plots	0.000 (0.002)	-0.001 (0.002)	0.001 (0.002)	-0.002 (0.002)
Scale	0.130** (0.054)	0.116** (0.054)	0.120** (0.055)	0.085 (0.057)
Concentration	0.038 (0.033)	0.039 (0.033)	0.030 (0.034)	0.021 (0.035)
Fertility	0.052 (0.046)	0.027 (0.046)	0.044 (0.048)	0.001 (0.050)
Cooperatives	0.353** (0.178)	0.316* (0.178)	0.361* (0.185)	0.285 (0.180)
Enterprises	-0.357*** (0.110)	-0.240** (0.110)	-0.367*** (0.115)	-0.200* (0.120)
Tianmen	-0.519*** (0.163)	-0.510 ***(0.166)	-0.525*** (0.167)	-0.632*** (0.188)
Yunmeng	-0.608*** (0.213)	-0.758*** (0.242)	-0.347 (0.235)	-0.637*** (0.246)
Xiantao	-0.614*** (0.194)	-0.571*** (0.196)	-0.312 (0.212)	-0.401** (0.197)
Zhongxiang	0.418*** (0.149)	0.358** (0.149)	0.381** (0.155)	0.220 (0.161)
Zhijiang	0.047 (0.140)	0.111 (0.141)	0.057 (0.146)	0.094 (0.149)
Constants	-2.603*** (0.567)	-2.891*** (0.590)	-3.105*** (0.613)	-3.196*** (0.631)
Athrho	15.507***(3.878)			
Wald test	15.992***			

Note: Robust standard errors of coefficients are in parentheses. ***, ** and * are significant at the 1, 5 and 10% levels, respectively.

in the two models differ slightly, but the core explanatory variables are in the same direction. This suggests that using the Bivariate Probit model is necessary, and the model results are robust. Therefore, only the estimation results of the Bivariate Probit model are reported below.

As shown in Table 2, from the perspective of farmers' adoption behavior of STFFT, agricultural extension service has a significant positive impact on the adoption behavior. This shows that agricultural extension service is still a meaningful way to encourage farmers to adopt scientific fertilization technology. From the perspective of farmers' scientific application behavior, the influence of agricultural extension services on farmers' scientific application behavior is different. Among them, the public sector significantly impacts farmers' scientific application behavior, followed by farmers' organizations. However, the effect of the private sector on farmers' scientific application behavior is not significant, but the coefficient is positive. Hypothesis 1 is verified.

The possible reason is that agricultural extension services led by the public sector, such as agricultural technology stations and soil and fertilizer stations, still play a central role in the agricultural technology extension system. It has the characteristics of low threshold, comprehensive coverage and high frequency, which can make most farmers accept scientific fertilization technology and information. Farmers' organizations represented by cooperatives and associations supervise agricultural production processes through standardized field management and technical services and control input to influence farmers' production behavior [35, 36]. Even if farmers are unwilling and able to adopt scientific fertilization technology, farmers' organizations can still encourage farmers to carry out scientific fertilization through technical support and management passively. The agricultural technology extension services provided by the private sector, represented by agricultural distributors and agricultural enterprises, often have limitations. Some farmers can only obtain supporting extension services when purchasing specific agricultural materials [23]. Moreover, due to the severe phenomenon of credit sales in fertilizer sales [37], agricultural material distributors usually increase the recommended amount of fertilizer to ensure their profitability, which may lead to unscientific fertilization behavior of farmers.

In addition, the estimation results show that farmers' adoption behavior and scientific application are also significantly associated with their education, demonstration, purpose, scale, cooperatives and enterprises (Table 2). For example, a positive coefficient for education implies that better-educated farmers are more likely to apply fertilizer scientifically [2]. A positive coefficient for demonstration indicates that demonstration households are more likely to adopt scientific fertilization technology and scientific application [27]. The purpose and scale positively affect scientific fertilization technology adoption and scientific application among rice farmers. This suggests that 'eat and sell' farming households will ensure the quality and safety of their produce through scientific fertilizer practices to meet their food safety needs and avoid the risks of quality testing. And large-scale farmers may have a greater demand for scientific fertilization technology than small-scale farmers [4, 38]. The positive coefficient for cooperatives and the negative coefficient for enterprises suggest that the presence of cooperatives in the village increases the probability of scientific fertilization among farmers. However, agricultural enterprises in the village are generally small and focus primarily on grain quality, rather than the farmers' field management process. Therefore, farmers may still choose traditional fertilization methods to save costs and reduce risks.

Robustness Tests

To further investigate the causal effect of agricultural extension services on rice farmers' scientific fertilization behavior and correct possible sample selectivity bias, we employ the propensity score matching method (PSM) with k-nearest-neighbor matching within a caliper (caliper of 0.05 and nearest neighbor of 1) for comparison. After standardizing data bias and conducting a common range of values test, mean treatment effects for the effect of agricultural extension services on farmers' scientific fertilization behavior were estimated. The results in Table 3 show that agricultural extension services and different agricultural extension service providers significantly contribute to farmers' adoption of scientific fertilization technologies and scientific application behavior. These findings further support the robustness of the estimation results.

The Mediating Effect Test of Value Perception

The Sobel test is more powerful than the traditional stepwise regression test for mediating effects and applies to models where the dependent variable is dichotomous

Table 3. Results of PSM estimates.

Variables	Adoption behavior			Scientific application		
	ATT	Boot S.E.	*T*-Value	ATT	Boot S.E.	*T*-Value
Agricultural extension services	0.195***	0.033	6.990	0.181***	0.031	6.750
Public sector	0.228***	0.037	7.010	0.208***	0.037	6.500
Private sector	0.355***	0.137	2.850	0.290**	0.140	2.280
Farmers' organizations	0.316*	0.179	2.110	0.316*	0.178	2.110

Note: Standard errors were obtained by the Bootstrap method 500 times. ***, ** and * are significant at the 1, 5 and 10% levels, respectively.

Table 4. Results of the test for mediating effects of value perceptions (public sector).

Variables	Value perception	Adoption behavior	Adoption behavior	Scientific application	Scientific application
Public sector	0.279*** (0.079)	0.209*** (0.023)	0.203*** (0.023)	0.196*** (0.023)	0.191*** (0.023)
Value perception			0.021** (0.008)		0.019** (0.008)
Other variables	Controlled	Controlled	Controlled	Controlled	Controlled
Sobel test		z = 2.051>0.97		z = 3.541>0.97	
Conclusion		The partial mediating effect is significant		The partial mediating effect is significant	

Note: ***, ** and * are significant at the 1, 5 and 10% levels, respectively. Standard errors in parentheses.
The same applies to Table 5.

Table 5. Results of the test for mediating effects of value perceptions (private sector).

Variables	Value perception	Adoption behavior	Adoption behavior	Scientific application	Scientific application
Private sector	0.537** (0.225)	0.497*** (0.066)	0.484*** (0.066)	0.440*** (0.065)	0.428*** (0.065)
Value perception			0.024*** (0.008)		0.022*** (0.008)
Other variables	Controlled	Controlled	Controlled	Controlled	Controlled
Sobel test		z = 1.839>0.97		z = 1.779>0.97	
Conclusion		The partial mediating effect is significant		The partial mediating effect is significant	

[39]. Therefore, we used the Sobel test to determine whether value perception's mediating role in agricultural extension services' influence on farmers' scientific fertilization behavior was significant.

Tables 4 to 5 report the regression results for value perception as a mediating variable for the impact of agricultural extension services on farmers' scientific fertilization behavior. The Sobel test results show that value perception partially mediated the influence of the public and private sectors on farmers' technology adoption behavior and scientific application. As the influence of farmers' organizations on value perception was insignificant, the mediating role between them and farmers' scientific fertilization behavior was not explored in this paper. Further, the sample was repeated 5000 times by means of the Bootstrap method in order to check the robustness of the above results. The regression results for the indirect effect of agricultural extension services on farmers' scientific fertilization behavior showed that the confidence intervals (p-Value) for the indirect effect of the public sector on farmers' technology adoption and scientific application behavior were [0.012, 0.112] (0.000) and [0.008, 0.112] (0.000) respectively. The confidence intervals for the indirect effect of the private sector on farmers' technology adoption and scientific application behavior were [0.025, 0.241] (0.000) and [0.020, 0.236] (0.000), respectively. Consistent with Sobel test results.

Based on the test results of the two methods, it can be concluded that agricultural extension services affect farmers' scientific fertilization behavior by affecting their value perception, and Hypothesis 2 is partially verified. This suggests that as farmers develop a deeper appreciation for the benefits of scientific fertilization, they are more likely to adopt fertilization technology and practice scientific fertilization in line with technical specifications [40]. Notably, agricultural technology extension services play a vital role in enhancing farmers' appreciation of the value of scientific fertilization technology.

Conclusions

Scientific fertilization technology is an important means to improve the level of agricultural scientific fertilization. However, in actual agricultural production, the application rate of scientific fertilization technology is low, farmers' enthusiasm to adopt it is not high, and some adopted farmers do not use the technology correctly according to the technical specifications and product requirements. Whether farmers are willing to adopt and correctly adopt scientific fertilization technology is the key to affecting the overall level of agricultural scientific fertilization. Agricultural extension services are an essential means to popularize scientific fertilization technology, disseminate scientific fertilization knowledge, and guide farmers in applying fertilizer scientifically. Therefore, it is essential to clarify whether agricultural extension services can guide farmers in adopting and correctly applying scientific fertilization technology. Based on this, this paper uses the survey data of rice farmers in Hubei Province, a prominent grain producing area in China, and takes soil testing and formula fertilization technology as an example to empirically explore the impact of agricultural extension services on farmers' scientific fertilization behavior and its mechanism. First, the study found that agricultural extension services significantly promote farmers' scientific fertilization behavior. When considering farmers' gradual fertilization decision-making, the agricultural extension services provided by the public sector and farmers' organizations significantly promote farmers' scientific application behavior. In contrast, the impact of agricultural extension services provided by the private sector is not apparent. Second, the study found that agricultural extension services provided by the public and private sectors will promote farmers' scientific fertilization by increasing their value perception.

The findings of this paper have important practical significance for the effective promotion of scientific fertilization, provide new ideas for changing farmers' production behavior, and provide practical policy guidance for developing countries to reduce chemical fertilizers effectively. Firstly, the relevant departments should increase their efforts in agricultural extension services. On the one hand, we should actively explore the promotion mechanism of scientific fertilization technology and promote the application of new fertilizer technology, new varieties and new equipment; on the other hand, we should adopt various forms and channels of promotion to improve the coverage of services. Secondly, the critical role of diversified subjects in promoting scientific fertilizer application technology should be taken seriously. While giving full play to the leading role of the public sector, the private sector and farmers' organizations should be guided to establish a professional agricultural extension service model and work together to build a diversified scientific fertilization extension service system. Thirdly, it is necessary to strengthen farmers' knowledge of the value of scientific fertilization technology. Providing agricultural extension services should strengthen the transmission of scientific fertilization technology's economic and ecological values to help farmers establish awareness of scientific fertilization, thereby increasing their initiative and enthusiasm.

It is undeniable that there are still some shortcomings in our study. First of all, the research area of this study is limited to Hubei Province. Whether the research conclusion applies to other regions in China still needs to be verified by a broader range of survey data. Secondly, our study only focuses on the behavior of rice farmers. In the follow-up study, we can pay attention to whether the adoption behavior of scientific fertilization technology of farmers planting other grain crops or economic crops differs from that of rice farmers.

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Conflict of Interest

The authors declare no conflict of interest.

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