International Journal of Sustainable Development Research
2025, Vol. 11, No. 1, pp. 48-61
https://doi.org/10.11648/j.ijsdr.20251101.15

Research Article

Fertilizer Reduction Technology: A Case Study in the Fujian Tea Garden Factors Affecting China's Tea Farmer's Willingness to Adopt Chemical

Daoning Wu[1], Shanhui Qin[2], Biao Geng[3, *], Liangguo Luo[4]

[1]School of Information Technology & Engineering, Guangzhou College of Commerce, Guangzhou, China

[2]Guangxi Xincheng County Vocational and Technical School, Xincheng, China

[3]Economical & Management College, West Anhui University, Lu'an, China

[4]Institute of Agricultural Environment and Sustainable Development, Chinese Academy of Agricultural Sciences, Beijing, China

Abstract

This study investigated factors affecting farmers' adoption about chemical fertilizer reduction technology (CFRT) in south-eastern of China by taking Fujian tea plantation as a case study. Both descriptive and regression analysis were employed to analyze survey data. The regression analysis showed that six independent variables were significant in explaining the factors affecting the farmers' decision to participate in CFRT. The results show that education level, quantity of chemical fertilizer, chemical fertilizer brand, professional training indicated a positive impact for the decision of CFRT adoption, while less than 10 mu of tea plantation, from 10 to 30 mu of tea plantation exerted a negative impact. Whereafter this study examines the robustness of benchmark regression by using bootstrap method. Finally, it is of significance that put forward to cultivate new types of professional farmers and agricultural technicians in order to popularize CFRT.

Keywords

Chemical Fertilizer Reduction Technology, Tea Farmers, Influencing Factors, Fujian

1. Introduction

It is getting more attention to over-fertilized farmland of food crops and cash crops in China due to its rising and adverse environmental impacts. Chinese government had proposed "zero-growth" action plan regulating fertilizer use by 2020. Specially, heavy synthetic N for high yield and quality components is common in tea planting production management all over China [1], which causes agriculture non-point pollution, and in return represents a considerable hidden threat to the sustainable development of tea production. Therefore, many researchers studied and integrated comprehensive technologies that increasing efficacy by reducing chemical fertilizer application in tea, which aims is to improve fertilization methods and fertilizer utilization The adoption of chemical fertilizer and

*Corresponding author: gengbiao202105@163.com (Biao Geng)

Received: 24 November 2024; **Accepted:** 19 December 2024; **Published:** 13 March 2025

reduction technology (CFRT) was known as set of environment-friendly agriculture, green fertilizer and agricultural conservation practices technologies, namely chemical fertilizer saving and efficiency improving technology. To assess the effect of CFRT in tea farming, this study had been established evaluation indicators of CFRT from five dimensions: i) technically, ii) economic, iii) social, iv) management, and v) regional variation.

Many agricultural researchers has been studying farmers' behaviors using the choice experiment method for decades, including farmers' willingness to adopt new agriculture technologies and reduce fertilizer [2, 3]. Decision-making of farmers' fertilization behavior regression models was widely used, such as logit, probit, tobit, the ordinary least squares (OLS) method and multiple linear regression [4]. Early studies concluded that key factors of over-fertilization, including education, household income, acreage of cultivated land, fertilizer prices, et al.

It was reported that a large number of existing studies have reported that promoting different crops of CFRT were reviewed in different provinces of China recently [5, 6].

Although national and local agricultural governmental as well as researchers have contributed to evaluating the for CFRT, there is gap that lack of understanding of the key factors influencing tea farmers to adopt CFRT. Firstly, studies related to CFRT have focused on grain crops, and few have addressed cash crops, cash crops account for more than 50% of China fertilizer use, thus an analysis of the determinants for CFRT is necessary. Second, social and economic effects of promotion and application of CFRT in the tea garden region remains unclear, scholars argue that farmers' decision making for CFRT are complex and may vary from among different farmers and region-by-region. So far, there has been very little research directly exploring behavioral mechanism for CFRT in the perspective of tea farmers. Thirdly, in particular, logit and probit models were the most widely used farmer' behaviors there remains a gap in empirical studies testing what determines whether tea farmers to accept CFRT in the tea garden of Fujian, It would also be interesting to assess the heterogeneity effects and fixed effects in farmers' individual CFRT decision making is not explicitly captured in these models, there exists difference among smallholder farmers, crucial factors that shapes the rate of exploitation rate of CFRT. Therefore, to fill in these gaps, this study attempts to use teas as a cash crop to analyze the key factors that affect the likelihood of adoption of CFRT by tea farmers in the Fujian, southeast of China. The remainder of the paper is organized as follows. Methodology and application is presented in Section 2, followed by result and discussion in Section 3. Section 4 provides the conclusion and recommendation.

2. Theoretical Foundation and Models

2.1. What Drives Tea Farmers Determine to Adopt CFRT

Planned behavior theory (PBT) model, protection motivation theory (PMT) and value-belief-norm theory of environmentalism (VBN), which is widely used in social psychology research. There are numerous well-known incentive theories regarding farmer behavior, including rational action theory (TRA), expected utility theory (EUT), social psychology methods (TRA), and The theory of cost-benefit analysis [7, 8].

Based on these theories, tea farmers use fertilizers in the pursuit of the maximum yield from the perspectives of smallholder peasants, but tea farmers, as rational people, will also compare their costs and benefits, if the benefits are greater than costs, can obtain greater net return, can improve the enthusiasm of farmers to participate in CFRT, which is good for developing tea productivity and increasing production. Individuals' choice behavior comes closer to their actual behavior when they pursuit high profit, this theory assumes that the decision maker chooses between risky or uncertain prospects by comparing their expected profit values with the purpose of maximizing themselves value [9].

The management of environmental problems originated from agricultural depends not only on the "breakthrough" of policy and law, but also on the adjustment of agricultural development structure and the change of farmers' behaviors. According to the status of China's agricultural development, which will still be mainly "small-scale agricultural economy". Scaling up, mechanization, specialization has long way to go, farmers will still be the main body of fertilizer application decision-making, agricultural productivity is still based on traditional experience-based agriculture mode, their behavior is directly related to farmers' fertilization behaviors, so in this study aims to find out the key factors play an important role in scientific fertilization from micro-individuals [10].

2.2. Sampling Survey Methods and Data Collection

Before full implementation, the structured household questionnaire was pre-tested as a pilot survey in the sample villages (Hubei and Chongqing), in October and November 2018. Investigator training and pilot survey were used to ensure reasonability and quality of questionnaire design. A pilot survey was conducted to make the questionnaires more clearly and easily understood by tea farmers. Prior to the survey, all of interviewers had received formal training to ensure that each interviewer has an accurate understanding of the questionnaire.

The survey topic is whether to willing to adopt CFRT by smallholder farmers. To explore the underlying factors related to adopt CFRT by tea farmers, we designed a comprehensive questionnaire based on previous research documented [11-13].

The impact of all independent variables were analyzed and concluded, including examined farmers' willingness to reduce chemical fertilizer use and its determinants factors based on many literatures [14-17]. These influencing factors included three main aspects as following: part one personal characteristic of farmer; part two household characteristic of tea farmers; part three cognition of farmer's subjective view of CFRT, focusing on over-fertilization, such as fertilization decision-making factors, part four externality characteristics (Table 1).

A tea farming household formal survey was conducted by the agricultural clean basin innovation team, Institute of Agricultural Environment and Sustainable Development, Chinese Academy of Agricultural Sciences in May 25 and June 3 of 2019. We randomly selected 2 two municipalities (i.e. Quanzhou and Ningde city) from Fujian, a province in Southeast of China, and similar randomly one survey country every municipalities, and 6 survey towns, 10~12 farmers every town, and they were randomly selected through village leaders and town leaders according to status of local tea production, as the survey interviewees. All of interviewers are undergraduates and graduate students majoring in agricultural economics and tea science specialty. Face-to-face interviews using structured questionnaires were conducted with the household head or the person who was the major decision maker and manager of tea farming activities. To ensure the accuracy and integrity of the survey, all questions in the questionnaire were asked through face-to-face interview with sample household. At the end of the interview, the interviewer pay lost earnings (such as money or gift) to the target household as a token of thanks.

The interviews were conducted by the authors and trained researchers, at least put in one hour for every in-depth interview. All questionnaires can be completed. The survey response rate was 100 percent. After the data collection, means, frequencies and percentages were calculated for each item by excel. Statistical analysis estimated results are reported by STATA software (STATA®/IC 15.0).

2.3. Economic Models Construction of Influencing Factors of CFRT Willingness

The linear probability model (LPM) showed the uniformity of error terms and possibility of getting the probability function result out of 0 and 1. Due to this problem LPM is not logically attractive model for dummy responsive variables. It is better to use Cumulative Distribution Function (CDF), namely logit or probit model when analyzing this type of questionnaire The logit and probit models guarantee that the estimated probabilities lie between the logical limit of 0 and 1. For discrete binary choice problem, this study we seek important factors that impact their choice behaviors by logit and probit models [18]. Therefore, according to theoretical foundation of farmers behaviors, the objective of the study was to test logit model and probit model, in the classical model of farmers behaviors, to explore the determinants of adopting CFRT in Fujian (Table 1).

Table 1. *Descriptive statistics of the explanatory variables of the model and their expected impacts.*

Explanation and definition of variables		Nature of variable	Mean	S.D	Expected direction
Y	Is willing to adopt CFRT? Yes=1; no=0	Binary	0.88.	0.33	
Personal characteristics					
Age	How old are you? less than 22=1; 22-35 =2; 36-50 years old, 3; 50 years old, 4	Continuous	3.37	0.61	Negative
Education level	What is your education? illiteracy =0; primary school =6; junior middle school =9; high school =12; college or above=16	Continuous	2.75	0.99	Positive
Household characteristics					
Households size	How many people in your family?	Continuous	5.82	2.41	Negative/Positive
Tea plantation workers	How many laborers that engaged in tea plantation?	Continuous	3.7	2.31	Negative
Tea incomes	How many your income of tea? <5000 RMB=1; 5000-10000 RMB=2; 10000-30000 RMB =3; 30000-50000 RMB=4; >50000 RMB=5;	Continuous	4.12	1.09	Postive
Tea garden acreage	How many your tea garden?	Continuous	24.21	5.10	Negative/Positive

Explanation and definition of variables		Nature of variable	Mean	S.D	Expected direction
Transferred land acreage	How many in transferred land acreage	Continuous	7.99	32.92	Negative
Cognition characteristics					
Organic fertilizer	Whether to use organic fertilizer? Yes=1; no=0	Dummy	0.78	0.39	Positive
Quantity of fertilizer usage	How about the fertilizer usage in tea production? Increased =0; decreased=1; unchanged=2	Dummy	1.26	0.72	Negative
Fertilizer brand	Are you familiar with fertilizer brand? Yes=1; no=0	Dummy	0.71	0.45	Positive
Tea styles	Which tea styles in your tea garden? Green tea =0; Black tea =1; Oolong tea =2; White tea=3	Dummy	1.89	0.97	Negative/Positive
Externality characteristics					
Agricultural extension	What about the effective of agricultural extensions? Very bad=0; bad=1; in general=2; better=3, very well=4	Dummy	2.31	1.28	Positive
Agricultural technician	What about the agricultural technicians for CFRT? Very bad=0; bad=1; in general=2; better=3, very well=4	Dummy	2.79	0.83	Positive
Technicians' education	Do you know technicians' education? Yes=1, no=0	Dummy	0.64	0.42	Positive
Professional training	Are you participate in CFRT training? Yes=1; no=0	Dummy	0.45	0.49	Positive
Cooperative	Are you participate in tea professional cooperative? Yes=1; no=0	Dummy	0.67	0.87	Positive
Government subsidies	How about government subsidies for CFRT? Very bad=0; bad=1; in general =2; better=3, very well=4	Dummy	2.63	1.26	Positive
Green certification	Are you green certification for tea plantation? Yes=1; no=0	Dummy	0.08	0.27	Positive
Scaling up	Are you scaling up tea production? Yes=1; no=0	Dummy	0.73	0.51	Positive

The details of explanatory variables used in the analysis are given in Table 1, which provides every variables hypothesis. The objective we use a limited dependent variable that can take only one of two values for the econometric estimation. Therefore, a binary logit and probit regression model was used to explained factors affecting tea farmers' participation in CFRT. As outlined above, logit and probit regression model were used because of the binary nature of the dependent variable. The main difference between the logit model and probit model is that the distribution of the error items is different, the logit model assumes that the error items obey the logic distribution and probit model assumes that the error items obey the standard normal distribution. Logit and probit models are selected for the empirical analysis as following and 136 samples of farmers can be analyzed.

Logit model:

To explore the key factors that whether farmers are willing to CFRT in tea production of Fujian, we use logit regression.

The model is as follows:

$$\ln(Y) = \ln\left(\frac{Y}{1-Y}\right) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + ... + \beta_n X_{ni} + u_i$$

where

Y = The predicted probability of the event (farmers' level of participation in CFRT), which is coded with 1= willingness to participate in CFRT, and 0=otherwise.

1 − Y = The predicted probability of the other decision (non-participants of CFRT)

z= Constant

β_n = Coefficients of explanatory variables

X_{ni} = Predictor variables

u_i = Error term.

i = number of surveyed farmers, $i = 1, 2 \cdots, 136$.

probit model:

The probit model of the factors affecting tea farmers' willingness to adopt CFRT can be constructed as following.

$$y = \begin{cases} 1, while\ y^* > 0, yes \\ 0, while\ y^* \leqslant 0, no \end{cases}$$

The binary discrete selection model, which is the perturbation item and obeys the standard normal distribution, thus affecting the farmer's risk cognition and avoidance ability of over-fertilization, can be expressed as:

$$\text{prob}(y=1 \mid X=x) = \text{prob}(y^* > 0 \mid x) = \text{prob}\{[\mu > -(\alpha + \beta X)] \mid x\}$$
$$= 1 - \Phi[-(\alpha + \beta X)] = \Phi(\alpha + \beta X)$$

where, Φ is a standard normal cumulative distribution function, y^* potential variables that are not observable, y is the actual observed factor variable, indicating whether farmers are willing to reduce the amount of fertilization, 0 is "unwilling" and 1 is "willing".

Marginal effect is another way of discussing logit and probit regression results. The technical definition of marginal probabilities for dichotomous outcomes is given as the partial derivative of equation with respect to x_j. Thus, the marginal probability is the slope of the probability curve relating x_j to $P(Y = 1 * X_1 = x_1, ..., X_k = x_k)$, holding all other predictors constant. The sign of the marginal effect is determined by β_j.

3. Results and Discussion

3.1 Descriptive Statistics of Respondents of CFRT in Fujian

At first economic model speciation, we choose 23 variables as many possible as, then selecting important variables by stepwise regression to get a simple and easily interpretable model. Finally, 19 key variables should be further analyzed (Table 1). Prior to the estimation of the logit regression model the explanatory variable were checked for the existence of multicollinearity. For this purpose, the presence of co-linearity was checked for categorical variables using contingency coefficient test. Therefore, sex, age, vocations et al were omitted from the logit model after the multicollinearity test.

As show in table 2, within our sample, about 17% of respondents were female. The mean age of the full samples is around 56 years old, namely middle-aged, with a relatively low level of education, 18.39% of them have a high school education or above, mostly second middle school. The average family size for tea farmers surveyed was 5 (rounded). we only choose 136 tea farmers as research objected, the main reason explain that rural households managing owned an average of 32.76 mu (1 mu = $\frac{1}{15}$ hectares), more than 56 percent of farmers was more 30 mu. On average, more than 60% of respondents were farmers (vocational). Of the 136 samples income less than 10,000 yuan, from 10,000 to less than 100,000 yuan, between 100,000 and 1,000,000 yuan and above 1,000,000 yuan accounted for 3.68%, 60.29%, 33.82 and 2.21% respectively. Because of Fujian is a tea-producing province all of China, they depend mainly on tea plantation for their livelihood.

Similarly, according to the table 3, majority of respondents considered that they did not overuse chemical fertilizer and organic fertilizer. Whereas nowadays tea garden over-fertilization can pose potential threaten to agricultural non-point pollution, 70.09% of respondents argued that fertilizer overuse can have direct or indirect impacts on agricultural environmental system, such as soil, surface water, groundwater, and air pollution, specially, the unabsorbed chemicals (nitrogen, phosphorus, and potassium etc.) by tea trees become the main sources of non-point pollutants. 88.06% of respondents are reluctant to adopt CFRT. Under these conditions, they given some reasons reported in table 4. Hence it is crucial to find agricultural extension, government subsidies, green certification, join in professional cooperative as well as scaling up most highly influence decision-makers of tea production for reduction chemical fertilizer and improving tea yield and quality (Table 3). Results indicate that tea farmers had positive perceptions on CFRT, and CFRT of tea cultivation socially acceptable is very high and strong. Accordingly, controlled application of chemical fertilizer can boost the growth in tea output and the increase the smallholder tea farmers economical income.

Furthermore, the survey result of the study suggested that 81.9% of the respondents voluntarily participated in CFRT, while the remaining 18.1% did not willingness to participate in CFRT. As shown in table 3, farmers gave various reasons for not participating in CFRT. These reasons included production or tea quality risk (51.52%), earnings risk (33.33%), lower government subsidies (9.09%), no training received (3.03%) and CFRT is complexed and sophisticated problem

(3.3%).

Table 2. The distribution of respondents by personal, household characteristics (n=136).

Characteristics		Percentage	Characteristics		Percentage
sex	female	16.91%	Years of education	0~6	38.97%
	male	83.82%		7~9	42.65%
Age	30~40	13.97%		10~12	13.24%
	40~50	33.82%		>12	5.15%
	50~60	30.88%	vacation	Farmer	61.03%
	>60	16.91%		Village leader	9.56%
Household size	0~4	26.45%		Agricultural technician	29.41%
	5~8	65.02%	Tea incomes	<10,000 yuan	3.68%
	>8	8.53%		10,000~100,000 yuan	60.29%
Tea plantation	0~10 mu	20.59%		100,000~1,000,000 yuan	33.82%
	10~30 mu	19.12%		>1,000,000 yuan	2.21%
	>30 mu	60.29%			

Note: data source from field study, 2019. year of education 0~6 including illiteracy and primary school are 9.56% and 29.41%, respectively. "mu" as the unit of measurement for calculations, which is commonly used in agricultural production in China, 1 mu = $\frac{1}{15}$ ha.

Table 3. Cognition characteristics of fertilizer use of respondents (n=136).

Characteristics option		Percentage
Amount of organic fertilizer per mu in the tea garden	Enough	4.41%
	Appropriate	58.82%
	Insufficient	11.76%
	Not applied	25.00%
Amount of chemical fertilizer per mu in the tea garden	Excessive	5.88%
	Appropriate	72.06%
	Insufficient	11.76%
	No applied	10.29%
Overfertilization can cause serious environmental pollution	Yes	70.90%
	No	29.10%
Negative effects of overfertilization	Impact the quality of tea	15.73%
	Soil pollution	37.04%
	Groundwater Pollution	35.19%
	Air pollution	12.04%
	Harm to human health	3.7%
Whether you are willing to accept CFRT	Yes	88.06%
	No	11.94%

Characteristics option		Percentage
	Irrelated	13.97%
	Less important	12.50%
Influence of agricultural extension	General	19.12%
	Important	37.50%
	More important	16.18%
Impact of government subsidies	Irrelated	10.29%
	Less important	10.29%
	General	14.71%
	Important	37.50%
	More important	26.47%
Green certification	Yes	8.09%
	No	91.91%
Join in professional tea cooperative	Yes	39.71%
	No	58.82%
Scaling up	Yes	60.29%
	No	21.32%

Table 4. Reasons that tea farmers were willing (or unwilling) to participate in CFRT in the tea garden.

Yes (Reasons) Percentage		No (Reasons) Percentage	
Reducing agricultural costs	20.73%	Production or tea quality risk	51.52%
Improving your agricultural environment	19.69%	Earnings risk	33.33%
Guarantee the quality of tea	49.74%	Lower government subsidies	9.09%
Fertilization technical training	5.70%	No training	3.03%
Government subsidies	4.15%	CFRT is complexed problem	3.03%

3.2. Factors that Affected Willingness to Participate in CFRT Among Smallholder Tea Farmers in Fujian

We take the dummy variable, the willingness of participating in CFRT, as the dependent variable. The logit and probit regression are employed to explore the factors affecting respondents' willingness to CFRT. The estimation results are presented in Table 5. Model (1) and Model (2) report the estimation results based on the logit model, and the estimated results using probit model are shown on Model (3) and Model (4). On the whole, the two models exhibit the similar findings. In the analysis, two more control variables are included in Model (2) and (4), which capture the classification of tea planting areas. Marginal effects at sample means of estimated variables were also calculated on the basis of Model (2) and Model (4), which are reported on column (3) and (6).

Among all characteristic variables, professional training variable with a 12% marginal effect on adoption CFRT likelihood, is the most powerful indicator, followed by education level, chemical fertilizer usage and knowledge of chemical fertilizer brand.

Firstly, tea farmers' education level is significantly associated with their willingness to CFRT, specifically, a 1% percent increase in education level would raise the willingness by 1.7%. The result of this finding is similar to previous work, such as Geng B & Luo L G (2018) showed farmers' education level is a key factor in their willingness to apply new agricultural technologies.

Secondly, there is a significantly positive relationship between the willingness of CFRT and chemical fertilizer use and knowledge about chemical fertilizer brand. Specifically, the estimated marginal effect coefficient of the logit and probit regression model shows that a 1% increase in perception chemical fertilizer brand by tea farmers upgrades the probability of adoption of CFRT by 12% (rounded) in Fujian tea garden, with the effects of all other variables keeping constant. The result indicates that tea farmers who are familiar with the detail of chemical fertilizer brand are more likely to follow CFRT [5]. In addition, farmers using more chemical fertilizer are more willing to take CFRT. The underlying reason is that as the rational tea smallholder farmers, the ultimate goal of tea yield and quality is to pursue maximum agricultural net income return, and 68% of farmers of survey tea production behavior are "long sighted", whose perceive chemical fertilizer application overuse cannot guarantee stable production and quality of tea, which was confirmed by the study conducted, such as [3, 10, 13, 19], these studies have been reported furthermore the excessive of chemical fertilizer will cause serious agricultural environment pollution (Table 3).

Thirdly, the estimated marginal effect of the logit and probit models indicated that a 1% increase in the professional training of tea farmers would upgrade the probability of CFRT by around 12%. The training of farmers is deemed to be indispensable evaluation social benefits, the more they attach importance training of tea farmers, the higher their willingness of CFRT become a possibility. Agricultural technical training is an important method of increasing farmers' scientific knowledge about fertilization and encouraging them to adopt an environmentally friendly agricultural production mode [20].

Fourthly, when the variables representing less than 10 (<10) mu of tea plantation and from 10 and 30 (10~30) mu of tea plantation are added to the logit and probit models, they have negative and statistically significantly affect the willingness of CFRT (Table 5), tea farmers who own form 10 to 30 mu of tea plantation and less than 10 mu of tea plantation want to produce more, therefore they were not prepared to reduce chemical fertilizer use. The plausible reason is that the small-scale farmers perceived that more fertilization can guarantee keep or increase tea yields and it is also essential way of resisting agricultural risks and uncertainties. Accordingly, tea farmers will apply more chemical fertilizers to ensure a stable or improve tea production. The study showed that farm size is significantly and negatively correlated with quantity of chemical fertilizer, but insignificantly correlated with tea yields. But 77% of respondents did not apply farmer manure (organic fertilizer) in the tea gardens (i.e., swine manure and poultry manure et al), and perceived the cost of organic fertilizer is expensive in the tea gardens. We learned an important information that rural farmer restricted the breeding of pigs in Fujian since 2015 according to the survey, which means tea farmer more use chemical fertilizer. Meanwhile, It is worth noting that the poorer the physical condition of the middle-aged farmer (Table 2), the more unfavorable it is to apply organic fertilizers and the stronger the incentives is to apply chemical fertilizers to ensure stable tea yields, especially if his/her physical condition further declines. Therefore, green certification variable is not an significant for CFRT. The likely reason is that the green certification is quite stringent, permitting no pesticides and no chemical fertilizer in Fujian were impossible to implement.

As indicated in the Table 5, less than 10 mu and 10~30 mu of tea plantation elasticity of tea farmers are willing to CFRT are difference, the main is data restriction with an extremely high proportion of zeros in the dependent variable, which can make the results sensitive to the choice of regression models. Consistent with Table 1, independent variables show expected signs and statistical significance are has been proven. Contrary to Table 1 scaling up the sign expected, the regression analysis of this variable revealed that frequency of scaling up is found to be statistically negative and significant at the 1% level of confidence (Table 5).

Table 5. *Baseline regression results of the determinants affecting farmers' willingness to adopt CFRT (n=136).*

Variable: Y	**Logit**			**Probit**		
	Model (1)	**Model (2)**	***dy/dx***	**Model (3)**	**Model(4)**	***dy/dx***
Education level	0.213**	0.198**	0.017 **	0.125**	0.117**	0.017**
	(0.100)	(0.100)	(0.008)	(0.054)	(0.054)	(0.008)
Organic fertilizer	0.205	0.078	0.007	0.134	0.075	0.011
	(0.840)	(0.855)	(0.073)	(0.442)	(0.446)	(0.065)
Chemical fertilizer usage	1.090***	1.043***	0.089***	0.657***	0.626***	0.091***
	(0.379)	(0.392)	(0.035)	(0.224)	(0.233)	(0.035)
Chemical fertilizer brand	1.404*	1.366*	0.116*	0.833**	0.817*	0.119*

Variable: Y	Logit			Probit		
	Model (1)	Model (2)	*dy/dx*	Model (3)	Model(4)	*dy/dx*
	(0.807)	(0.793)	(0.069)	(0.420)	(0.423)	(0.063)
Professional training	1.444*	1.432*	0.122*	0.849**	0.844**	0.123 **
	(0.763)	(0.767)	(0.067)	(0.411)	(0.417)	(0.063)
Participate in cooperative	-0.903	-0.849	-0.072	-0.518	-0.492	-0.072
	(0.725)	(0.722)	(0.060)	(0.375)	(0.388)	(0.056)
Green certification	-1.861	-2.011	-0.171	-1.121*	-1.186	-0.173
	(1.267)	(1.364)	(0.121)	(0.660)	(0.742)	(0.112)
Scaling up	0.907	0.973	0.083	0.508	0.554	0.081
	(0.634)	(0.636)	(0.054)	(0.335)	(0.349)	(0.115)
Less than 10 mu of tea plantation (<10 mu)		-14.665***	-1.248 ***		-4.488***	-0.656***
		(0.895)	(0.235)		(0.499)	(0.128)
From 10 to 30 mu of tea plantation (10~30 mu)		-14.377***	-1.223***		-4.351***	-0.636 ***
		(0.820)	(0.233)		(0.503)	(0.129)
Constant	2.822**	17.294***		1.710**	6.085***	
	(1.296)	(1.541)		(0.699)	(0.889)	
Number of observations	116	116		116	116	
R^2	0.26	0.28		0.28	0.29	

Notes: The table reports the marginal effects from logit or probit models of characteristics on the likelihood of willingness to adopt CFRT. The dependent variable is willingness to CFRT dummy, which equals one if tea farmers willingness to adopt CFRT and zero otherwise. Model (1) and model (2) restrict the strata variable, the acreage of tea plantation enter logit regression (conditional sample). Model (3) and model (4) are similar to Model (1) and Model (2), restrict the strata variable, the acreage of tea plantation enter probit regression (conditional sample), respectively; $^{dy/dx}$ = Marginal effect of explanatory variable on the expected value of the depended variable. The notations *, **, and *** represent the 10%, 5%, and 1% levels of significance respectively.

3.3. Bootstrapping the Logit and Probit Results

There may be one concern that the small sample size may bias our estimation regression results. To test the validity of the baseline regression results, we performed the bootstrap sampling method, which holds a unique advantage in data analytics with small sample size [21, 22], because it optimally tested the validity of logit and probit regression results by using the relatively small number of observations.

The bootstrap approach repeatedly draws samples from our original dataset with replacement. Not only this method will alleviate the concern for our small number of survey data, but also produce random samples in case that our original sample is randomly drawn from the population. In this study, we perform such random data-generating for 1000 times, and the new datasets are called bootstrap samples. The estimated logit and probit regression coefficients will fell within the estimated bootstrap 95% confidence interval if our previous findings are valid. Bootstrap results for 1000 replications are shown in Table 6, reporting the coefficients estimated from the logit and probit regressions, the lower limits and upper limits of the bootstrap estimation. Most of the coefficients fell within the estimated bootstrap 95% confidence interval, indicating that our estimated coefficients of logit and probit regressions are valid and they are derived from a random sample.

Table 6. Robustness of logit and probit regression coefficients.

Variable	Logit			Probit		
	Coefficient	Bootstrap CI			Bootstrap CI	
		Lower	Upper	Coefficient	Lower	Upper
Education	0.213	-0.101	0.561	0.125	-0.036	0.286
Organic fertilizer	0.205	-3.276	3.014	0.134	-1.267	1.364
Fertilizer usage	-1.090	-2.222	0.603	-0.657	-1.245	-0.013
Fertilizer brand	-1.404	-4.174	0.566	-0.833	-1.879	0.456
Professional training	1.444	-3.286	3.639	0.849	-0.585	2.341
Cooperative	-0.903	-3.190	1.146	-0.518	-1.529	0.607
Green certification	-1.861	-2.649	-0.285	-1.121	-1.898	-0.137
Scaling up	0.907	-1.025	2.703	0.508	-0.449	1.612

Note: Drawing 1,000 replications of 100 repeated samples of population of dataset were drawn to determine if the estimated logistic regression coefficients from our model fell within the estimated bootstrap 95% confidence interval.

3.4. Extensions

3.4.1. The Exploitation Rate of CFRT

The participation of tea farmers in fertilizer reduction is lagging behind the willingness of tea farmers to participate in fertilizer reduction, and the factors affecting the willingness and behavior of tea farmers to participate in fertilizer reduction are both similar and different. In this section, we will further investigate factors affecting the exploitation rate of CFRT. The exploitation rate of CFRT is proxied by planting areas adopting the reducing chemical fertilizer and integrated technology.

Table 7 reports the results using the exploitation rate of CFRT as its dependent variable. As can be seen from Table 7, participating in cooperation is statistically significant and positive in all regressions, suggesting that planting areas adopting the reducing chemical fertilizer and integrated technology would raise by around 23% (column 1) if tea farmers participate in the tea cooperation. The results of column (1) also show that tea plantation family labors in household is unexpectedly negatively associated with the exploitation rate. One possible reason that they argue more input and more output, and potential worry about less fertilization lead to reduce tea production compared to previous when facing risk and uncertainty.

The coefficient on areas of transferred land is significantly negative, indicating that a 1% increase in areas of transferred land will lead to 0.1% decrease in the exploitation rate of CFRT. The underlying reason may be that tea farmers with bigger area of transferred land tend to use more use chemical fertilizer to ensure tea yield and obtain economic return.

Column (3) and (4) explore agricultural technicians' role on the exploitation rate. The positive coefficients on agricultural technicians suggest that the exploitation rate will be upgraded with more agricultural technicians publicizing and training tea farmers. Besides, column (4) includes the interaction term of agricultural technicians and technicians' education level based on column (3). The positive coefficient on the interaction term suggested that the smallholder farmers understand more about the educational background of agricultural technicians, the more they are willing to plant tea using the reducing chemical fertilizer and integrated technology. This finding that we should strengthen and improve agricultural technology extension system, and expand the coverage of the agricultural technology extension system. guide young agricultural technicians with high education to townships, to the village services.

Table 7. Alternative dependent variable of CFRT.

Explained variable: exploitation rate of CFRT	(1)	(2)	(3)	(4)
Participate in cooperative	0.231***	0.242**	0.158**	0.142**
	(0.077)	(0.097)	(0.065)	(0.064)
Tea plantation family labors in household	-0.062***			
	(0.023)			
Area of transferred land		-0.001**		
		(0.001)		
Agricultural technicians			0.350***	0.218*
			(0.111)	(0.140)
Agricultural technicians * technicians' education				0.273*
				(0.172)
Control variables	Yes	Yes	Yes	Yes
Constant	-0.104	-0.228	-0.236**	-0.221**
	(0.135)	(0.197)	(0.117)	(0.111)
Number of observations	116	116	116	116
R^2	0.31	0.27	0.37	0.40

Notes: The table presents heterogeneous effects of exploitation rate of CFRT. The dependent variables in columns (1)-(4) deployed stepwise methods. All control variables in Table 5 are added in regressions. Standard errors reported in the parentheses are robust. *, ** and *** indicate passing the test at the significance levels of 10%, 5%, and 1%, respectively.

3.4.2. The Heterogeneity Effect of Tea Types

One concern was that the effect of training and agricultural technicians' participation to the exploitation rate of CFRT will respond to different tea types. In this section, we classify the samples tea into three types, namely Oolong tea, White tea and Black tea. We will explore how the three tea types impact on the exploitation rate of CFRT.

Table 8 show the results of the heterogeneity effect of tea type, which include the interaction term of the training received and three tea types (columns (1), (2) and (3)), and the agricultural technicians' participation and three tea types (columns (4), (5) and (6)). As the coefficients on the interaction terms of the training received and Black tea (Training received * Black tea.) show, planting Black tea has an adverse impact on the positive relationship between farmers' training received and the exploitation rate of CFRT. Besides, planting Black tea is also negatively associated with the positive effect of agricultural technicians' participation on the exploitation rate of CFRT. The underlying reason may be that black tea farmers are willing to accept the CFRT, widely put into place, they tend to pay more attention to negative outcomes and weigh them more heavily than positive ones when considering a making-decision.

In addition, the significantly positive coefficients on both the professional training and the agricultural technicians' participation indicate that the extension of farmers' training and agricultural technicians' participation will increase farmer's exploitation rate of CFRT. Therefore, it is important for publicity and professional training and agricultural technician to carry out scientific fertilization technology, which can improve the awareness of farmers reduction chemical fertilizer. As agricultural technician must provide CFRT to the most influential tea farmers, then popularize the knowledge of scientific fertilization in the farmers' groups, guide farmers to learn reasonable fertilization. Theoretically, under the guidance of agricultural technology extension personnel, it can help farmers to achieve the goal of increasing tea production and income on the basis of rational fertilization. The research shows that participating in technical training has a positive effect on raising farmers' safety tea production awareness and optimizing farmers' chemical fertilizer use behavior, so it is necessary to establish correct fertilization idea and fertilization behavior for farmers through various channels of technology promotion and learning (Adnan et al., 2017).

Table 8. Estimated results of the benchmark model with explanatory variables and an interaction on the exploitation rate of CFRT.

Explained variable: exploitation rate of CFRT	Publicity and professional training effect			Agricultural technician effect		
	Oolong tea.	White tea	Black tea	Oolong tea.	White tea	Black tea
Professional training	0.153* (0.086)	0.208*** (0.063)	0.272*** (0.069)			
Professional training * Oolong tea.	0.116 (0.116)					
Professional training * White tea.		0.086 (0.172)				
Professional training * Black tea.			-0.307*** (0.091)			
Agricultural technicians				0.271** (0.126)	0.397*** (0.111)	0.497*** (0.112)
Agricultural technicians * Oolong tea.				0.292* (0.172)		
Agricultural technicians * White tea.					-0.006 (0.201)	
Agricultural technicians *Black tea						-0.487*** (0.148)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.271** (0.134)	-0.262* (0.135)	-0.293** (0.130)	-0.228** (0.111)	-0.224* (0.114)	-0.205* (0.106)
Number of observations R^2	116 0.270	116 0.263	116 0.304	116 0.395	116 0.360	116 0.418

Note: Notes: The table presents fixed effects of exploitation rate of CFRT. Standard errors reported in the parentheses are robust..*, ** and *** indicate passing the test at the significance levels of 10%, 5%, and 1%, respectively.

4. Conclusions and Recommendations

According to theory of planned behavior (TPB), farmers will take into account cost-benefit when facing risk of reduction of tea yield and income, and the pursuit of maximizing economic benefits will affect the choice of farmers' subsequent making-decision. Adoption is a complexed decision-making process that is influenced by several factors ranging from individuals. The influence of factors on chemical fertilizer reduction decision-making is examined, including:

(1) Education level. High education level more inclined to promotes environmental-friendly agriculture technology, and a higher likelihood of rational application of fertilizers for tea producers.

(2) Farmers' knowledge about chemical fertilize brand. Tea smallholders are familiar with chemical fertilizer types e and its brand are more preferred to adopt CFRT.

(3) Professional training. Training on CFRT technology and government's subsidy may incentive to adopt chemical fertilizer reduction to a certain extent, thus improving the enthusiasm of farmers to adopt the alternative technology model of organic fertilizer.

(4) Scaling up of tea plantation. This result is contrary to our hypothesis expectation.

The participation of tea farmers in fertilizer reduction behaviors is lagging behind the willingness of tea farmers to participate in CFRT, and the factors affecting the willingness and behavior of tea farmers to participate in fertilizer reduction are both similar and different, so this study provides new insight into exploiting the heterogeneous effect and fixed effect exploitation rate of CFRT. This study suggesting that it is used to participate in cooperative-related training and agricultural technician extension will actively facilitate different types tea farmers to conducive to their willingness to adopt CFRT, which promote the transformation of tea production and chemical fertilizer fertilization mode. Based on these conclusions, we suggest the sound recommendations, as following:

Firstly, positively pursuing and improving adult scientific

and cultural quality vocational education in rural areas, and improving the overall of the rural in order to strengthen the cultivation of new types of professional farmers with professional skills, through the integration of various educational resources in rural areas. Secondly, fully taking advantage of the current internet technology to publicize CFRT, improving technology efficiency (TE) and fertilizer use efficiency (FUE) on tea plantation. Thirdly, Vigorously training more agricultural technology advocators can effectively further stimulate and guide tea farmers scientific chemical fertilizer reduction. More importantly, agricultural extension are important factors affecting farmers' behavior decision-making on CFRT.

This study, however, has some limitations. first, One limitation of the study that we analyses individual choices influential factors under various hypothetical contexts, and never in-depth discuss the mechanism of farmers behaviors. Another limitation is we obtain from small sample one region, to unsatisfied apply Structural Equation Modeling (SEM). Although Fujian province is representative tea plantation, this result is only a reference for the sustainable development of tea plantation of Fujian, and cannot be extended to the whole country. Further study analysis technical efficiency of tea farmers and its influencing factors in Fujian.

Abbreviations

CFRT Chemical Fertilizer Reduction Technology

Acknowledgments

This work was jointly supported by National Key R&D Program of China, Technical Evaluation of Chemical Fertilizer and Pesticide Double Reduction, Reduction and Increase Application (2016YFD0201306); National Key R&D Program of China (Project No:2016YFD0201306), Research on the synergistic model of enterprise aggregate population (Project No: WXXYHD2023); First-class discipline in Anhui Province: Agricultural and Forestry Economic Management (Project No.0044619001). The Impact of Market Integration Development on Regional Employment Structure in Hefei Metropolitan Area: Internal Mechanism, Empirical Evidence and Policy Optimization (Project No: 2022AH051664).

Authors Contributions Statement

The authors declare that they have contributed to the article at a similar rate.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Xiangde Yang, Kang Shi, Yuan zhi, et al, 2018. Effects of long-term nitrogen application on soil acidification and solution chemistry of a tea plantation in China [J]. Agriculture, Ecosystems & Environmen, 252(5): 74-82. https://doi.org/10.1016/j.agee.2017.10.004

[2] Rajendran N, Tey Y S, Brindal M, Ahmad Sidique S F, et al, 2016. Factors Influencing the Adoption of Bundled Sustainable Agricultural Practices: A Systematic Literature Review [J]. International Food Research Journal, 23(5), 2271-2279. https://doi/full/10.1080/14702541.2022.2151041

[3] Shee A, Azzarri C, Haile B, 2019. Farmers' Willingness to Pay for Improved Agricultural Technologies: Evidence from a Field Experiment in Tanzania [J]. Sustainability, 12: 1-13. https://doi.org/10.3390/su12010216

[4] Cristian R F, Borges J A R, Machado J A D, 2020. A Review and Some Reflections on Farmers' Adoption of Sustainable Agricultural Practices Worldwide [J]. Science of The Total Environment, 729: 1-6. https://doi.org/10.1016/j.scitotenv.2020.138831

[5] Weifeng Zhang, Guoxin Cao, Xiaolin Li, et al, 2016. Closing Yield Gaps in China by Empowering Smallholder Farmers [J]. Nature, 537: 671. https://doi.org/10.1038/nature19368

[6] Kanter D R, Searchinger T D, 2018. A Technology-Forcing Approach to Reduce Nitrogen Pollution [J]. Nature Sustainability, 1(10): 544-552. https://doi.org/10.1038/s41893-018-0143-8

[7] Kassie M, Teklewold H, Jaleta M, et al, 2015. Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa [J]. Land Use Policy, 42: 400-411.

[8] Adnan N, Md Nordin S, Rahman I, et al, 2017. Adoption of Green Fertilizer Technology among Paddy Farmers: A Possible Solution For Malaysian Food Security [J]. Land Use Policy, 63(1): 38-52. https://doi.org/10.1016/j.landusepol.2014.08.016

[9] Taherdoost H, 2018. A review of technology acceptance and adoption models and theories [J]. Procedia Manufacturing, 22: 960-967.

[10] Dessart F J, Barreiro-Hurlé J, Van Bavel R, 2019. Behavioural Factors Affecting the Adoption of Sustainable Farming Practices: A policy-oriented Review [J]. European Review of Agricultural Economics, 46(3): 417-471. https://doi.org/10.1093/erae/jbz019

[11] Eba N, Bashargo G, 2014. Factors Affecting Adoption of Chemical Fertilizer by Smallholder Farmers in Guto Gida District, Oromia Regional State, Ethiopia [J]. Science Technology & Arts Research Journal, 3(2): 237-244. https://doi.org/10.4314/star.v3i2.31

[12] Adnan N, Nordin S M, Bahruddin M A, et al, 2019. A State-Of-The-Art Review on Facilitating Sustainable Agriculture through Green Fertilizer Technology Adoption: Assessing Farmers Behavior [J]. Trends in Food Science & Technology, 86: 439-452. https://doi.org/10.1016/j.tifs.2019.02.040

[13] Floress, K., García de Jalón, S., Church, S. P, et al, 2017. Toward a theory of farmer conservation attitudes: dual interests and willingness to take action to protect water quality. Journal of Environmental Psychology53: 73-80. http://doi.org/10.1016/j.jenvp.2017.06.009

[14] Stuart D, Schewe R L, Mcdermott M, 2014. Reducing nitrogen fertilizer application as a climate change mitigation strategy: Understanding farmer decision-making and potential barriers to change in the US [J]. Land Use Policy, 36: 210-218. https://doi.org/10.1016/j.landusepol.2013.08.011

[15] Rajendran N, Tey Y S, Brindal M, Ahmad Sidique S F, et al, 2016. Factors Influencing the Adoption of Bundled Sustainable Agricultural Practices: A Systematic Literature Review [J]. International Food Research Journal, 23(5), 2271-2279.

[16] Adnan N, Nordin S M, Bahruddin M A, et al, 2019. A State-Of-The-Art Review on Facilitating Sustainable Agriculture through Green Fertilizer Technology Adoption: Assessing Farmers Behavior [J]. Trends in Food Science & Technology, 86: 439-452. https://doi.org/10.1016/j.tifs.2019.02.040

[17] Nanzad B, Anderson K B, Conder J A, 2017. Evaluation of the Logit/Probit Transform Method to Modeling Historical Resource Production and Forecasting Compared to Conventional Hubbert Modeling [J]. International Journal of Coal Geology, 182: 42-51. https://doi.org/10.1016/j.coal.2017.08.016

[18] Jiaqi Huang, Antonides G, Nie F, 2020. Social-Psychological Factors in Food Consumption of Rural Residents: The Role of Perceived Need and Habit within the Theory of Planned Behavior [J]. Nutrients, 12(4) 1-23. https://doi.org/10.3390/nu12041203

[19] Pingping Wang, Wendong Zhang, Minghao Han, et al, 2019. Does fertilizer education program increase the technical efficiency of chemical fertilizer use? evidence from wheat production in china [J]. Sustainability, 11(2): 543. https://doi.org/10.3390/su11020543

[20] Paudel K P, Gauthier W. M, Westra J V, et al, 2008. Factors Influencing and Steps Leading to the Adoption of Best Management Practices by Louisiana Dairy Farmers [J]. Journal of Agricultural and Applied Economics, 40(01), 203-222. https://doi.org/10.1017/s1074070800028066

[21] Biao Geng, Liangguo Luo, 2018. Farmers' Willingness to Reduce Fertilizer Input and Adopt Organic Fertilizer——Based on the Perspective of Non-Point Source Pollution Prevention and Control in the Upper Reaches of Erhai Watershed [J].. Chinese Journal of Agricultural Resources and Regional Planning, 39(4): 74~82.