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RESEARCH ARTICLE

IMPACTS OF TECHNICAL ENVIRONMENT ON THE ADOPTION OF ORGANIC FERTILIZERS AND BIOPESTICIDES AMONG FARMERS: EVIDENCE FROM HEILONGJIANG PROVINCE, CHINA

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KEYWORDS

biopesticides, green production, organic fertilizer, technical environment

HIGHLIGHTS

- Farmer adoption of organic fertilizer and biopesticides was found to be positively correlated.
- The technical environment had a significant positive impact on farmers' adoption of organic fertilizers and biopesticides.
- Technology training and local accessibility to new agricultural technologies enhanced both the adoption of organic fertilizers and biopesticides.
- Exchanging information about production techniques with others generally increased the likelihood of adopting organic fertilizers by 6%.

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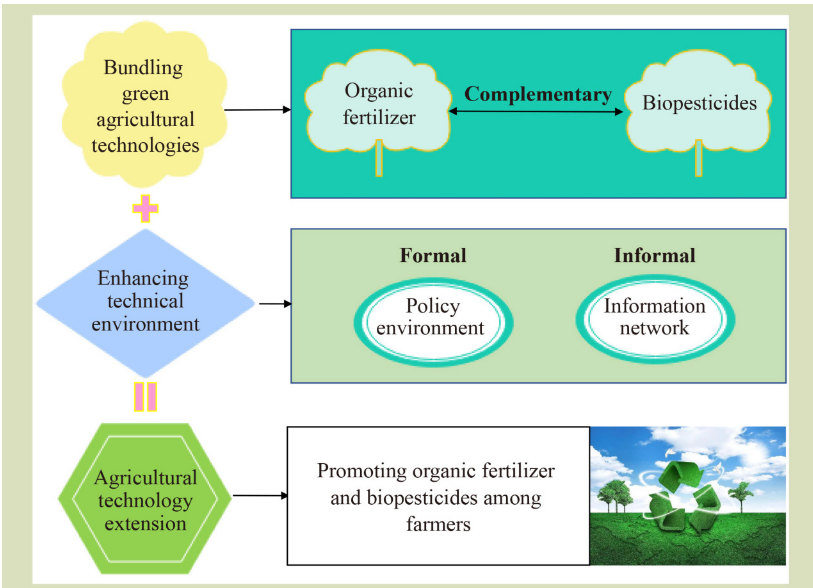
GRAPHICAL ABSTRACT



ABSTRACT

Excessive application of mineral fertilizers and synthetic pesticides poses a substantial threat to the soil and water environment and food security. Organic fertilizer and biopesticides have gradually become essential technology for reducing mineral fertilizer and pesticide inputs. In the process, the technical environment is critical for promoting farmer behavior related to the adoption of organic fertilizer and biopesticides. This paper analyzes the influence of the technical environment on farmer behavior related to the adoption of organic fertilizer and biopesticides based on a survey of 1282 farmers in Heilongjiang Province, China, using the bivariate probit model. The results indicate that (1) farmer behavior related to the adoption applying organic fertilizer and biopesticides were positively correlated; (2) the technical environment had a significant positive impact on farmer behavior related to the adoption of organic fertilizer and biopesticides; and (3) the technical environment had a heterogeneous effect across different groups of farmers. This research provides insights useful for promoting organic fertilizer and biopesticides to farmers. It can be helpful to bundle relevant environmental technologies, conduct technology training for farmers and strengthen the construction of rural information networks.

1 INTRODUCTION

Due to the severe pollution of agricultural environment in developing countries, sustainable agricultural development is increasingly becoming an essential strategy[1,2]. The promotion of green agricultural technologies is a vital approach to address problems such as degradation of agricultural ecological environment[3,4]. The application of organic fertilizer and biopesticides can effectively replace mineral fertilizers and pesticides, and improve the quality, efficiency and competitiveness of green agricultural development[5]. Examining the influence of the technical environment on farmer behavior related to the adoption of organic fertilizer and biopesticides can not only lay a solid foundation for the reduction of mineral fertilizers and synthetic pesticides, and the improvement of utilization rates of these alternatives in China, but also provide useful experiences for other developing countries.

There are serious contradictions between agricultural development in China and the environment, among which, agricultural, non-point-source pollution is the top priority. Mineral fertilizers and synthetic pesticides have contributed greatly to the growth of food production[6]. The heavy dependence on mineral fertilizers and synthetic pesticides, and excessive application rates of both have risked severe soil and surface water pollution and have seriously restricted the development of green agriculture in China[7]. Data show that the national average fertilizer application in 2020 was 314 $kg \cdot ha^{-1}$, far exceeding the internationally accepted safe upper limit of 225 $kg \cdot ha^{-1}$[8]. The national average pesticide application intensity was 14.8 $kg \cdot ha^{-1}$ in 2018, nearly five times the global average. Despite the large potential, the current adoption of organic fertilizer and biopesticides among farmers is relatively low[9].

Farmers are the basic decision makers in agricultural production. Their high adoption rates of green-technology is crucial to the reduction and substitution of mineral fertilizers and synthetic pesticides. There is an increasing awareness of significance of understanding farmer behavior in response to technology promotion. As with many green technology tools, there are numerous studies on the factors influencing adoption of organic fertilizer and biopesticides. The technical environment interacting with agricultural technology refers to the complex of all external factors that influence the farmer adoption behavior under certain spatial and temporal conditions, including natural ecology, agricultural development, agricultural policies, information networks, intermediary services and social culture[10,11]. Scholars note that the technical environment is a pivotal external condition for the promotion and application of agricultural technology, which both constrains and guides farmer behavior, and constitutes an important vehicle for the farmers adoption[12]. Thus, it is imperative to explore the influence of technical environment on farmer behavior related to the adoption of organic fertilizer and biopesticides technologies. In addition, farmers tend to adopt multiple technologies at the same time, and the choices are not mutually exclusive[13]. Identifying the linkages between farmer behavior related to the adoption of agricultural green technologies can help in the promotion of their adoption to farmer groups. In this regard, it is indispensable to have a fine-grained understanding of the intrinsic link between technology adoption behaviors.

Although the importance of the technical environment on sustainable agricultural technology has been established, examination of the technical environment in depth is lacking. Our study fills an existing research gap by examining the influence of the technical environment (including both formal technology training organized by local governments and informal peer technology communication with neighbors and friends) on farmer adoption of organic fertilizer and biopesticides from a systematic perspective. Many studies have shown that selecting multiple green agricultural technologies tends to be complementary. The bivariate probit model is used to consider the protentional correlation between the choices of two environment-friendly technologies, organic fertilizer and biopesticides[14]. The study provides a theoretical basis and practical guidance for related technology promotion intended to expand its use benefiting farmers, while enhancing environmental quality.

This paper is structured as follows. Next section reviews relevant literature and is followed by the definition of concepts and methods. Then the presentation of data and variables is followed by the model estimation results. The paper draws policy implications in the conclusion.

2 RELEVANT STUDIES

To address the low adoption of organic fertilizer and biopesticides, scholars have conducted a substantial volume of research, mainly focusing on two aspects. The first group of studies has examined factors influencing farmer adoption of organic fertilizer and biopesticides. The second set includes the studies of the farmer behavior related to the adoption of green production technologies. The results of the above two types of studies are summarized in the following subsections.

2.1 Farmer adoption of organic fertilizer and biopesticides

The promotion of a new technology is inseparable from the technical attributes and technical survival environment[15]. This approach allows factors influencing behavior related to the adoption of organic fertilizer technology and biopesticides technology to be summarized into technical environment characteristics and other characteristics.

2.1.1 Technical environment characteristics

Regarding the influence of technical environment factors on farmer adoption of organic fertilizer and biopesticides, academic studies have focused on three aspects: government policies, market drivers and information networks.

Government incentive policies and regulatory instruments can positively promote the adoption of organic fertilizer and biopesticides by farmers. Government incentives such as promoting green technologies, granting green input subsidies, and conducting technical training can increase farmer willingness and adoption rate of green technologies[16–18]. In addition to incentives, penalties and regulations can also motivate farmers to use organic fertilizer and biopesticides[19].

Market drivers have a facilitating effect on farmer behavior related to the adoption of technology and are stronger than the effect of government incentives[20]. Market drivers include the price of agricultural products after the substitution of green for conventional production factors, the recognition of the value of organic agricultural products, and the ease of marketing organic agricultural products, all of which have a positive effect on the adoption of organic fertilizer and biopesticides[10,21–23].

Information networks can also facilitate the adoption of organic fertilizer and biopesticides by farmers[24,25]. Social networks are important for farmers to obtain information, and whether farmers adopt technologies is often influenced by the behavior of farmers running large-scale farms, cooperative status, social customs and the behavior of village cadres[23,26,27].

2.1.2 Other characteristics

Technical attributes are quite important and are characterized through farmer perceptions[10]. Positive perceptions of technology significantly increase the likelihood that farmers will adopt technological advances. Many scholars have noted that ecological perceptions and perceptions of effectiveness significantly affect the likelihood of adoption of organic fertilizer and biopesticides[28,29]. More specifically, perceived waste of agricultural resources, perceptions of environmental protection, and perceptions of usability and affordability positively and significantly affect farmer intentions and behavior related to the adoption of biopesticides[29].

Secondly, the characteristics of technology adoption subjects matter. Farmer personal characteristics make an important contribution to their technology adoption behavior. Farmer characteristics include amount of land, labor inputs and quantity of livestock. In terms of land characteristics, the larger the scale of operation, the higher the likelihood of applying organic fertilizer and biopesticides[30,31]. Land fragmentation will weaken such adoption[32]. In terms of labor, the greater the number of household laborers, the more likely the household is to adopt organic fertilizer. Raising livestock and poultry will increase the likelihood of applying organic fertilizer[33,34]. When it comes to individual characteristics, age, education and risk preference often have a positive and significant effect on the level of adoption of green production technologies[22,33,35]. Meanwhile, it has also been suggested that the younger or the more risk-averse the farmer is, the higher the probability of applying green production technologies[36].

2.2 Correlation between differing technology adoptions

Several scholars found that there appears to be a correlation between differing technology adoptions, and suggest that different technologies are complementary and enhance advantages of the use of each of them. Farmers may simultaneously adopt several green technologies. Other research indicates that farmer own resource endowment is limited and the adoption of one green technology may crowd out the resources needed for the adoption of another technology.

Many studies have shown that selecting multiple green agricultural technologies tends to be complementary. In terms of fertilizer application technologies, Chu et al.[37] and Zuo[38] analyzed the factors influencing farmer application of commercial organic fertilizer and farmyard manure using data from 298 farmers in the Taihu Lake basin and 138 farmers in Ningjin County, Shandong Province. Both studies concluded that farmer selection of commercial organic fertilizer and farmyard manure were complementary. They agreed that farmers who use commercial organic fertilizer were more likely to also use farmyard manure than those who did not use commercial organic fertilizer. Kong et al.[39] examined the factors influencing small-scale use of soil testing and organic fertilizer technologies. The findings indicate a small-scale farmer complementary use of the two technologies, that is, small-scale farmers who used one technology were also more likely to use the other technology.

A few studies suggest substitution effects farmer behavior related to the adoption of multiple technologies. Zhang et al.[40] used data from 446 small-scale households in Henan Province, to study the factors influencing behavior relate to the application of organic fertilizer. They concluded that behavior of small-scale farmers related to the application of commercial organic fertilizer and farmyard manure had a substitution relationship, that is, small-scale farmers who applied one organic fertilizer were likely to reduce their application of the other organic fertilizer. Tran and Kurkaloval[41] studied the spatial and temporal heterogeneity of farmer conservation tillage adoption on a sustained basis. The result indicate that farmers do not use conservation tillage on a sustainable basis and substitute other technologies for conservation tillage after a period of time.

2.3 Research gap

While the above studies have provided a basis for important implications, there are also areas for expansion.

First, most of the studies on the relevant factors have primarily focused on the production and management characteristics of farmers, ecological perceptions and policy incentives, but the technical environmental factors have not been sufficiently explored. Existing studies have not fully discussed the technical environment that affects farmer adoption of organic fertilizer and biopesticides. Most scholars have only included selected technical environmental factors in their studies. In addition, the existing studies only confirmed that adoption of organic fertilizer and biopesticides technologies could be influenced by a few technical environment variables, but did not further analyze and compare the relative magnitude of the influence of different factors[10].

Second, a possible association between the choice of organic fertilizer and biopesticides technologies has received little attention from the academic community. Under the combined effect of internal and external factors, the adoption of several green technologies likely results in their interaction producing a linkage, i.e., the adoption of one technology is often influenced by another. Understanding the linkage between green agricultural technology application behavior and bundling technologies strengthens farmer motivation to adopt green production technologies[13] and facilitates technology promotion. Therefore, when analyzing the factors influencing farmer technology adoption choices, it is also necessary to consider whether there is an intrinsic link between different technologies.

3 CONCEPT FRAMEWORK

3.1 Concept definition

3.1.1 Technical environment

The interaction of agricultural technology with the technical environment refers to the complex of external factors that influence the adoption of technology under spatial and temporal conditions. The interaction involves ecology, agricultural development, agricultural policies, information networks, intermediary services, and social culture[10,11], among others. The role of the technical environment is critical to the promotion of agricultural technology application. It is both an important carrier for farmer technology adoption as well as a constraint, and guides farmer choices[12].

3.1.2 Adoption of organic fertilizer and biopesticide

(1) Technology adoption behavior

Technology adoption behavior of an individual is a dynamic decision-making process (Fig. 1). The process involves several steps: initial understanding of the technology, gradual formation of attitudes and making an adoption decision[42]. The process involving agricultural technology adoption follows the same general path of technology adoption. In the past, agricultural technology adoption refers to the behavior of farmers who recognize and accept a technology after understanding, examining and judging it, and actually applying it in practice. More recently, scholars have extended the definition of agricultural technology adoption and argue that the final adoption is not simply a choice of technology, but the evaluation of the performance of the adopted technology and, then, the decision whether to continue its use[9]. The technology adoption path studied in this paper refers to technology adoption behavior in a narrow sense.

(2) Organic fertilizers

Organic fertilizer refers to fertilizer made from organic materials such as plant and animal matter, or animal manure that are decomposed by microbial fermentation. Compared with mineral fertilizers, organic fertilizer can enrich and improve the soil microbiota and could improve crop quality, but they have low nutrient concentrations, slow fertilization effect and are relatively labor-intensive[43].

(3) Biopesticides

Biopesticides are formulations that use living organisms or their metabolic end products to control insects, weeds, fungi and other agricultural pests. The advantages of biopesticides are high efficiency and low residue, low environmental hazard, and selective. However, biopesticides also have inherent weaknesses such as slow onset of action and susceptibility to temperature and humidity conditions that lower their effectiveness[44].

3.2 Theoretical analysis and hypothesis

We apply the theory of planned behavior (TPB)[45] to explain the effect of technical environment on farmer adoption of technology. The TPB is an extension of the theory of reasoned action[46] proposed by Ajzen and Fishbein. Ajzen extended their contribution by introducing a concept of individual perceived behavioral control based on the inheritance of the theory of rational behavior. Thus, the TPB was developed. As a universal model in the field of technology adoption, the TPB is often used to explain the mechanism of technology adoption by individuals indicating that individual willingness to act is the result of the combination of three factors: individual behavioral attitudes, subjective norms and perceived behavioral control. In general, the more positive the individual behavioral attitude, the more positive the subjective norm, the stronger the perceived behavioral control and the greater individual behavioral intention. Thus, the more likely the person is to engage in a specific behavior.

Subjective norms and perceived behavioral control can reflect the technical environment of farmer adoption of technology (Fig. 2). Subjective norms involve the social pressure that individuals feel in the process of implementing a certain behavior. Farmers are not only economical-driven people but also socially-oriented people, and their intentions and behaviors are influenced by subjective norms. When farmers decide whether to adopt a new technology, their behavioral decision is influenced by the social relationships that appeal to them, including but not limited to family, friends and cooperatives. Perceived behavioral control refers to the degree of control that individuals feel they have when engaging in a behavior, that is, when faced with the choice of whether to

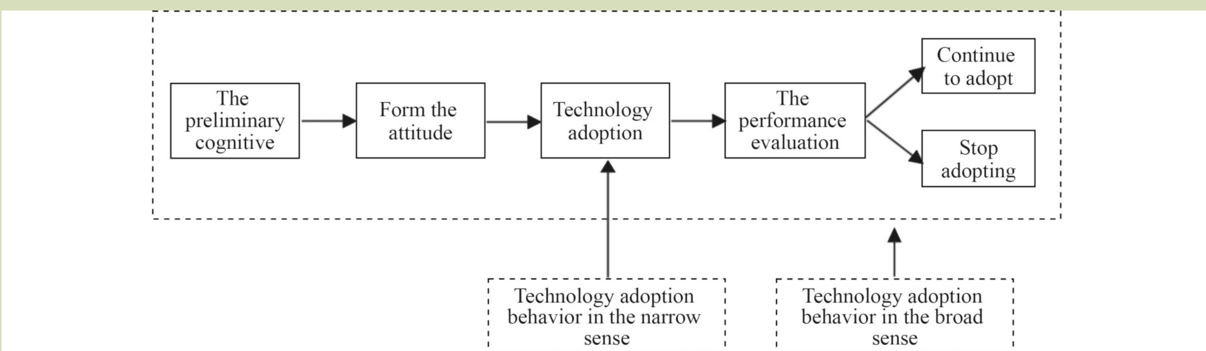


Fig. 1 Agricultural technology adoption behavior.

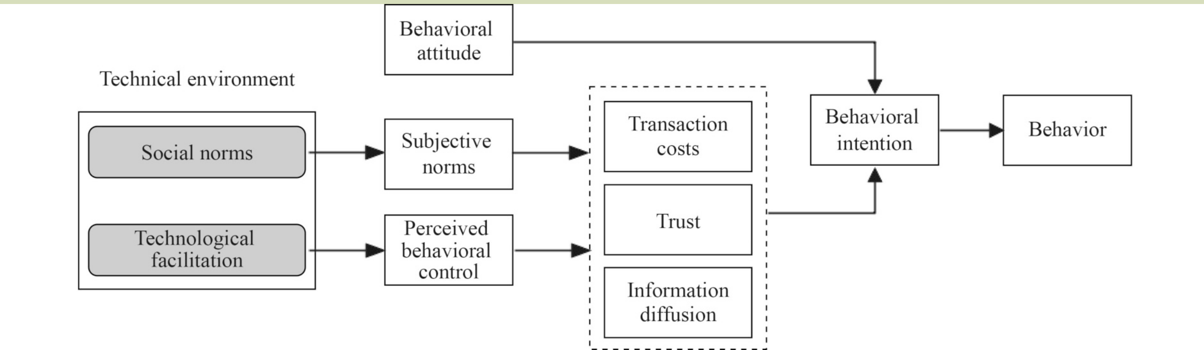


Fig. 2 Mechanisms of technical environment influence on farmer adoption of technology.

adopt a new technology. The perceived behavioral control captures the farmer overall assessment of how difficult it will be to actually operate the technology. In general, the better the technological facilitation, resource endowment and opportunities farmers perceive to have in agricultural production, the lower the expected resistance (against the new technology), the stronger the perceived behavioral control and the more likely that farmers will adopt the new technology.

According to Samuelson, technological progress can delay the emergence of the phenomenon of diminishing marginal returns to resources. For farmers who have long been engaged in agricultural production, the choice to adopt new technologies that can increase agricultural productivity can maximize profits. As far as farmers are concerned, their access to new technologies is usually limited. Most of the knowledge and exposure to new technologies come from experience exchanged among farmers, personal observations and learning. Government departments, agricultural technology extension departments and agricultural enterprises are another source of knowledge. The technical environment interacting with agricultural technology refers to the complex external factors that influence technology adoption behavior in a particular time and space, including policy environment, information environment and other factors[47], which constrain and guide farmer behavior in agricultural production. The adoption of new technologies results from the interaction between decision makers and the technical environment. A stimulating technical environment can reduce transaction costs, increase trust and promote information diffusion [48]. Thus, the degree to which the technical environment matches technical attributes determines farmer ability to obtain information related to new technologies. Information acquisition affects the farmer willingness to adopt or farmer technology adoption behavior.

4 METHODOLOGY

4.1 Empirical model

Choice of organic fertilizer or biopesticides technologies both suit binary choice models. The two technologies belong to the class of environment-friendly green agricultural production technology. It has been speculated that there may be correlation between selecting both technologies, i.e., there may be correlation between the perturbation terms of the two equations. The possibility of efficiency loss of the probit model is established separately for the two dependent variables modeling the choice of organic fertilizer and biopesticides selection. Thus, the section focuses on the bivariate probit model discussion, as shown in Eq. (1):

$$\begin{cases} y_{1i}^{*} = X_i\beta_1 + \varepsilon_{1i} \\ y_{2i}^{*} = X_i\beta_2 + \varepsilon_{2i} \end{cases} \tag{1}$$

where, y_{1i}^{*} and y_{2i}^{*} denote choices of organic fertilizer and biopesticides, respectively, i = 1,2,...,N represents the ith observed sample, X_i denotes various influencing factors of farmer organic fertilizer and biopesticide adoption behavior, β_j (j = 1, 2) is the corresponding estimated coefficient, and ε_{mi} (m = 1, 2) is the random disturbance term.

The observable variables y_1 and y_2 are determined by the Eq. (2):

$$y_j = \begin{cases} 1, \ if \ y_j^{*} > 0 \\ 0, \ if \ y_j^{*} \leqslant 0 \end{cases} \quad (j = 1,2) \tag{2}$$

If the selection behavior of small-scale farmers regarding organic fertilizer and biopesticides are independent of each other, Eqs. (1)–(2) are univariate probit models, and ε_{mi} (m = 1, 2) are independently and identically distributed. However, if small-scale farmers adopt organic fertilizer and biopesticides at the same time, then, ε_{mi} obeys a two-dimensional joint normal distribution with an expectation of 0 and a variance of 1, and the correlation coefficient is ρ.

4.2 Data and variables

The data used in this study were from field research conducted in Heilongjiang Province between July and August, 2018. In the selection of the sample, the research follows the principle of stratified sampling combined with random sampling. A total of 135 villages were randomly chosen in Heilongjiang Province, and 10 farm households and randomly selected in each village. The survey is conducted in the form of face-to-face interviews, and a total of 1348 questionnaires were collected. Heilongjiang Province was selected because it is the leading grain-producing province and the adoption of organic fertilizer and biopesticides in this region. After eliminating invalid questionnaires, 1282 questionnaires were included in the analysis, an effective rate of just over 95%. The questionnaires covered various aspects of households and farming, including topics such as the family characteristics, agricultural operation, environmental awareness and rural environmental problems.

The dependent variables in this study were farmer behavior in adoption of organic fertilizer and biopesticides[13]. This study captured the technical environment through two dimensions, i.e., policy environment and information network[10]. Measures of policy incentives have a significant influence in promoting farmer behavior in adoption of technologies[18,49]. Agricultural cooperatives are crucial in channeling information to farmers[38]. Also, easy access to new agricultural technologies is vital for farmers to adopt, related to obtaining information about new technologies and developing personal awareness[50]. The exchange of information about agricultural production technology with others enhances information acquisition, enriches technical knowledge and experience, and reduces the uncertainty of new agricultural technologies[51]. Control variables explored in this study include farmland[10,30,32], labor force structure[10,22,33], farmer cognition[28,29] and householder characteristics[14,33,40].

4.3 Descriptive statistics of farmer behavior related to the adoption of organic fertilizer and biopesticides

Table 1 give the definitions and descriptive statistics of variables studied. Among the surveyed farmers, 27.2% used organic fertilizer, 12.1% adopted some type of biopesticides technology and 8.27% adopted both. The adoption rate of both organic fertilizer and biopesticides technology is low.

From the perspective of the technical environment, in terms of policy incentives, 30% of the surveyed farmers received agricultural technology training (Table 1). In terms of information network, about a fifth (20.8%) of farm households were members in a local cooperative. Nearly half (47.2%) found it easy to access new technologies locally, and the vast majority (81%) of farmers frequently exchanged information about agricultural production technology with others.

Among characteristics specified as control variables, the average farmed area by the interviewed household was 13.6 ha (Table 1), a large average farm scale (as compared to other farms in China). The average number of plots per household was seven. The soil quality was medium-high. There were two agricultural laborers per household on average and their average age was 48 years old. A farm workers received 8 years of formal schooling. The average number of years of education reflects low education levels of household members engaged in farming and operation of rural households.

Knowledge and opinions about the surrounding environment had a mean value of recognizing soil degradation of 2.9, which is close to “somewhat serious degradation” (Table 1). The perception of a need to protect land is 3.4, which suggests the farmer response is nearly midway between “it is necessary to take protective measures for arable land” and “it is very necessary to take protective measures for arable land”. The use of organic fertilizer and biopesticides aims, among others, at enhancing environmental quality and was reflected in the surveyed farmer choice of a response option along the four-point scale (Table 1). The mean response regarding the need for environmental improvement is 3.4 (Table 1). The mean suggests farmers choosing between “useful” and “very useful” response options. The result indicates that the interviewed farmers recognize the role of green technology in improving the quality of farm land due to the reduction of mineral fertilizer and pesticide inputs.

4.4 Adoption of organic fertilizer and biopesticides in different technical environments

Table 2 presents the adoption of organic fertilizer and biopesticides by farmers in different technical environments. This summary of survey results shows that farmers in technical environments characterized by the presence of specific factors have a higher adoption of organic fertilizer and biopesticides. Specifically, farmers who have participated in technical training are more likely to adopt organic fertilizer and biopesticides than those who have not participated in technical training. If

Table 1 Definitions and descriptive statistics of variables related to organic fertilizer and biopesticide adoption

Variable type	Variable name	Definition	Mean	St. Dev
Dependent variables	Organic fertilizer	Do you use organic fertilizer in your actual production: Yes = 1, No = 0	0.272	0.445
	Biopesticides	Do you use biopesticides in your actual production; Yes = 1, No = 0	0.121	0.326
Technical environment				
Policy environment	Training	Household members have been trained in agricultural technology; Yes = 1, No = 0	0.300	0.458
Information network	Cooperatives	Does your family participate in professional farmer cooperatives; Yes = 1, No = 0	0.208	0.406
	Accessibility	Local accessibility to new agricultural technologies; Yes = 1, No = 0	0.472	0.499
	Exchange	Regularly exchange information about production techniques with others; Yes = 1, No = 0	0.810	0.392
Control variables				
Farmland	Planting area	Based on the actual area of cultivated land operated (ha)	14.28	38.57
	Number of plots	Actual number of operated plots (block)	6.726	6.532
	Land quality	Low = 1, lower = 2, medium = 3, higher = 4, high = 5	3.23	0.815
Workforce	Laborers	Number of persons	2.077	0.722
	Age	In years	48.445	10.735
	Education	In years	7.923	2.607
Intrinsic cognitive	Soil degradation perception	How do you view the current soil degradation problem: soil is not degrading = 1, degradation is not serious = 2, degradation is somewhat serious = 3, degradation is serious = 4, degradation is very serious = 5	2.878	1.156
	Land protection perception	Is it necessary to protect farm land: not at all necessary = 1, not necessary = 2, necessary = 3, very necessary = 4, extremely necessary = 5	3.367	1.076
	Environmental improvement perception	Cereal-bean rotation useful in improving farm land quality and reduced pesticide and fertilizer input use: not at all useful = 1, not useful = 2, useful = 3, very useful = 4, exceptionally useful = 5	3.43	1.006
Family characteristics	Family income in 2017	10,000–30,000 yuan = 1, otherwise = 0	0.230	0.422
		30,001–50,000 yuan = 1, otherwise = 0	0.218	0.413
		50,001–100,000 yuan = 1, otherwise = 0	0.211	0.408
		100,001 or more yuan = 1, otherwise = 0	0.252	0.434
	Share of agricultural income	Percentage of total household income from agriculture; 90% or more = 1, otherwise = 0	0.719	0.450
	Share of total household income from agriculture; 50%–90% = 1, other = 0	0.207	0.406	
	Number of family members	Actual number of family members (persons)	3.506	1.223
Householder characteristics	Village leadership status	Household head currently a village leader; Yes = 1, No = 0	0.156	0.363
	Years of farming	Actual years of farming by the household head (years)	29.776	10.785

Table 2 Adoption of organic fertilizer and biopesticides in different technical environments

Adoption	Technical training		Cooperative		Technology access		Technical exchange	
	Attended	Never attended	Attended	Never attended	Easy	Not easy	Frequently	Infrequently
Org. fertilizer (%)	38.8	22.3	35.6	25.0	34.9	20.4	30.0	15.2
Biopesticide (%)	18.5	9.4	17.2	10.7	16.0	8.6	13.0	8.2

family members had participated in cooperatives, they were more likely to adopt organic fertilizer and biopesticides than non-participants. Farmers who believed it is easy to obtain new agricultural technologies locally were more likely to have adopted organic fertilizer and biopesticides than those who thought otherwise. Finally, farmers who communicated with other about technology were more likely to have adopted organic fertilizer and biopesticides than those who did so infrequently.

5 RESULTS

Given the likelihood of correlation between the adoption of organic fertilizer and biopesticides, in order to ensure the reliability of the empirical results, this analysis applied the variance inflation factor (VIF) to test for possible multicollinearity between the measured variables. The VIF values obtained for these variables ranged from 1.03 to 3.28 indicating the absence of serious multicollinearity among the explanatory variables. Next, the bivariate probit model was applied to analyze the effect of the technical environment on the organic fertilizer and biopesticide adoption.

5.1 Bivariate probit model regression results

This study used Stata 14.0 statistical software to estimate the bivariate probit model of the influence of the technical environment on organic fertilizer and biopesticide adoption behavior. The estimations obtained are given in Table 3. Overall, the model fit is reasonable, the majority of technical environment variables were statistically significant, and the signs of the coefficients are consistent with expectations. Specifically, the chi-square value of the model was 97.4 being significant at the 1% level. The test result confirms a correlation between the random perturbation terms of the equations modeling the adoption of organic fertilizer and biopesticide by farmers justifying the use of the bivariate probit model. The correlation coefficient ρ between the random error terms of the two models was significant indicated by Wald test and was positive, indicating that behavior related to the adoption of organic fertilizer and biopesticides were significantly and positively correlated, that is, farmers who used organic fertilizer were also likely to use biopesticides.

5.1.1 Effect of technical environmental factors

The results of this analysis show that among the policy incentive factors, technical training positively and significantly affects farmer choice of organic fertilizer and biopesticides use. The effect was significant in both equations, with impact coefficients of 0.209 and 0.270, and marginal effects of 0.025 and 0.013 indicate that compared to farmers who have not received technical training, the probability that technical training recipients will use of organic fertilizer and biopesticides increased by 2.5% and 1.3%, respectively. The effect of training reflects its important role in promoting organic fertilizer and biopesticides use. This finding is consistent with expectations. Additionally, the effect is consistent with the findings of Daadi et al.[35] who concluded that government technical training has a positive effect in promoting farmer organic fertilizer application, and Liu et al.[49] who concluded that farmers who participated in technical training tend to apply high efficiency and low toxicity pesticides. Technical training can deepen farmer knowledge of organic fertilizer and biopesticides, and improve the awareness of green production technology benefits, and support policies encouraging adoption.

Among the effects of variables related to information network factors, the ease of access to new technologies significantly and positively promoted farmer adoption of organic fertilizer and biopesticides. In both adoption equations, the coefficients of 0.248 and 0.277, and marginal effects of 0.034 and 0.012, were statistically significant. The marginal effects indicate that farmers who perceived the new technologies were easily accessible in their location have 3.4% and 1.2% higher probabilities of using organic fertilizer and biopesticides, respectively, than farmers holding opposite views. Easy access to technology is integral and important in the diffusion of organic fertilizer and biopesticides. The finding is consistent with expectations and coincides with the conclusion of He and Zhang[50] that the higher the ease of farmer access to technological information, the more likely farmers display pro-environmental behavior. A possible explanation of these result is the belief that farmers with easy, local access to new technologies have more information that reduces the information asymmetry they face making decisions about the adoption of new technologies.

The exchange of information among family and neighbors significantly and positively influenced organic fertilizer adoption (Table 3). In terms of marginal effects, farmers who frequently communicate with acquaintances about technology have a 6.2% higher probability of adopting the use of organic fertilizer, with all other factors being equal. This finding is consistent with expectations and essentially consistent with the earlier findings of Niu et al.[25] that peer effects have a significantly positive impact on the adoption of green control

Table 3 Bivariate probit model regression results of decision to adopt organic fertilizer and biopesticides

Item	Organic fertilizer			Biopesticides		
	Coefficient	Std. Err.	Marginal effects	Coefficient	Std. Err.	Marginal effects
Technical environment						
Training	0.209**	0.096	0.025	0.270**	0.110	0.013
Cooperatives	0.075	0.100	0.008	0.100	0.114	0.005
Accessibility	0.248***	0.085	0.034	0.277***	0.100	0.012
Exchange	0.265**	0.116	0.062	0.045	0.133	−0.009
Control variables						
Area	0.019*	0.010	0.004	0.011	0.007	0.000
Plots	0.001	0.006	0.001	−0.003	0.006	−0.000
Land quality	0.056	0.048	0.006	0.080	0.060	0.004
Laborers	−0.097	0.061	−0.032	0.069	0.073	0.010
Age	−0.000	0.007	−0.001	0.004	0.007	0.000
Education	0.043**	0.018	0.010	0.011	0.022	−0.001
Soil degradation perception	−0.010	0.037	−0.002	−0.007	0.043	−0.000
Land protection perception	0.096**	0.044	0.024	0.001	0.051	−0.005
Environmental improvement perception	0.054	0.044	0.005	0.085	0.051	0.005
Income (× 10^3 yuan)						
10–30	0.278	0.176	0.041	0.206	0.200	0.007
30–50	0.425**	0.176	0.084	0.121	0.211	−0.007
50–100	0.692***	0.176	0.138	0.306	0.210	−0.005
> 100	0.584***	0.176	0.107	0.303	0.211	−0.001
Share of ⩾ 90% agricultural income 50%–90%	0.153	0.097	0.047	−0.061	0.116	−0.012
	−0.009	0.150	0.040	−0.468**	0.213	−0.029
No. of family members	−0.015	0.034	−0.002	−0.021	0.037	−0.001
Leadership	−0.202*	0.114	−0.029	−0.216	0.138	−0.009
Years of farming	−0.003	0.005	0.000	−0.003	0.006	−0.000
Constant		−2.200***			−2.416***	
Observations	1282					
ρ	0.589***					
Wald test of ρ = 0	chi2(1) = 97.4, Prob > chi2 = 0.00					

Note: ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

techniques among farmers. A possible reason is that farmer decisions about the adoption of new technology will depend on the behavior of farmers sharing similar identities. In the context of rural China, social learning is considered the most important way for information exchange and production comparisons for farmers. By exchanging learning with friends and neighbors, they can obtain valuable information to judge expected benefits and risks, which has an important impact on their organic fertilizer adoption behavior[9].

5.1.2 Influence of other factors

Among the other factors, the planting area significantly and positively influenced farmer organic fertilizer adoption. The corresponding marginal effect of 0.004 indicates that for every additional 6.67 ha in planting area, the probability of farmers using organic fertilizer would increase by 0.4%, on average. This outcome is consistent with expectations and supports the earlier empirical findings of Anthoinette et al.[30] who concluded that a larger scale of operation can significantly increase farmer ability to input organic fertilizer. The larger the scale of farming operations, the heavier the dependency on agricultural income. Also, a large farm is under pressure to increase output, recognizing the short-term orientation of their activities and drawbacks of expanded fertilizer use to increase production and income. Under such pressure, larger farms are more inclined to adopt organic fertilizer in actual production.

Improving education of agricultural workers can encourage the adoption of organic fertilizer as indicated by the marginal effect. For each additional year above the average number of years of formal education of a farm workers, the probability of using organic fertilizer increases by 1%. Earlier studies concluded that education significantly and positively influences farmers to exhibit pro-environmental behavior[39]. The higher the average educational level of the agricultural labor force, the greater the knowledge base, the greater the receptivity, and the greater the awareness of the environmental problems of agricultural mineral fertilizers use and their hazards. Therefore, the tendency to choose organic fertilizer in agricultural production is increasing.

In terms of intrinsic perception, the effect of desiring of arable land conservation on organic fertilizer adoption was positive and significant with a marginal effect of 0.024 (Table 3). Farmers who perceive the need to conserve their farmland have a higher probability of using organic fertilizer than those less supportive of such measures. A possible explanation is that long-term mineral fertilizer and pesticide use has caused soil acidification and land consolidation, which have seriously damaged the agricultural resource environment. Farmers aware of the role of organic fertilizer in environmental improvement have a higher perception score regarding land protection, and are more likely to use organic fertilizer.

Among the household characteristics, household income has a significant positive effect on the adoption of organic fertilizer. The estimation results show that farm households with annual household incomes of 30,000–50,000, 50,000–100,000 and > 100,000 yuan tend to apply organic fertilizer. The marginal effects corresponding to the three listed income categories are 0.084, 0.138 and 0.107, respectively, and the probability of adopting organic fertilizer increases by 8.4%, 13.8%, and 10.7%, respectively. A similar effect has been reported by Anthoinette et al.[30]. A possible explanation is that a higher annual household income improves affordability and more likely the choice of organic fertilizer. Farming households deriving 50%–90% of their income from agriculture have 2.9% lower probability of using biopesticides. This finding is consistent with that of Zhang et al.[40] that higher agricultural income shares exhibit pro-environmental behavior. It is reasonable to expect that households with a higher share of agricultural income are more dependent on agriculture and tend to avoid the risks brought by inappropriate use of synthetic pesticides, and thus have a greater preference for the adoption of biopesticides.

Among the householder characteristics, the status of being the village leader has a lower the adoption of organic fertilizers. The marginal effect indicates the probability of using organic fertilizer by village leaders is reduced by 2.9%, all other factors being equal. The current finding contradicts the findings of Luo[14] that village leaders are more likely to adopt agricultural technologies. A possible explanation of the observed difference is the relatively larger farms in Heilongjiang and the smaller labor resources in households of village leaders. A village leader, due to his office duties, may have less time for farming and chooses convenient and accessible mineral fertilizers.

5.2 Heterogeneity analysis

In exploring the influence of the technical environment on farmer organic fertilizer and biopesticides technology adoption, the current study examined the role of the technical environment across different groups of farmers. The heterogeneity of organic fertilizer and biopesticides adopters accounts for the farming scale and farm income share of the household total income.

5.2.1 Analysis of the effect of the technical environment on production behavior of different farming scale groups

Farmers operating more than 6.67 ha of cropland are classified as large grain farmers in northern regions[52], including Heilongjiang. The province under investigation in this paper is the top grain-producing province in China. Farmers in the sample were divided into small-scale (planting area < 6.67 ha) and large-scale (planting area 6.67 ha or more) groups. Each group was examined using empirical tests to determine the possible differences in technology adoption.

Table 4 presents the results of the bivariate probit regression analysis. Significant correlation coefficients ρ confirm the positive correlation of organic fertilizer and biopesticides in the large and small farms. Accessibility of new technology is a key factor influencing adoption of organic fertilizer and biopesticides, regardless of the farming scale, that is, farmer perception of easy, local access to new technology improves the chances of organic fertilizer and biopesticides use. It is possible

Table 4 Regression model results for households with different farming scales

Item	Small-scale farmers				Large-scale farmers			
	Organic fertilizer		Biopesticides		Organic fertilizer		Biopesticides	
	Coef.	Marginal effects	Coef.	Marginal effects	Coef.	Marginal effects	Coef.	Marginal effects
Technical environment								
Training	0.186	0.011	0.309**	0.018	0.287**	0.049	0.283*	0.010
Cooperatives	−0.030	−0.021	0.157	0.015	0.150	0.021	0.182	0.008
Accessibility	0.272**	0.034	0.257*	0.009	0.237**	0.031	0.309**	0.014
Exchange	0.432***	0.062	0.321*	0.007	0.101	0.059	−0.266	−0.027
Control variable	YES		YES		YES		YES	
	Prob > chi2 = 0.00, ρ = 0.715***				Prob > chi2 = 0.00, ρ = 0.490***			

Note: ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

that having certain knowledge of new technologies is a prerequisite for their adoption and the ease of accessing technical information facilitating the understanding is a key adoption factor. Technical training also influences the adoption of biopesticides by farmers regardless of the size (Table 4). A possible reason is that technical training helps farmers understand the efficacy, application methods and regulations related to biopesticides.

In the case of small-scale farmers, interpersonal technical information exchange affects the adoption of organic fertilizer and biopesticides. The interpersonal communication is an important channel for small-scale farmers to acquire new technologies. By sharing information with acquaintances, farmers obtain a comprehensive picture of green production technologies, expand their knowledge, and are therefore more inclined to apply new technology. For large-scale farmers, the technical training can influences their use of organic fertilizer, possibly because it enables large-scale farmers to learn fully about the relevant attributes of organic fertilizer and related regulations providing scientific understanding of the benefits of scale from using organic fertilizer, inducing adoption.

5.2.2 Technical environment and the choice of technology across farmer groups with different agricultural income shares

The sum of farm and non-farm income is the total income from employment. The current study reclassified the surveyed rural households into type 1 farmers (< 90% of total household income from agriculture) and type 2 farmers (90% or more of total household income from agriculture) based on the proportion of agricultural income in income total[53].

Table 5 presents the results of the bivariate probit regression

Table 5 Regression model results for households with different dependence on farm income measured by farm income share

Item	Farmers with high agriculture income share				Farmers with low agriculture income share			
	Organic fertilizer		Biopesticides		Organic fertilizer		Biopesticides	
	Coef.	Marginal effect	Coef.	Marginal effect	Coef.	Marginal effect	Coef.	Marginal effect
Technical environment								
Training	0.320*	0.012	0.668***	0.023	0.171	0.027	0.137	0.005
Cooperatives	0.183	0.043	0.046	−0.003	0.037	−0.006	0.147	0.012
Accessibility	0.473***	0.082	0.393*	0.005	0.199*	0.023	0.252**	0.014
Exchange	0.542**	0.151	−0.081	−0.020	0.242*	0.042	0.161	0.003
Control variable	YES		YES		YES		YES	
	Prob > chi2 = 0.00, ρ = 0.716***				Prob > chi2 = 0.00, ρ = 0.542***			

Note: ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

analysis. Easy accessibility to new technology (including information) promotes the adoption of organic fertilizer and biopesticides for both part-time and full-time farmers. The reason behind the observed outcome is the trust of farmers in friends and relatives, and frequent technical communication with those groups reduces uncertainty about new technology.

Among part-time farmers, technical training encourages the adoption of organic fertilizer and biopesticide use. Part-time farming can increase household income, and those with relatively higher income can afford inputs consistent with the adoption of green agricultural production technologies. Part-time farmers seem more likely to use organic fertilizer and biopesticides.

5.3 Robustness test

To further verify the reliability of the above results, robustness tests were performed on farmer behavior related to the adoption of organic fertilizer and biopesticides using two probit regression models[54]. The model results are shown in Table 6. Compared with the results of the bivariate probit model in Table 2, the significance and direction of variables are consistent, which indicates that the regression results are relatively robust.

5.4 Address the potential endogeneity

To examine the robustness of results, the possibility of endogeneity was examined. Due to the limitations of the data, some variables could not be included in the model, which might lead to possible biased estimates. Also, there may be a potential endogeneity between training and farmers adoption behavior. Therefore, the instrumental variable method was employed.

The proportion of farmers participating in technical training (excluding the farmers themselves) in their villages was selected as the instrumental variable. As a result of peer pressure, the training participation of other farmers in the same village can impact the behavior of individual farmers to participate in technical training. The selected instrumental variable is correlated with the core variable, but not affect whether or not farmers adopt organic fertilizer or biopesticides. Hausman test was conducted to check the consistent of coefficients from the probit and IV-probit model. The null hypothesis could not be rejected, which indicates there is no significant endogeneity (Prob > chi2 = 0.2047 and 0.1764 for Organic fertilizer and Biopesticides).

6 CONCLUSIONS AND IMPLICATIONS

Using survey data from Heilongjiang Province, China, this study investigated the impact of the technical environment on farmer adoption of organic fertilizer and biopesticides. The study applied the bivariate probit model. The results draw the following main conclusions. (1) Farmer adoption of organic fertilizer and biopesticides was significantly and positively correlated. (2) The technical environment has a significant positive effect on farmer adoption of organic fertilizer and biopesticides. Specifically, technical training and ease of access to new technologies had positive effects on farmer organic fertilizer and biopesticides use. Family and friends as a source of technical information exchange had positive effects on farmer organic fertilizer use. (3) The role of technical environment variables differed significantly among different farmer groups. Technical training promoted the adoption of biopesticides among farmers operating farms of different sizes. In addition, technical information obtained through an exchange with family and friends appears to significantly increase the adoption of organic fertilizer and biopesticides among small-scale farmers. Technical training is an important factor that can influence the use of organic fertilizer among large-scale farmers. Family and friends as a source of technical information can effectively promote the adoption of organic fertilizer among farmers with a varied dependence on income from farming.

The main conclusions of this study have the following implications for the formulation of organic fertilizer and biopesticides extension policies.

Firstly, bundling the organic fertilizer and biopesticides for promotion can be effective. The study results show that there is a significantly positive correlation between the adoption of organic fertilizer technology and biopesticides technology. Therefore, the actual adoption promotion program of organic fertilizer and biopesticdes should guide farmers in their adoption choices by stressing the enhanced effect of the combination of both categories of technology on increasing yields and incomes.

Secondly, improving the matching degree of technical environment and technical attributes is recommended. From one perspective, it is necessary to vigorously design and implement agricultural technology training for farmers to improve the matching of technical environment and technical attributes. The empirical results show that technical training is important in farmer adoption of organic fertilizer and biopesticides. Deepening farmer awareness of

Table 6 Robustness test

Item	Organic fertilizer			Biopesticides		
	Coef.	Std. Err.	Marginal effects	Coef.	Std. Err.	Marginal effects
Technical environent						
Training	0.215**	−2.260	0.065	0.279**	−2.510	0.053
Cooperatives	0.072	−0.720	0.022	0.096	−0.840	0.018
Accessibility	0.249***	−2.940	0.075	0.262***	−2.590	0.050
Exchange	0.261**	−2.270	0.079	0.048	−0.360	0.009
Control variable						
Area	0.019*	−1.790	0.006	0.011	−1.530	0.002
Plots	0.001	−0.220	0.000	−0.004	−0.600	−0.001
Land quality	0.050	−1.030	0.015	0.071	−1.210	0.014
Laborers	−0.093	−1.520	−0.028	0.064	−0.890	0.012
Age	0.000	−0.020	0.000	0.005	−0.710	0.001
Education	0.042**	−2.290	0.013	0.013	−0.570	0.002
Soil degradation perception	−0.006	−0.170	−0.002	0.005	−0.110	0.001
Land protection perception	0.097**	−2.180	0.029	−0.003	−0.060	−0.001
Environmental improvement perception	0.050	−1.140	0.015	0.071	−1.350	0.014
Income (× 10^3 yuan)						
10–30	0.302*	−1.700	0.074	0.238	−1.180	0.040
30–50	0.433**	−2.420	0.112	0.142	−0.670	0.022
50–100	0.702***	−3.920	0.199	0.304	−1.440	0.053
> 100	0.598***	−3.340	0.164	0.333	−1.570	0.059
Share of ⩾ 90% agricultural income 50%–90%	0.155	−1.600	0.048	−0.038	−0.330	−0.007
	0.000	0.000	0.000	−0.437**	−2.060	−0.067
No. of family members	−0.014	−0.400	−0.004	−0.022	−0.570	−0.004
Leadership	−0.203*	−1.770	−0.061	−0.202	−1.440	−0.039
Years of farming	−0.003	−0.570	−0.001	−0.003	−0.520	−0.001
Constant		−2.221***			−2.447***	
Wald chi2		125.37***			55.30***	
Prob > chi2		0.00			0.00	

Note: ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

environmentally-friendly production technologies through technical training can increase their interest in the adoption of organic fertilizer and biopesticides, and enhance their scientific farming knowledge and application abilities, thus promoting the transformation of agriculture to green development. From another perspective, it is also essential to reinforce the information network facilitating the exchange of agricultural production technology information. Local government is required to pay full attention to the vital contribution of rural information networks. To expand limited information sources on agricultural technology, the government can consider to build a public information exchange and mutual assistance e-platforms led by village cadres, agricultural specialists, farm experts and other professionals. Also, due to the significance of the exchange of information among family and neighbors in the diffusion of information in rural areas, it is indispensable to cultivate and support farm demonstrations of adoption of organic fertilizer and biopesticides, so as to normalize information channels for farmers.

Thirdly, differentiation of promotion policies targeting farmer groups should be considered. Different groups of farmers may have heterogeneous agricultural business goals and motivations to use technology. Consequently, it is necessary to recognize the presence of various farmer groups before implementing diversified and differentiated policy tools, and incentives encouraging the adoption of new, environmentally-friendly agricultural technologies.

The limitations of this study could address in the following ways. More detailed information on the use of organic fertilizer and biopesticides should be obtained in future surveys, not just information on an overall decision to adopt these technologies. This would allow examination of adoption behavior at a greater depth. Also, a future focus on organic fertilizer adoption, should distinction between the use of farmyard manure and commercial organic fertilizer, including all types of organic fertilizer. Also, from the current data it is not possible to examine factors such as individual farmer attitudes, so future studies should attempt to capture a wider range of factors that might influence adoption behavior.

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Compliance with ethics guidelines

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