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How do chemical fertilizer reduction policies work? —Empirical evidence from rural china

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China has issued a series of policies to regulate the usage of chemical fertilizer. Are these policies effective? If so, how do they work? To answer the above questions, this study empirically analyzed the effects of different types of policies (regulatory, incentive, and publicity policies), as well as their internal mechanisms and the moderating role of farmers' risk attitudes, on the usage of chemical fertilizers in agricultural production. We found that the policies and their interactions had positive significant effects on the reduction of chemical fertilizer usage while the influences of their interaction variables were the most statistically significant, and the relationships between the policies and reduction were negatively regulated by the risk attitudes of the surveyed farmers. Furthermore, the policies encouraged chemical fertilizer reduction by improving the farmers' income expectations while the farmers' risk attitudes negatively regulated the intermediary effects of their income expectations. This study enhances the understanding of the influence of economic rationality on individual decision-making, as postulated in neoclassical economics, to a certain extent. The conclusions are of much practical significance to the substantial reduction of chemical fertilizers and the green transformation of agriculture in China.

KEYWORDS

policy effects, risk attitude, chemical fertilizer reduction, mediating effect, moderating effect

1 Introduction

China is the largest producer and consumer of chemical fertilizers in the world (Zhang et al., 2013). For a long time, the country's strategy for agricultural development has been to increase agricultural production and income, so the use of chemical fertilizers has been increasing but has led to inefficient and excessive usage for major crops. The contradiction between agricultural development and environmental protection has become more prominent. Reducing fertilizers is a major measure taken to relieve pollution and promote the sustainable development of agriculture. To reduce the progressive imbalance in the "population–resources–environment" system, enhance the ecological environments of rural areas, and increase the efficient use of chemical fertilizers, the

Chinese government has been encouraging a green shift in agricultural production by implementing policies to reduce usage. In 2015, the Ministry of Agriculture issued an action plan for the "zero growth of chemical fertilizer usage by 2020." Under the guidance of this central policy, local governments, especially in agricultural provinces, have introduced their own policy measures to guide and support the reduction of chemical fertilizers (Hong et al., 2015; Zheng et al., 2018; Huang et al., 2019).

At present, the policy tools of government intervention in environmental governance show a diversified development trend, which can be divided into three types: command control, economic incentive and publicity guidance (Wang and Gu, 2013; Li et al., 2017), which can be named as regulatory, incentive, and publicity policies. Among them, economic incentive and publicity guidance are positive incentive policies, while command control is negative incentive policy, and the implementation effects of different types of policies are different (Huang et al., 2016). The success of these policies depends on the farmers' responses to their implementation (Li et al., 2019). Behavioral economics postulates that individuals are willing to participate in policies if they expect such policies to grant them high benefits and low costs of implementation (Su et al., 2011; He and Wang, 2019). The farmers' expectations of how these policies would affect their incomes ought to be the key concern of the policy arrangement. The current policy tools of the central government's intervention in environmental governance are diverse and can be divided into three types: regulatory, incentive, and publicity policies (Wang and Gu, 2013; Li et al., 2017). The effects of different types of policies would also be different (Huang et al., 2016).

As a protective measure, chemical fertilizer reduction can improve soil conditions and increase crop yields but such benefits take a long time to realize, so reduction carries certain levels of uncertainty and risk (Huang and Ji, 2012; Li et al., 2019). Therefore, government departments should also consider the effects of farmers' expectations of income stability when making policy choices. According to risk aversion theory, farmers will consider potential risks and uncertainties while pursuing the maximization of expected benefits (Staatz and Stock, 1987; Ma and Ding, 2013). The long return periods of reduction would pose high levels of uncertainty and risk for crop yields and incomes. Therefore, whether farmers respond positively to policies also depends on their risk attitudes. Those with low degrees of risk aversion are more willing to try new production methods to obtain long-term benefits. So, we can ask the question: What kinds of effect do different types of policies have on farmers' reducution of chemical fertilizers? How do they work? What kind of policy arrangement is more conducive to encouraging farmers to reduce chemical fertilizers? The answers to these questions would not only enhance the neoclassical economic understanding of how economic rationality influences farmers' decision-making but also provide an empirical basis for the formulation of measures that optimize and improve agricultural policies. Compared with the existing research, the innovation of this paper is mainly reflected in two aspects: 1) The existing literature mostly focuses on the impact of farmers' individual characteristics, land management methods and other factors on farmers' chemical fertilizer decision-making, and lacks in-depth analysis of its mechanism. Based on farmers' income expectation, this paper constructs an intermediary effect model to focus on the mechanism of the impact of different types of policy incentives on farmers' chemical fertilizer reduction behavior, and supplements the existing literature in the research content. 2) In this paper, risk attitude is taken as the adjustment variable, which is deeply discussed in the same analysis framework as policy incentives and farmers' chemical fertilizer reduction behavior, which is an effective expansion of the existing research.

2 Literature review

Scholars at home and abroad have conducted much research on farmers' use of fertilizers. They generally believed that although the use of chemical fertilizers plays a positive role in crop production (Gul et al., 2022), the excessive use of chemical fertilizers is the main cause of water pollution (Chandio et al., 2018). Moreover, higher fertilizer consumption is found to boost the short- and long-run carbon dioxide emission levels in Nepal (Rehman et al., 2022). So, the reduction of chemical fertilizer application has been key to the green revolution in many countries around the world (Chandio et al., 2018).

Basing their ideas on natural scientific experiments, some scholars have discussed the effects of chemical fertilizer reduction on the organic matter contents and crop yields of farmland. Compared with the application of single chemical fertilizers, combined applications of organic and other environmentally friendly fertilizers could significantly improve soil activity and enhance the organic matter contents in paddy fields (Huang et al., 2009; Shao et al., 2014; Mao et al., 2015). Liu et al. (2018) showed that grain yields could be significantly improved when organic fertilizer was applied. Wang (2019) studied the mixing methods of different proportions of fertilizers and concluded that mixtures including farmyard manure not only could improve the yields of grain crops but could also significantly improve the nutritional levels of rice. Shen et al. (2019) concluded that yields of wheat increased by 1.86% when the ratio of organic fertilizer to chemical fertilizer was one to five.

Other scholars have focused on the factors influencing farmers' practices. Huang and Ji (2012) analyzed the effects of farmland ownership confirmation on long-term investments and believed that such confirmation could eliminate the uncertainty of land-use rights to protect the rights of farmers, motivate them to make long-term investments, and increase environmentally friendly practices, such as the use of organic fertilizers. Li et al. (2019) believed that expansions of the scales of cultivated land encouraged farmers to use organic fertilizers. He and Huang (2001) thought that land-use property rights had significant effects on farmers' usage of fertilizers. Huang et al. (2019) considered family agricultural labor resources to be related to the selection of fertilizers.

The above studies have provided good micro-level analyses of which factors influence farmers' usage of chemical fertilizers. However, most of the current research has focused on the influences of farmers' individual and management characteristics but has paid limited attention to external factors such as macro-policies. Effective policies help to provide good guarantees for particular economic activities and to expand the bounded rationality of farmers, thus affecting their behaviors and choices. Among studies that have examined macro-policies, Abhilash and Singh (2009) believed that the strict implementation of laws and regulations could affect the supply of pesticides in terms of their production, distribution, and application while also affecting the demand for them by restricting their excessive application. Spraggon, (2002), Lichtenberg (2013), and Yang and Luo (2018) also believed that national policies had significant effects on farmers' environmental behaviors and that different types of policies produced different effects. Dong et al. (2019) advocated increasing subsidies, tax relief, and other related preferential policies to encourage farmers' cleaner production.

Current research on agricultural policies has focused on the direct influences of policies on farmers' decision-making but has given less consideration to the moderating effects of farmers' risk attitudes. Further discussion on how policies affect farmers' behavior is rarely reported. Although an examination of the relationships between macro-policies and chemical fertilizer reduction is necessary, the green transformation of agriculture requires the exploration of an effective path to promoting chemical fertilizer reduction and improving fertilizer efficiency comprehensively while treating farmers' risk attitudes as a moderating variable and analyzing the effects of policies on farmers' reducution.

This study empirically tested the influences and internal mechanisms of three types of policies (regulatory, incentive and publicity policies) and examined the role played by risk attitudes to formulate countermeasures and suggestions for the effective application of reduction policies to encourage farmers to reduce their usage of chemical fertilizers.

3 Theoretical foundations and hypotheses

3.1 Effects of different types of policies on chemical fertilizer reduction

According to the hypothesis of the "economic man," human beings desire to maximize their utility. Chemical fertilizer reduction is essentially a kind of agricultural management behavior driven by farmers' pursuits of their own utility maximization (Schultz, 1964). Under the assumption that income represents utility, farmers would adjust their production decisions according to trade-offs between costs and incomes. However, farmers' simple reliance on market forces to adjust production and management decisions is often inefficient for two reasons (William and Gary, 1980). First, farmers have limited rationality, i.e., they are limited in their knowledge and possess incomplete information, so they cannot form an accurate understanding and evaluation of a new mode of production in a short time. The rational choice of whether to adopt a new method is supported by learning (Hodgson, 2012). Second, individual farmers are heterogeneous. In the equilibrium analysis of neoclassical economics, the hypothesis of homogeneity is made for individual farmers while the different choices made by heterogeneous farmers under the same conditions are ignored. In reality, individual farmers often exhibit different economic behaviors because of their different levels of rationality. Effective government policies can provide good guarantees for particular economic activities, expand the bounded rationality of farmers, and guide farmers to make correct choices, thus effectively alleviating market failure and encouraging farmers to reduce their usage of chemical fertilizers.

The main types of policies that encourage chemical fertilizer reduction are regulatory, incentive, and publicity. Regulatory policies are command-and-control policies that restrict farmers' behaviors by criticizing and penalizing them for not complying with regulations, thereby increasing the costs of farmers' non-cooperation. Incentive policies provide financial subsidies to farmers who reduce, thus lowering their adoption costs and increasing their incomes. Publicity policies increase farmers' information and knowledge through publicity and training programs to reduce the costs of information searching and to encourage farmers to reduce.

To sum up, we formulate our first hypothesis, H1, H1a, H1b, and H1c.

H1. Policies have positive effects on farmers' reduction of chemical fertilizers.

H1a. Regulatory policies have positive effects on farmers' reduction of chemical fertilizers.

H1b. Incentive policies have positive effects on farmers' reduction of chemical fertilizers.

H1c. Publicity policies have positive effects on farmers' reduction of chemical fertilizers.

The government may use all kinds of policies simultaneously, thus creating interactions among them. For example, the adoption of incentive policies and publicity policies at the same time may have a complementary effect, which is stronger than the reduction effect of a single type of policies. Moreover, the interaction of multiple policies may also weaken the effect of a single policy, so the internal mechanism remains to be identified. Hence, we propose our second hypothesis, H2.

H2. Interactions among regulatory, incentive, and publicity policies have significant effects on farmers' reduction of chemical fertilizers.

3.2 Moderating effects of risk attitudes

The contingency effects of costs and benefits should be considered when farmers make decisions on chemical fertilizer reduction, whose benefits would take a long time to appear. The effects of the reduction policies would be subject to the income uncertainty caused by the adoption of new production methods. This uncertainty is defined in behavioral economics theory as the risk resulting from the farmers' reduction of chemical fertilizers.

Government policies would improve farmers' income expectations, which assumes confidence in the stability of their incomes. Only when farmers have full confidence in the benefits and ease of reduction could the policies be effective. According to risk theory, farmers' risk attitudes strongly affect their decisions regarding production (Paudel et al., 2000). In practice, their limited cognition does not fully encompass the possible losses incurred in production and management without any deviations. When they adopt a new mode of production, they heighten predictions of risk because they lack successful experiences to emulate, which discourages reduction. Therefore, heterogeneous farmers have different levels of risk aversion, which influence their decisions. More scholars have begun to pay attention to the effects of farmers' risk attitudes on their production decisions. Many behavioral experiments have quantified risk attitudes and have demonstrated that those of different types of farmers were heterogeneous and diverse (Zhou et al., 2012). Generally speaking, if farmers are averse to risk, they are less willing to adopt new modes of production. Hence, we propose our third hypothesis, H3.

H3. Farmers' risk attitudes are negatively related to the effects of reduction policies, i.e., lower degrees of risk aversion allow for stronger policy effects on their reduction of chemical fertilizers.

3.3 Internal mechanism of policies on chemical fertilizer reduction

Chemical fertilizer reduction policies can directly affect farmers but can also affect them through a series of intermediary mechanisms. Generally speaking, an optimistic attitude toward reduction is a necessary condition for commencing reduction. Regulatory, incentive, and publicity policies should first enhance the willingness to reduce fertilizers by raising income expectations in two ways.

First, policies enable farmers to realize that the feasibility and benefits of reduction would result in higher future incomes (Zhao and Zhou, 2012). Moreover, those farmers who have already achieved positive results from reduction would serve as examples to inspire confidence in others. Second, policies can improve income expectations by reducing the actual costs of reduction through economic incentives such as subsidies and through decreasing the costs of time, energy, and information searching required for changing the mode of production, thus improving the farmers' rational and cognitive levels, as well as indirectly raising their incomes. Hence, we propose our fourth hypothesis, H4.

H4. Policies have additional positive effects on farmers' reducution of chemical fertilizers, for which their income expectations are an important internal transmission mechanism.

Figure 1 shows a moderated mediating effect model proposed in this study, which includes the direct impact of different types of policies on farmers' reducution of chemical fertilizers (H1, H2), the moderating effect of farmers' risk attitude (H3) and mediating effect (H4). Concurrently, this study also controls the possible influence of other related factors.

4 Data, variables, and models

4.1 Data sources

The data used in this study were produced by the field research conducted by the research group in the provinces of Henan, Hubei, Shandong, and Yunnan from June to September 2020. The former two are located in the central regions of China, whereas the latter two are in the eastern and western regions, respectively. These provinces were selected for their different levels of economic development, which can better reflect the situation of regions with different levels of economic development. The questionnaire includes four parts: ① Farmers' Individual characteristics (age, gender, level of education, political identity, risk attitude, etc.); ②Family management characteristics (family income structure, labor force structure, scale of cultivated land); ③ Farmers' cognitions about reduction; ④ Reduction conditions. The principle of stratified random sampling was applied to select 9 City as the survey areas. Two townships were randomly selected from each municipal unit, then two or three villages were selected from each town as sample villages, from which about 30 farmers were randomly selected for the survey sample group. The inclusion of both grain and cash crop farmers ensured that the sample was highly representative. A total of 800 questionnaires were distributed. All were returned and

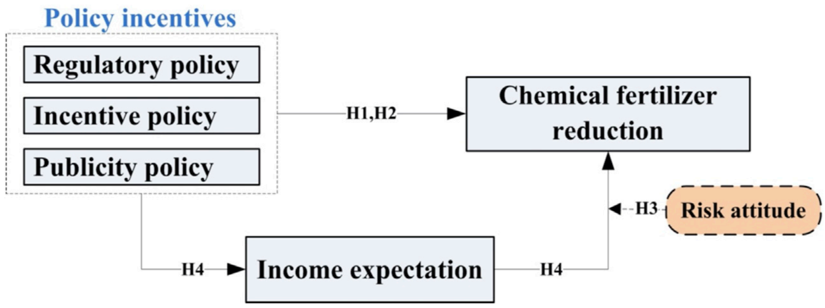

FIGURE 1
Path analysis of different types of policies affecting farmers' reducution of chemical fertilizers.

screened to filter out questionnaires with missing responses and logical errors to produce a final number of 733 valid samples, thus achieving an effective rate of 91.63%.

4.2 Variables

For binary questions in the questionnaire, we assigned 1 to a "yes" and 0 to a "no" answer.

4.2.1 Explained variable

4.2.1.1 Chemical fertilizer reduction

Refers to usage declining in both frequency and dosage. The binary question, "Have you reduced your usage of chemical fertilizers in agricultural production?," was used to collect data on this variable. A binary logistic regression model was then used to quantitatively analyze the influences of policies on reduction.

4.2.2 Explanatory variables

4.2.2.1 Regulatory policy

Supervision and direct control of fertilizer usage by restricting the frequency of usage and dosage' criticism and penalization of those farmers who do not reduce their usage. The binary question, "Does your local government (village or township) supervise the usage of chemical fertilizers?," was used for this variable.

4.2.2.2 Incentive policy

Financial incentives, usually in the forms of subsidies, and price concessions. The binary question, "Do you receive any financial incentives for reducing your usage of chemical fertilizers?," was used for this variable.

4.2.2.3 Publicity policy

This takes the form of campaigns for public relations and education. The responsible government departments disseminate information and knowledge about reduction, as well as provide technical support, to farmers. The binary question, "Have you ever participated in any seminars or training programs about chemical fertilizer reduction?," was used for this variable.

4.2.3 Moderator variable

4.2.3.1 Risk attitude

Most of the research on farmers' risk attitudes has been classifications of farmers into different risk types. However, some studies have argued that this kind of treatment is highly subjective and does not fully reflect the differences in risk attitudes (Fellner and Maciejovsky, 2007; Huang et al., 2009; Li and Guo, 2009; Hou et al., 2014; Gao and Niu, 2019). Therefore, this study chose the utility function method to quantitatively measure the degrees of farmers' risk aversion. Combining the measurement method of the risk aversion coefficient by Guiso and Paiella (2008), with the basic characteristics of our research objects, this study designed a simulation experiment to quantify the risk attitude of each farmer by asking the question, "Suppose that you were invited to play a game in which you picked a ball from a jar with 50 red and 50 black balls. If you picked a red ball, you won 3,000 yuan but won nothing for a black one. How much money would you spend to play this game?" The risk aversion index of all the farmers was obtained by constructing the expected utility function according to the maximum amounts that the farmers would be willing to pay. Of course, we assumed that these amounts would be lower than their expected winnings. The amount of 1,500 yuan is 11.3% of the rural population's per capita consumption in 2019. Therefore, participation in this game would pose certain risks to the farmers, thus allowing us to obtain a more objective view of the levels of their risk aversion (Li and Guo, 2009).

If the resource endowment (wealth) of farmer i is $W_i, U_i(*)$ is the utility function of i, and P_i is the amount that farmer i may win, then P_i equals $(3000 - Z_i)$ or $-Z_i$, Z_i is the maximum amount that farmer i is willing to pay. The probability of choosing a ball of either color is the same, i.e., 0.5. Therefore, the utility equation can be expressed as:

TABLE 1 Specific meaning of variables.

Variable	Symbol	Variable description	Mean	St. Dev.
Explained variable				
Chemical fertilizer reduction	Y	"Have you reduced your usage of chemical fertilizers in agricultural production?" No = 0; Yes = 1	0.7681	0.4223
Explanatory variable				
Regulatory policy	X_1	"Does your local government (village or township) supervise the usage of chemical fertilizers?" No = 0; Yes = 1	0.5593	0.4968
Incentive policy	X_2	"Do you receive any financial incentives for reducing your usage of chemical fertilizers?" No = 0; Yes = 1	0.3711	0.4834
Publicity policy	X_3	"Have you ever participated in any seminars or training programs about chemical fertilizer reduction?" No = 0; Yes = 1	0.6257	0.4843
Moderator variable				
Risk attitude	E	"Suppose that you were invited to play a game in which you picked a ball from a jar with 50 red and 50 black balls. If you picked a red ball, you won 3,000 yuan but won nothing for a black one. How much money would you spend to play this game?" The actual risk aversion index is calculated by utility function	0.5353	0.0894
Mediator variable				
Income expectation	M	" I think that my reduction of chemical fertilizers could increase my income." 1 = Not at all; 2 = lesser degree; 3 = neutral; 4 = greater degree; 5 = absolutely	3.1514	1.0908
Control variables				
Level of education	K_1	Years of Education (unit: years)	7.7053	5.1930
Gender	K_2	Male = 1, Female = 0	0.6153	0.4869
Age	K_4	Actual age (unit: years)	51.1514	13.2434
Political identity	K_3	"Party member or public official?" No = 0, yes = 1	0.1392	0.3461
Household income	K_5	Actual total household income (unit: 10,000 yuan)	10.0208	14.4171
Agricultural labor force	K_6	Actual number of agricultural labor force in households	1.5075	0.8583
Scale of cultivated land	K_7	Scale of cultivated land	0.6069	5.0118
Regional dummy variable	K_8	Setting regional dummy variables at provincial level	—	—

$$U_i(W_i) = 0.5U_i(W_i + 3000 - Z_i) + 0.5U_i(W_i - Z_i) = E(U_i(W_i + P_i)) \quad (1)$$

A second-order Taylor expansion is performed on the right side of the equation:

$$E(U_i(W_i + P_i)) \approx U_i(W_i) + U_i'(W_i)*E(P_i) + 0.5U_i''(W_i)*E(P_i)^2 \quad (2)$$

Substituting Eq. 1 into Eq. 2 and simplifying obtains the absolute risk aversion index $R_i(W_i)$ of farmer i:

$$R_i(W_i) = -U_i''(W_i)\big/U_i'(W_i) = 2E(P_i)\big/E(P_i)^2 = (3000 - 2Z_i)\big/\left(4500000 - 3000Z_i + Z_i^2\right) \quad (3)$$

4.2.4 Mediator variables

4.2.4.1 Income expectations

A farmer's subjective perceptions of the growth in their income as a result of chemical fertilizer reduction. The variable was measured by a Likert five-point scale (see Table 1) for the question, "I think that my reduction of chemical fertilizers could increase my income."

4.2.5 Control variables

This study controlled for each farmer's individual (Norris and Batie, 1987; Gao et al., 2017) and family characteristics (Gao et al., 2017), as well as for regional dummy variables, which may have affected the farmer's reduction of chemical fertilizers.

① Individual characteristics: level of education K_1 (unit: year), gender K_2 (male = 1, female = 0), age K_3 (unit: year), and political identity (party member or public official = 1; otherwise, 0).
② Family characteristics: household income K_5 (unit: 10,000 yuan), agricultural labor force K_6 (unit: person), and scale of cultivated land K_7 (unit: Hectare).
③ Regional dummy variables: to control for each region's external influences such as natural conditions, level of economic development, policy differences, crop varieties, and crop systems.

4.3 Statistical analysis

Table 1 shows that most of the farmers in our sample are 46–65 years old (53.89%). Female farmers account for only 38.47% of the sample. The level of education is mostly junior high school or below (79.26%). Party members and public officials account for 13.92%. Farmers with high degrees of risk aversion account for 63.71%. The number of family agricultural workers in the majority of the sample was less than 2. More than half of all respondents have an income of at least 80,000 yuan per year. The proportion of households with cultivated land areas of less than 0.2 ha accounts for 41.75%. The farmers who think that reduction could increase their incomes is 27.97% and who have reduced their usage is 76.81%.

4.4 Models

A binary logistic model with interaction variables was used to measure the effects of the policies. To test H1 and H2, this study first examined the direct effects. The binary choice model is expressed as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_1 X_2 + \beta_5 X_1 X_3 + \beta_6 X_2 X_3 + \beta_7 X_1 X_2 X_3 + \gamma K_i + \mu \quad (4)$$

In Eq. 4, i is the $i\text{-}th$ farmer, Y is their participation in fertilizer reduction, X_1, X_2, and X_3 are the regulatory, incentive, and publicity policies, respectively, while X_1X_2, X_1X_3, X_2X_3 and $X_1X_2X_3$ are the interaction terms of the respective policies, K is the control variable, $\beta_1 \sim \beta_7$, and γ are the coefficients to be estimated, β_0 is the constant term, and μ is a random error term.

Different risk attitudes may have produced the different effects, so this study introduced the risk attitude variable into Eq. 4 to investigate the moderating effects of the risk attitudes on the three policy variables (H3):

$$Y = a_0 + a_1 X_1 + a_2 E + a_3 X_1 E + \eta K_i + \mu \quad (5)$$

$$Y = a_0' + a_1' X_2 + a_2' E + a_3' X_2 E + \eta' K_i + \mu' \quad (6)$$

$$Y = a_0'' + a_1'' X_3 + a_2'' E + a_3'' X_3 E + \eta'' K_i + \mu'' \quad (7)$$

In Eqs. 5–7, E is risk attitude while X_1E, X_2E, and X_3E represent the moderating effects of risk attitudes on the relationships between the respective policies and reduction. If a_3, a_3' *and* a_3'' are statistically significant, then the moderating effects of risk attitudes (E) are verified and H3 is supported. To avoid multicollinearity caused by the interaction terms, the relevant data were centralized before analysis. To avoid the formulation of an overly complex model, the next model does not consider the interactions among the policy variables.

To test H4, we established a model including policies, income expectations, risk attitudes, and reduction. A stepwise regression method was used to test the mediating role of income expectations and the moderating role of risk attitudes in the mediating effect.

1) We tested the effects of the policies and risk attitudes on reduction:

$$Y = \alpha_0 + \alpha_1 X + \alpha_2 E + \alpha_3 X * E + \gamma_1 K_i + \mu_1 \quad (8)$$

2) We estimated the effects of the policies and risk attitudes on the mediating variables by using the following model:

$$M = b_0 + b_1 X + b_2 E + b_3 X * E + \gamma_2 K_i + \mu_2 \quad (9)$$

In Eq. 9, M is the mediator variable and the explanations of the other variables are the same as those in Eqs. 4–7. If b_1 is statistically significant, then M is a reasonable mediator.

3) We estimated the direct effects of the policies and intermediary variables on reduction and estimated the moderating effects of the risk attitudes:

$$Y = \alpha_0' + \alpha_1' X + \alpha_2' E + \alpha_3' X * E + \varphi M + \gamma_3 K_i + \mu_3 \quad (10)$$

4) We estimated the effects of the risk attitudes, mediating variables, and their interactions on reduction:

$$Y = b_0' + b_1' E + b_2' M + b_3' M * E + \gamma_4 K_i + \mu_4 \quad (11)$$

In Eq. 11, $M*E$ is the interaction between income expectation and risk attitude. If α_1, b_1 *and* φ are statistically significant, then the mediating effects of income expectations (M) are verified and H4 is supported. If b_3' is statistically significant, then risk attitudes have significant moderating effects on the mediating effects of income expectations.

5) We ensured that the empirical conclusion was robust by the bootstrap method instead of the stepwise regression method to verify the presence of the mediating effects.

5 Results and analysis

To ensure the rationality and effectiveness of the study's methodology, a multicollinearity test was conducted for each variable. Generally speaking, Variance Inflation Factor (VIF) > 3 would have indicated a low degree of collinearity between the variables, whereas VIF >10 would have indicated a high degree. The results showed the maximum VIF of each index to be 1.526, so the collinearity level of the index was within the acceptable region and met the condition of the binary logistic regression.

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TABLE 2 Empirical results of policies' effect on farmers' reduction of chemical fertilizer.

Variable	Model 1		Model 2		Model 3		Model 4		Model 5	
	Coefficient	St. Dev	Coefficient	St. Dev	Coefficient	St. Dev	Coefficient	St. Dev	Coefficient	St. Dev
Regulatory policy	0.957***	0.194					0.689***	0.236	0.600*	0.351
Incentive policy			1.450***	0.263			1.564***	0.302	1.214**	0.598
Publicity policy					2.266***	0.215	2.477***	0.23	2.302**	0.895
Regulatory policy * Incentive policy									0.363	0.714
Regulatory policy * Publicity policy									0.042	0.508
Incentive policy * Publicity policy									0.309	1.194
Regulatory policy* Incentive policy * Publicity policy									0.464***	0.178
Level of education	−0.012	0.019	−0.008	0.019	−0.036	0.027	−0.008	0.024	−0.009	0.024
Gender	0.064	0.194	0.034	0.196	0.077	0.214	0.052	0.227	0.057	0.226
Age	−0.027***	0.009	−0.017*	0.009	−0.044***	0.009	−0.027***	0.01	−0.027***	0.01
Political identity	0.562*	0.333	0.578*	0.332	0.357	0.373	0.259	0.387	0.25	0.386
Household income	0.035**	0.017	0.034**	0.017	0.067***	0.017	0.032*	0.018	0.032*	0.018
Agricultural labor force	−0.043	0.12	0.046	0.125	0.032	0.126	0.086	0.142	0.089	0.142
Scale of cultivated land	0.006*	0.003	0.005	0.003	0.012***	0.003	0.006*	0.003	0.006*	0.003
Regional dummy variable	Controlled		Controlled		Controlled		Controlled		Controlled	
Constant term	1.96***	0.582	1.364**	0.592	1.985***	0.631	0.238	0.671	0.316	0.697
Chi^2	70.72***		81.902***		177.507***		234.526***		235.601***	
−2 log likelihood value	723.243		712.069		615.936		558.917		557.842	
Prob > chi^2	0.000		0.000		0.000		0.000		0.000	

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TABLE 3 PSM matching results.

		Unmatched	Matching	Total
Regulatory policy	Control group	2	321	323
	Processing group	1	409	410
	Total	3	730	733
Incentive policy	Control group	24	437	461
	Processing group	0	272	272
	Total	24	709	733
Publicity policy	Control group	1	273	274
	Processing group	2	457	459
	Total	3	730	733

TABLE 4 Test results of balance hypothesis.

	Regulatory policy		Regulatory policy		Regulatory policy	
	Unmatched	Matching	Unmatched	Matching	Unmatched	Matching
pseudo R2	0.084	0.009	0.197	0.007	0.025	0.010
LR chi2	84.18	10.40	190.30	5.27	24.43	12.30
Mean deviation	18.1	8.1	28.6	4.3	10.6	5.2
B	70.4	21.8	29.1	19.7	26.3	23.2
R	1.36	1.34	0.01	0.97	6.94	1.18

5.1 Preliminary analysis of policy effects on chemical fertilizer reduction

The empirical results are shown in Table 2. The differences among the five models are as follows. Models 1, 2, and 3 contain the independent variables of the regulatory, incentive, and publicity indicators, respectively. In Model 4, the three kinds of policy indicators are included in the regression equation simultaneously. Finally, in Model 5, the policies and their interaction terms are included in the regression equation as explanatory variables. The effects of each policy and their interaction terms are explained in more detail.

First, in model 1, the effects of regulatory policies on chemical fertilizer reduction are statistically significant at the 1% level. The regression coefficient is 0.957, which indicates that they had significantly encouraged reduction. When farmers refuse to reduce, they risk incurring fines and damage to their reputations. The pursuit of identity and the desire to avoid economic losses motivate farmers to reduce and earn opportunities to obtain some indirect benefits, such as higher comparative advantages for their agricultural products and better reputations among their fellow farmers (Yang, 2014). Thus, regulatory policies have increased the probability of reduction, which supports H1a.

Second, in model 2, the effects of incentive policies are significantly positive at the 1% level. The regression coefficient is 1.450, which indicates that they had also significantly encouraged reduction. Since chemical fertilizer reduction is a new agricultural production technology with high costs and uncertain benefits in the short term, sole reliance on market mechanisms for regulation would be inefficient (William and Gary, 1980). To subsidize farmers would be equivalent to granting additional income, which would motivate them to reduce. The policies would also reduce the farmers' expected costs. Institutional economic theory states that policymaking affects the transaction costs of different activities (Akerlof, 1980). The policies would guide the farmers to form consistent values and establish cooperative mechanisms, which would, to some extent, effectively increase their mutual acceptance and reduce the transaction costs of reduction while establishing long-term mutual trust that would facilitate their access to information, capital, and other resources, thus encouraging them to reduce. Therefore, incentive policies have played significant roles in reduction, which supports H1b.

Third, in model 3, the effects of publicity policies are significantly positive at 1% level. The regression coefficient is 2.266, which indicates that they had also significantly encouraged reduction. Since chemical fertilizer reduction is a new type of

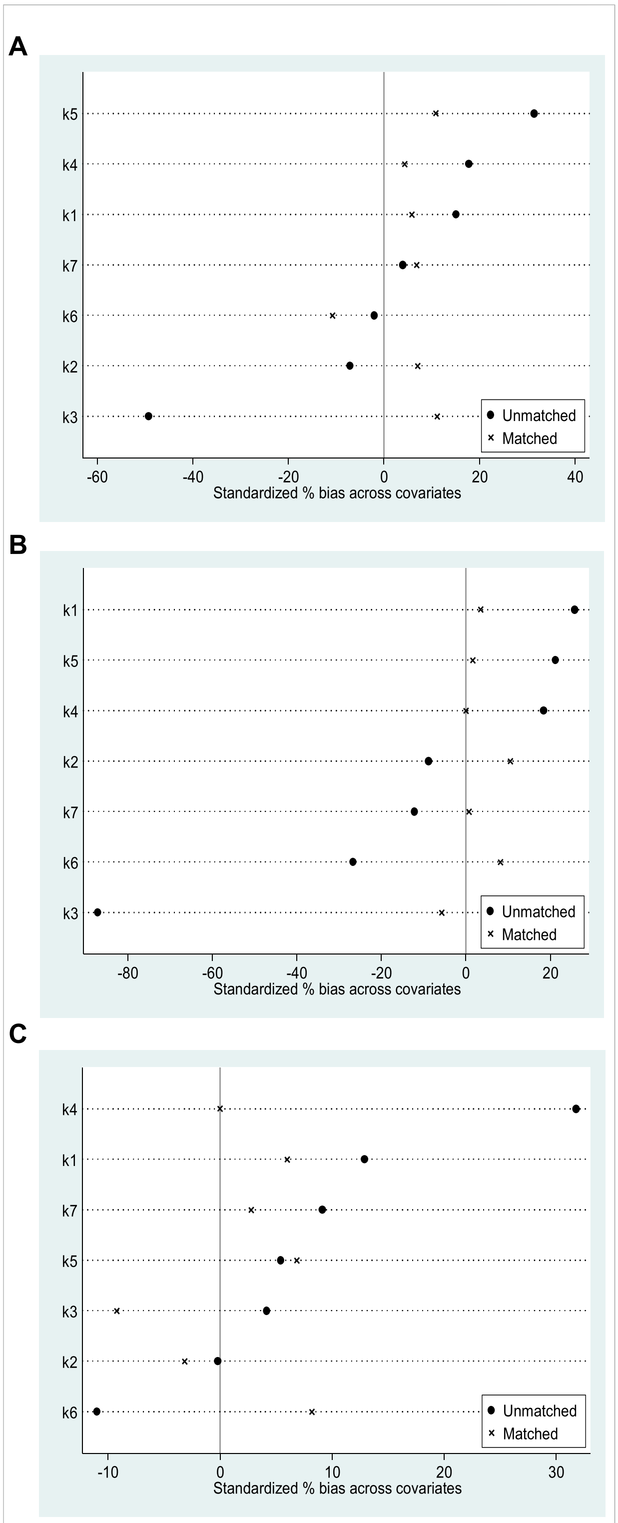

FIGURE 2
Test results of balance hypothesis.

agricultural technology, farmers would have a limited understanding of it. The government's publicity and training efforts could provide them with scientific and more comprehensive knowledge, which not only could encourage their acceptance of new fertilizers and technology but also increase their cognition of the value of reduction and improve their technical abilities to participate in reduction successfully. Therefore, publicity policies have played a significant role in reduction, which supports H1c.

The results (model 4) show that the regulatory, incentive, and publicity policies have played significant roles in the reduction of chemical fertilizers. Their regression coefficients are 0.689, 1.564, and 2.477, respectively, indicating that publicity policy has had the strongest effects, which may have been the result of having more channels of information, which stoked the farmers' enthusiasm for reduction, which supports H1.

Finally, the results of the interaction variables (see model 5) show significant positive effects with their coefficients being 0.600, 1.214, 2.302, and 0.464, respectively. The interactions between any two kinds of policies have not been significant, whereas those among all have been significantly positive, thus supporting H2. We can conclude that only the implementation of all three policies simultaneously could produce the optimal effects.

Of the control variables (model 5), family income and the scale of cultivated land have had significant positive effects, indicating that farmers with higher family incomes or larger scales of farmland were more likely to reduce. Therefore, the appropriate expansion of the scale of farmland has been an effective way to encourage reduction among farmers with high degrees of risk aversion. The influence of age is significant and negative, indicating that older farmers were less willing to reduce. The influences of gender, political affiliation, agricultural labor force, and level of education are not significant.

5.2 Robustness check

The propensity score matching method (PSM) can effectively reduce the sample selection bias and endogenous problems caused by various reasons (Wang and Li, 2017). Here, this method is used to conduct a robustness test on the effect of policy incentives on farmers' fertilizer reduction behavior.

5.2.1 Propensity score matching method matching results

This part matches the sample data of the three policies respectively. In this process, there may be a certain degree of sample loss. Table 3 lists the matching results of the sample data in this paper. It can be seen from the results that in the matching of the three policies, there are different numbers of sample losses, but they are all within the acceptable range, and the matching results of the three policies are better.

5.2.2 Balancing test

Before PSM estimation, it is necessary to check the balance of samples. As shown in Table 4, after PSM matching, the mean

TABLE 5 Test results of policy incentives.

	Regulatory policy	Regulatory policy	Regulatory policy
ATT	0.163***	0.243***	0.407***
	(0.047)	(0.055)	(0.047)
ATU	0.195***	0.236***	0.367***
	(0.041)	(0.038)	(0.039)
ATE	0.177***	0.239***	0.392***
	(0.037)	(0.037)	(0.039)

***Indicates the significance level of 1%.
**Indicates the significance level of 5%.
*Indicates the significance level of 10%, and the median in brackets is the standard error.
The matching method is k nearest neighbor (let k = 4).

TABLE 6 Empirical results of the moderating effect of risk attitude.

Variable	Regulatory policy		Incentive policy		Publicity policy	
	Coefficient	St. Dev	Coefficient	St. Dev	Coefficient	St. Dev
Regulatory policy	3.027***	1.131				
Incentive policy			1.819**	0.912		
Publicity policy					2.355*	1.259
risk attitude	−9.004***	1.400	−7.628***	1.267	−9.844***	1.499
Regulatory policy * risk attitude	−7.264***	2.067				
Incentive policy * risk attitude			−5.992***	2.775		
Publicity policy * risk attitude					−8.637***	2.335
Level of education	−0.024	0.020	−0.019	0.020	−0.04	0.025
Gender	0.001	0.203	0.006	0.204	0.069	0.226
Age	−0.026***	0.009	−0.014	0.009	−0.040***	0.009
Political identity	0.728**	0.346	0.728**	0.343	0.538	0.390
Household income	0.037**	0.017	0.036**	0.017	0.066***	0.018
Agricultural labor force	−0.022	0.125	0.053	0.129	0.06	0.134
Scale of cultivated land	0.007**	0.003	0.006**	0.003	0.012***	0.003
Regional dummy variable	Controlled		Controlled		Controlled	
Constant term	6.936***	1.019	5.474***	0.935	7.133***	1.051
Chi^2	117.246***		122.49***		225.775***	
−2 log likelihood value	676.726		671.481		567.668	
Prob > chi^2	0.000		0.000		0.000	

value of sample deviation of the three policies decreased significantly, all lower than 10%, and the pseudo R2, LR chi2 and B values decreased in varying degrees. At the same time, Figure 2 further shows that the sample matching effect is good and PSM estimation can be carried out.

5.2.3 Propensity score matching method estimation of policy effect

The estimated result of policy incentive effect is obtained by nearest neighbor matching. Results as shown in Table 5, ATT, ATU, and ATE in the three policy models passed the significance test of 1%. The ATT value in the Regulatory policy is 0.163, which means that when the command control is carried out, the possibility for farmers to choose the alternative behavior of fertilizer reduction is increased by 16.3%; Similarly, according to the ATT values in the other two models, compared with the absence of economic incentives, the possibility of farmers' choice of fertilizer reduction substitution behavior increased by 24.3%, while compared with the absence of publicity and guidance, the possibility of farmers' choice of fertilizer reduction substitution behavior increased by 40.7%. It is consistent with the previous conclusion in terms of the significance of variables and the degree of influence, which proves that the conclusion is robust.

TABLE 7 The influence of policies on intermediary variables.

Variable	Regulatory policy		Incentive policy		Publicity policy	
	Coefficient	St. Dev	Coefficient	St. Dev	Coefficient	St. Dev
Regulatory policy	0.440***	0.162				
Incentive policy			0.508***	0.146		
Publicity policy					0.745*	0.425
risk attitude	−1.954***	0.562	−1.756***	0.519	−2.544***	0.603
Regulatory policy * risk attitude	1.703**	0.758				
Incentive policy * risk attitude			1.494*	0.844		
Publicity policy * risk attitude					2.573***	0.784
Constant term	3.523***	0.383	3.474***	0.372	3.876***	0.384
Control variables	Controlled		Controlled		Controlled	
Number of observations	733		733		733	
Adjusted R^2	0.078		0.048		0.078	
p value	0.000		0.000		0.000	

TABLE 8 Effects of policies and mediating variables on farmers' reduction of chemical fertilizer.

Variable	Regulatory policy		Incentive policy		Publicity policy	
	Coefficient	St. Dev	Coefficient	St. Dev	Coefficient	St. Dev
Regulatory policy	3.034**	1.238				
Incentive policy			1.294*	0.745		
Publicity policy					1.795*	0.695
Income expectation	1.216***	0.123	1.232***	0.123	1.183***	0.133
risk attitude	−8.471***	1.541	−7.070***	1.416	−9.135***	1.642
Regulatory policy * risk attitude	−6.584***	2.265				
Incentive policy * risk attitude			−4.868*	2.823		
Publicity policy * risk attitude					−7.274***	2.583
Level of education	−0.046	0.028	−0.037	0.027	−0.062	0.035
Gender	−0.192	0.231	−0.22	0.236	−0.153	0.254
Age	−0.030***	0.010	−0.019*	0.010	−0.042***	0.011
Political identity	0.987**	0.393	1.033***	0.396	0.667	0.424
Household income	0.029	0.019	0.017	0.019	0.053***	0.018
Agricultural labor force	−0.045	0.142	0.007	0.147	−0.006	0.149
Scale of cultivated land	0.007**	0.003	−0.005	0.003	−0.011***	0.003
Regional dummy variable	Controlled		Controlled		Controlled	
Constant term	3.983***	1.125	2.443**	1.054	4.148***	1.182
Chi^2	250.928***		263.151***		328.719***	
−2 log likelihood value	543.043		530.820		464.735	
Prob > chi^2	0.000		0.000		0.000	

TABLE 9 Mediating effect of policies on farmers' reduction of chemical fertilizer and its bootstrap test.

	Mediator	Intermediary effect	BootSE	LLCI	ULCI	Relative effect value (%)
Regulatory policy	Income expectation	0.5876	0.1312	0.357	0.877	51.21
Incentive policy		0.3666	0.1263	0.121	0.6282	21.28
Publicity policy		0.7667	0.1435	0.5079	1.0669	27.14

5.3 Moderating effects of risk attitudes

Because of the complexity of the interaction effects of the different policies, our analysis of the moderating effects of risk attitudes did not include the interaction variables. Table 6 shows the results of the moderating effects of risk attitudes on different types of policies.

The effects of risk attitudes on the reduction of chemical fertilizers are significantly negative. With the other factors controlled, the results show that farmers were more likely to reduce when their degrees of risk aversion were low. The interaction variables of risk attitudes and each kind of policy are significantly negative. The regression coefficients for the regulatory, incentive, and publicity policies are −7.264, −5.992, and −8.637, respectively, indicating that risk attitude has had significant negative moderating effects on all three. The higher the degree of risk aversion, the weaker were the effects of the policies on reduction, which supports H3.

5.4 Intermediary effects of policies on chemical fertilizer reduction

Table 7 reports the estimated results of the effects of the policies on income expectations. All three kinds of policies have had significant positive effects, suggesting the prerequisite to test the intermediary effects. Table 8 reports the effects of the policies and mediating variables on reduction. The regulatory, incentive, and publicity policies pass the significance test at the levels of 5%, 10%, and 10%, respectively, which also supports H1. In addition, the effects of income expectations passed the significance test at the level of 1%.

According to the above results, the policies have had significant effects on the intermediary variable and the effects of income expectations have also been significant, which verifies the indirect causal chain by which policies have affected reduction through income expectations, whose significant mediating role supports H4.

The bootstrap method was used to replace the stepwise regression method to verify the robustness of our conclusion. By judging whether the confidence interval contains 0, we can test the intermediary effect of income expectation. When the upper (ULCI) and lower bounds (LLCI) do not contain 0, it indicates that the mediation effect has passed the test. The results in Table 9 show that in the three types of policy models, there is no 0 between the ULCI and LLCI, and the mediating effects of income expectation on the three types of policy models have been significant, which is the same as the results of the stepwise test and further supports H4.

6 Conclusion and recommendations

6.1 Conclusion

1) The effects of regulatory, incentive, and publicity policies on the reduction of chemical fertilizer usage are significantly positive. According to the control variables, total household income and cultivated scale have had significant positive effects on reduction, whereas age has had significant negative effects. The interaction variables indicate that the three policies applied in combination have had significant positive effects on reduction, thus indicating complementarity among different types of policies.
2) Risk attitudes negatively moderate the relationships between the policies and reduction. The interaction variables for the policies and risk attitudes have had significant negative effects on reduction, indicating that higher degrees of risk aversion have weakened the effects of the policies on reduction.
3) The internal mechanism by which the policies affect reduction is their positive effects on the farmers' income expectations. A moderated mediation model showed that risk attitudes have negatively moderated the mediating effects of income expectation. Farmers with higher degrees of risk aversion had lower income expectations, which weakened the effects of the policy.
4) The bootstrap method showed that policies have encouraged farmers to participate in reduction by increasing their income expectations. Therefore, heightening their expectations would help to enhance the positive effects of the policies.

6.2 Recommendations

1) Regulatory, incentive, and publicity policies are indispensable to environmental governance. The government should strengthen regulatory policies, pay more attention to incentive policies, attempt innovations in publicity policies, establish policy coordination mechanisms, and use comprehensive means to encourage the reduction of chemical fertilizer usage.
2) Farmers' risk attitudes have significant negative moderating effects on the effects of policies, so the government should help to reduce the risks faced by farmers in agricultural production while improving their capability for facing the risks that accompany reduced usage of chemical fertilizers. Especially in the context of the current COVID-19 and uncertainty, it is necessary to explore an agricultural insurance system with Chinese characteristics, actively guide farmers to purchase agricultural insurance, and reduce the risk of fertilizer reduction.

3) All three kinds of policies encourage reduction by increasing the farmers' income expectations. Therefore, the government should improve agricultural support to enhance their expectations of eventual higher incomes resulting from their reduced usage of chemical fertilizers.

This study empirically analyzed the effects of different types of policies (regulatory, incentive, and publicity policies), as well as their internal mechanisms and the moderating role of farmers' risk attitudes, on the usage of chemical fertilizers in agricultural production. Although this paper designed a questionnaire for farmers in strict accordance with the research content and model requirements, and conducted field research, due to time and research conditions, this paper failed to obtain a large range of samples. The research area only includes Shandong, Henan, Hubei and Yunnan provinces. The survey and analysis results may not completely reflect the overall situation of farmers' chemical fertilizer reduction behavior in China. The next stage of research plans to increase the number of research areas, increase the total amount of data, and make the research evidence more sufficient and the results more reliable.

Data availability statement

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

Author contributions

YY had the original idea for the study. ZL were responsible for data collecting. YY and ZL carried out the analyses. MH revised and edited the manuscript. All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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