frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 26 October 2022
DOI 10.3389/fenvs.2022.1043434

OPEN ACCESS

EDITED BY
Ghaffar Ali,
Hainan University University, China

REVIEWED BY
Ujang Paman,
Islamic University of Riau, Indonesia
Pengzhi Qi,
Zhejiang Ocean University, China

*CORRESPONDENCE
Guoping He,
hesy1117@sina.cn

SPECIALTY SECTION
This article was submitted to Environmental Economics and Management, a section of the journal Frontiers in Environmental Science

RECEIVED 13 September 2022
ACCEPTED 30 September 2022
PUBLISHED 26 October 2022

CITATION
He G, Feng J and Xiao T (2022), Effect of agricultural subsidies on heterogeneous farmers' fertilizer application intensity and its mediating mechanism: Based on China household finance survey database.
Front. Environ. Sci. 10:1043434.
doi: 10.3389/fenvs.2022.1043434

Effect of agricultural subsidies on heterogeneous farmers' fertilizer application intensity and its mediating mechanism: Based on China household finance survey database

Guoping He[1]*, Jie Feng[1] and Taofen Xiao[2]

[1]School of Economics, Hainan University, Haikou, China, [2]Management school, Hainan University, Haikou, China

Agricultural subsidies have an important effect on the farmer's fertilizer application behavior, but the differences in the effect on different farmers and its mediating mechanism have not been sufficiently studied. Using relevant data from the CFHS database in 2015, this paper focused on the differences in the effect of agricultural subsidies on fertilizer application intensity among farmers with different operation scales and planting structures, as well as the mediating mechanism of the effect of agricultural subsidies on farmers' fertilizer application intensity. It was found that agricultural subsidies in general helped farmers reduce fertilizer application. This finding still held after replacing the explanatory variables. However, the effect of agricultural subsidies on fertilizer application intensity varied significantly across farmers with different operation scales and planting structures. The fertilizer reduction effect of agricultural subsidies was weakened by the increase in the operation scale and the share of food crop cultivation, i.e., the fertilizer reduction effect of agricultural subsidies on smaller farmers and cash crop cultivation was greater relative to larger farmers and food crop cultivation. Farmers' operation scale, planting structure and farm machinery inputs are important mediating variables of the effect of agricultural subsidies on farmers' fertilizer application intensity. The agricultural subsidies played a role in reducing fertilizer application intensity by encouraging farmers to expand their operation scale and increase food crop cultivation, and increased fertilizer application intensity by incentivizing farmers to purchase farm machinery and adopt mechanical farming. Finally, some suggestions were put forward to play the fertilizer reduction effect of agricultural subsidies based on the findings of the study.

KEYWORDS

agricultural subsidies, heterogeneous farmers, fertilizer application intensity, mediating mechanism, CHFS

1 Introduction

Since the 1970's, in order to meet the increase in demand for agricultural products caused by the increase in population, coupled with the backwardness of fertilizer and pesticide application technology and the lack of awareness of the hazards of excessive fertilizer and pesticide application, the amount of fertilizer and pesticide application in China has increased year by year. According to the China Statistical Yearbook, the amount of fertilizer applied in China in 1978 was 8.84 million tons, which reached 54 million tons in 2019, by an increase of more than six times. However, the utilization rate of chemical fertilizers and pesticides was low. China had produced 20% of the world's food with about 7% of the world's arable land, but the use of chemical fertilizers and pesticides was 35% of the global total (Zhang, 2020). In 2017, the utilization rate of chemical fertilizers for the three major food crops of rice, corn and wheat in China was 37.8%, and that of pesticides was 38.8%, while the utilization rate of nitrogen fertilizers and pesticides for food crops in developed countries in Europe and the United States was basically 50% above (Yang et al., 2020). The long-term application of large amounts of chemical fertilizers and pesticides not only increased the cost of agricultural production, brought harmful substances residues to agricultural products that were detrimental to human health, but also imbalanced soil nutrients, decreased fertility and organic matter, led to soil acidification and slabbing, and might eventually lose its farming value (Dou et al., 2016; Liu et al., 2020; Kharbach and Chfadi 2021). In recent years, this situation has attracted the great attention of the Chinese government, which has issued a series of policies and regulations to promote green agricultural development, such as the "Reform Program for Establishing a Green and Ecological Oriented Agricultural Subsidy System," "Opinions on Innovative Institutional Mechanisms to Promote Green Agricultural Development," "Technical Guidelines for Green Agricultural Development (2018–2030)," "The "National Agricultural Green Development Plan for the 14th Five-Year Plan," etc. However, few studies have been conducted so far on the effects of agricultural subsidies on agricultural green development. This paper focuses on the effects of agricultural subsidies on the farmers' fertilizer application intensity.

2 Literature review

With regard to farmers' fertilizer application behavior, in-depth studies have been conducted in the literature so far and found that the characteristics of farm decision makers (household heads), operation and resource characteristics, market environment and agricultural subsidies had important effects on farmers' fertilizer application behavior. Regarding the influence of household head characteristics, most studies found that fertilizer application intensity was higher for male-headed farmers than for females (Gong et al., 2010; Leake, 2015); education level (Han and Zhao, 2009), environmental awareness (Xiang et al., 2021), and risk preference (Lv et al., 2021) had a negative effect on fertilizer application intensity, but the risk preference had a positive impact on fertilizer utilization (Zhu et al., 2022). Xiang et al. (2021) also examined the effect of farmers' perception of fertilizer reduction risk on reduction behavior and found that perception of reduction risk had a negative effect on reduction behavior, which, however, was weakened by environmental awareness. Qiao and Huang (2021), in a study of 306 cotton farmers in China, also found that the risk preference had a negative effect on fertilizer application intensity when the likelihood of fertilizer application achieving the desired effect was high, and a positive effect on fertilizer application intensity when the likelihood of achieving the desired effect was low. Regarding the effect of farmers' operation characteristics on fertilizer application, most studies found that operation scale had a negative effect on fertilizer application intensity (Guo et al., 2018; Wu et al., 2021) and a positive effect on fertilizer utilization efficiency (Zhu et al., 2022). A study by Wu et al. (2021) on data from fixed observation sites in rural China found that expanding the operation scale by land transfer had a significantly negative effect on food crop cultivation and farmers' fertilizer application intensity in northwest of China. However, Leake's (2015) study of 160 smallholder farmers in Ethiopia found that the operation scale had a positive effect on fertilizer application intensity. The existing studies have also examined the effects of organic fertilizer application, fertilization by soil testing, agricultural mechanization, and product certification on fertilizer application, and found that the organic fertilizer application (Wang et al., 2018) and fertilization by soil testing (Su and Wang, 2014) reduced fertilizer application intensity; the product certification increased farmers' willingness to reduce fertilizer application (Tang, 2019); but the agricultural mechanization increased fertilizer application intensity (Wu et al., 2021).

Regarding the effect of farmers' resource characteristics on fertilizer application, Li and Zeng (2022) examined the effect of land tenure stability on fertilizer reduction behavior in land leases using survey data from 414 large-scale grain farmers in Anhui Province, China, and found that lease term had a positive effect on fertilizer reduction behavior; default had a negative effect on fertilizer reduction behavior. Zhu et al. (2022), using data from a Chinese household financial survey, found that farmers who leased land had relatively low fertilizer utilization rates; irrigation conditions and land quality had positive effects on the fertilizer utilization efficiency. More studies have also examined the effects of farm labor resources and off-farm employment on fertilizer application intensity. Yang et al. (2021) found that the number of farm laborers had a negative effect on fertilizer application intensity, but Zhu et al. (2022) proposed that for maize farmers, fertilizer utilization tended to decrease as labor increased. Many studies have acknowledged that off-farm employment increased the fertilizer application intensity (He et al., 2006; Han and Zhao 2009; Eba and Bashargo 2014; Ma et al., 2018). However, some studies have also found that the off-farm employment reduced fertilizer application intensity by enhancing farmers' capability to access and adopt green production technologies (Grunt et al., 2022). Zhang et al. (2020), using prefecture-level cities in Sichuan and Henan provinces in China as study objectives, found that the effect of off-farm employment of rural labors on fertilizer application intensity in mountainous areas showed an inverted "U"-shaped relationship; in the plain areas there was a positive effect. Some literature has also examined the effects of farming experience and information resources on fertilizer application. For example, a study by Lv et al. (2021) on survey data from 741 maize farmers in three northeast provinces of China found that farmers' social network resources had a negative effect on the fertilizer application intensity. However, a study by Eba and Bashargo (2014) on survey data from 350 farmers in Ethiopia found that farming experience and information resources had a positive effect on the fertilizer application intensity.

Regarding the effect of market environment on farmers' fertilizer application, Leake (2015) found that fertilizer price and market distance had a negative effect on fertilizer application intensity, but credit facilitation increased fertilizer application intensity. Zhu et al. (2022) noted that the use of online banking increased fertilizer use efficiency. Wu and Ge (2019), through a study of 516 wheat farmers in Shaanxi Province, China, found that technical guidance was beneficial in reducing fertilizer application intensity, but He et al. (2006) suggested that agronomic training increased fertilizer application intensity, probably because most agronomic training was organized by fertilizer suppliers for promotional purposes.

Regarding the effect of agricultural subsidies on fertilizer application, some studies have found that agricultural subsidies were beneficial in reducing fertilizer application (Wu and Ge, 2019; Guo et al., 2021; Yang et al., 2021; Zhang et al., 2021). Some studies also proposed that agricultural subsidies (Yang and Qiao, 2018), comprehensive agricultural subsidies (Yu et al., 2017), agricultural insurance (Luo et al., 2016; Niu et al., 2022); and four agricultural subsidies (good seed subsidies, direct agricultural subsidies, agricultural machinery purchase subsidies, and comprehensive agricultural subsidies) (Wu and Miao, 2017) increased farmers' fertilizer application. Zuo and Fu (2021) also argued that formula fertilizer subsidies reduced farmers' fertilizer productivity and environmental efficiency of fertilizers.

The existing studies have also examined the mechanisms by which agricultural subsidies acted on fertilizer application and the differences in their effects on heterogeneous farmers. For example, Guo et al. (2021) found that subsidies for rice cultivation reduced the intensity of fertilizer application by promoting the use of farm machinery and expanding the scale of operation, and that this effect was reinforced by farming experience, but field management and off-farm labor capacity weakened this effect. Hou et al. (2016) proposed that agricultural subsidies significantly reduced fertilizer application by maize farmers, but had no significant effect on fertilizer application by wheat and japonica rice farmers. Zhang et al. (2021) indicated that the fertilizer reduction effect due to agricultural subsidies was small when the proportion of food crops grown was less than 74.68%. Yang et al. (2021) found that the fertilizer reduction effect of agricultural subsidies was positively related to the degree of part-time farming. A study by Cui and Liu (2022) on 402 citrus growers in China showed that the government's services and subsidies for green agriculture had a significant incentive effect on farmers' chemical fertilizer reduction behavior, and the effect was greater for larger farmers; the stronger the awareness of green agriculture among farmers' neighbors, the greater this effect would be. Niu et al. (2022) argued that policy agricultural insurance pilots exacerbated fertilizer surface source pollution in China, and this effect was relatively more pronounced in eastern and high disaster areas.

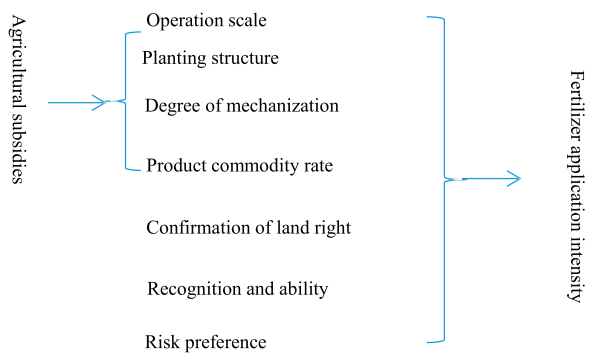

FIGURE 1
Mechanism of agricultural subsidies' effects on farmers' fertilizer application intensity.

Although a rich literature has been conducted on the effects of agricultural subsidies on farmers' fertilizer application, the differences in the effects of agricultural subsidies on the fertilizer application intensity by heterogeneous farmers and the mediating mechanisms have not been sufficiently studied. Based on the existing literature, this paper used the survey data from China Household Finance Investigation and Research Center in 2015 to further investigate the differences and mechanism of the effects of agricultural subsidies on fertilizer application intensity of different farmers. The innovation of this paper is mainly reflected in the expansion of the research on the impact of agricultural subsidies on farmers' chemical fertilizer application and the specific is as follows. Firstly, this paper examined the differences in the impact of agricultural subsidies on the fertilizer application intensity of farmers with different business scales and different planting structures. Secondly, this study analyzed the mediating mechanisms of the impacts of agricultural subsidies on the fertilizer application intensity of farmers. Besides, it provided a reference for improving the agricultural subsidy policy and giving better play to the fertilizer reduction effect of agricultural subsidies.

3 Theoretical analysis and research hypothesis

As shown in Figure 1, according to the literature and experience, the main factors affecting the farmers' fertilizer application intensity include operation scale, planting structure, and farming method (mechanization degree). Agricultural subsidies may influence the farmers' fertilizer application intensity through these factors.

First, depending on the scale benefits of adopting fertilizer reduction technologies (e.g., fertilization by soil testing) (Mao and Cao, 2020), the scale of farmer operations may be conducive to reducing fertilizer application intensity, i.e., fertilizer application intensity may be relatively lower for farmers with larger operations (Guo et al., 2018; Wu et al., 2019). In contrast, agricultural subsidies, especially for large-scale operations, will motivate farmers to expand their operation scale (Wu and Miao, 2017), which may have a positive effect on reducing fertilizer application (Guo et al., 2021).

Second, the optimal fertilizer application intensity varies among crops, and thus the planting structure of farmers may have an important effect on fertilizer application intensity (Zhang et al., 2021). In addition, special subsidies for some crops cultivation, such as subsidies for food crops cultivation may incentivize farmers to increase food crops cultivation and thus have an effect on fertilizer application intensity (Guo et al., 2021).

Third, in general, fertilizer application intensity may be lower with more refined traditional farming compared to mechanical farming, and thus the degree of mechanization of farming may have an important effect on farmers' fertilizer application intensity. In contrast, agricultural subsidies, especially subsidies for farm machinery purchases, will encourage farmers to purchase farm machinery and adopt mechanized tillage, thus having an impact on fertilizer application intensity (Guo et al., 2021).

Fourth, product commodity rate, land property right, perception of fertilizer application by farmer decision makers, and risk preference may also have important effects on the farmers' fertilizer application intensity. For the profit maximization of commodity producers, the intensity of fertilizer application may be higher for commodity producers than for farmers whose products are used for their own consumption in order to achieve more output. Thus, fertilizer application intensity may be relatively higher for farmers with higher product commodity rates. Longer and more frequent fertilizer application will damage the long-term productivity of land, and farmers are more concerned about the long-term productivity of their own land than leased land and are more likely to adopt conservation techniques on their own land, such as applying farmyard manure and organic fertilizers, returning straw to the field, etc. (Lu et al., 2022) and thus fertilizer application intensity may be relatively lower on their own land. Similarly, farmers are more concerned about the long-term productivity of land that has been titled than land that has not yet (Zou et al., 2020), and fertilizer application intensity on titled land may be relatively lower (Ma, 2009; Fort, 2008). Therefore, property rights may be an important factor influencing the fertilizer application intensity by farmers. The fertilizer application intensity by farmers is also necessarily related to their knowledge and ability to apply fertilizer. If a farmer is more aware of the hazards of applying more fertilizer over a longer period of time and has a greater ability to learn (fertilizer reduction technologies), then he is more likely to reduce fertilizer application. If a farmer is experienced in fertilizer application, then the intensity of fertilizer application is likely to be relatively low. Reducing fertilizer application may cause the risk of yield reduction, and thus farmers' risk preference may have an impact on fertilizer application intensity (Qiao and Huang, 2021). Risk lovers are more likely to adopt fertilizer reduction technologies to reduce fertilizer application intensity compared to risk-averse (Luan and Qiu, 2013; Chen et al., 2019).

Based on the above analysis, the following hypothesis can be formulated: agricultural subsidies occur on the farmers' fertilizer application intensity mainly by affecting the scale of operation, planting structure, and mechanization; this effect varies significantly for heterogeneous farmers.

4 Empirical analysis of the effects of agricultural subsidies on the farmers' fertilizer application intensity

4.1 Data source

The data used in this article are derived from the data of China Household Finance Survey Database (CHFS) in 2015. CHFS is a sample survey project carried out by the China Household Finance Survey and Research Center across China. At present, five surveys have been carried out in 2011, 2013, 2015, 2017, and 2019. However, since 2017 and 2019 did not involve the application of chemical fertilizers by farmers, this paper selected the data of 2015. The survey content of CHFS 2015 covered all the information required for this study, with a sample size of 37,289 farmers. To meet the needs of this study, the samples were screened and cleaned up. Because the focus of

TABLE 1 Variable description and statistical characteristics.

Variable	Value	Percent	Mean	Std. Dev	Min	Max
fertil	¥/Hectare		6,175.39	41323.26	0.75	2571441.00
subm	¥		620.58	2073.74	0.00	100 000.00
sub	Yes = 1	80.30				
	No = 0	19.70				
age	years		54.39	10.88	21.00	90.00
edu	Unedu = 1	7.76				
	Primary = 2	37.22				
	Junior = 3	40.88				
	H.S. or STS = 4	12.66				
	College or above = 5	1.48				
risk	averse = 1	77.11				
	neutral = 2	15.44				
	preference = 3	7.45				
scale	Hectare		0.89	3.10	0.0067	120.00
stru	%		86.65	26.70	0.00	100.00
RC	%		55.44	40.51	0.00	100.00
transfer	Yes = 1	21.42				
	No = 0	78.58				
RL	Yes = 1	46.88				
	Yes = 0	53.12				
arevenue	¥		11132.50	17353.23	8.00	581845.00
machine	¥		4,299.83	24663.06	0.00	1000000.00

this paper is the application of chemical fertilizers by farmers, this paper only retains samples of farmers engaged in planting. Meanwhile, samples with missing values for other variables that need to be used in this paper are excluded. Finally, a total of 4,202 valid farmer samples were obtained. These samples covered a wide range of most provinces in China, including 29 provinces (autonomous regions and municipalities) and 162 counties (districts and county-level cities), so these samples can ensure the reliability of research conclusions. Besides, 80.30% of the farmers in these samples received agricultural subsidies.

4.2 Variable selection

As in Table 1, the explained variable is farmers' fertilizer application intensity (*fertil*), measured by fertilizer input per unit area (RMB/ha.). The mean value of fertilizer application intensity in the samples is RMB 6,175.39/ha, the maximum value is RMB 2,571,441.00/ha, and the minimum value is RMB 0.75/ha.

The explanatory variable is agricultural subsidies received by farmers (*subm*). The mean value of agricultural subsidies in the samples is RMB 620.58, the maximum value is RMB 100,000.00, and the minimum value is RMB 0.

The control variables include household head characteristics, farmer operation characteristics, and farmer resource characteristics.

(1) Household head characteristics: Household head characteristics include *age*, education level (*edu*), risk preference (*risk*, risk aversion = 1; risk neutral = 2; risk loving = 3)[1]. Among them, age and education level mainly reflect the cognitive ability of farmers. The mean age of household heads in the samples is about 54 years old, with the youngest being 21 years old and the oldest 90 years old. The education level is mainly primary and junior high school, accounting for 37.22% and 40.88% of the total sample size, respectively; followed by those who have not attended school, accounting for 7.76%; those have attended high school and junior high school education, accounting for

1 In the 2015 Household Financial Tracking Survey questionnaire, a question was designed to examine respondents' risk preference: if you had a sum of money to invest, which investment item would you most prefer? If the respondent chose to invest in a low-risk item, the farmer was defined as risk averse; if the respondent chose to invest in an item with average risk, the farmer was defined as risk neutral; if the respondent chose to invest in a high-risk item, the farmer was defined as a risk lover.

12.66%; and those with college education and above, accounting for 1.48%. Among the sample farmers, 77.11% is risk averse; 15.44% is risk neutral; and 7.45% is risk loving.

(2) Farmers' operation characteristics: Farmers' operation characteristics include three variables, namely operation scale (*scale*), planting structure (*stru*), and commodity rate (RC). The operation scale is reflected by crop cultivation area (ha.). The average household operation scale in the samples is about 0.89 ha, the smallest is 0.0067 ha, and the largest is 120.00 ha. The planting structure is reflected by the share of food crop output value in household agricultural output value, with a mean value of 86.65%, a minimum value of 0%, and a maximum value of 100%. The commodity rate, reflected by the proportion of sales revenue of agricultural products to the output value of agricultural products, has a mean value of 55.44%, a minimum value of 0%, and a maximum value of 100%.

(3) Farmers' resource characteristics: Farmers' resource characteristics include the property right characteristics of the land operated by farmers, annual per capita household income (Arevenue), and farm machinery inputs (*machine*, a substitution variable for the degree of mechanization of farming). Among them, the property right characteristics of the land operated by farmers is reflected by whether the land right is confirmed (RL. Yes = 1; No = 0) and whether the land is transferred into (transfer. Yes = 1; No = 0). The percentage of farmers whose land has been titled in the samples is 46.88%. The percentage of farmers who had transferred into their land management rights is 21.42%. The average annual per capita income of the sample farmers is RMB 11,132.50, the minimum value is RMB 8.00, and the maximum value is RMB 581845.00. 66.78% of the farmers have an annual per capita income lower than the average value. The farm machinery inputs is reflected by the value of farm machinery owned. The mean value of owning farm machinery is RMB 4299.83, the minimum value is RMB 0, and the maximum value is RMB 1,000,000.00.

4.3 Model setting

To examine the effects of agricultural subsidies on the farmers' fertilizer application intensity, the following econometric model was set up based on the previous theoretical analysis.

$$ln\ (fertil_i) = \alpha_i + \beta_i ln\ (subm_i) + \gamma_i X_i + \mu_i \quad (1)$$

In model (1), $fertil_i$ denotes the fertilizer application intensity of the ith farmer; $subm_i$ denotes the amount of agricultural subsidies received by the ith farmer; X_i is a set of control variables; and μ_i is a random disturbance term. Since there are anomalous observations for the variables of fertilizer application intensity (*fertil*), agricultural subsidies (*subm*), scale of operation (*scale*), per capita income (*Arevenue*), and value of farm machinery owned (*machine*), these variables are taken as logarithms in the model (NOTE: since there are zero values for the variables of *subm* and *machine* in the sample, these two variables are added by 1 and then logged).

TABLE 2 Baseline regression and robustness test.

	Baseline regression	Robustness test
ln(subm)	−0.019*** (−2.844)	
sub		−0.031* (−1.723)
age	−0.001* (−1.723)	−0.001* (−1.781)
edu	−0.003 (−0.320)	−0.003 (−0.385)
risk	−0.023** (−2.046)	−0.023** (−2.049)
ln(scale)	−0.038** (−2.021)	−0.046** (−2.476)
stru	−0.001*** (−2.823)	−0.001***(−2.867)
RC	0.001*** (5.935)	0.001*** (5.796)
RL	−0.018 (−1.303)	−0.018 (−1.327)
transfer	0.213*** (11.075)	0.213*** (11.091)
ln(Arevenue)	−0.010* (−1.658)	−0.010* (−1.676)
ln(machine)	0.008*** (4.259)	0.008*** (4.126)
_cons	3.658*** (45.158)	3.648*** (45.002)
N	4,202	4,202
Prob> chi2	0.000	0.000
R^2	0.064	0.062

Note: ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively.

4.4 Baseline regression and robustness test

4.4.1 Baseline regression

As in the first column of Table 2, agricultural subsidies have a significant negative effect on the farmers' fertilizer application intensity. Each 1% increase in agricultural subsidies reduces the farmers' fertilizer application intensity by 0.019% on average at the 1% significance level.

The control variables affect the farmers' fertilizer application intensity. First, the effect of household head characteristics. The age of the household head has a negative effect on the farmers' fertilizer application intensity at 10% significance. This may be because generally, the older the age, the more experienced the fertilizer application is and the more accurate the fertilizer application is (Shi et al., 2015). There is also a negative but non-significant effect of education level on farmers' fertilizer application intensity. This may be due to the fact that more educated farmers are more inclined to non-farm employment and thus do not pay enough attention to agricultural production and precision fertilizer application. Farmers' risk preference has a negative effect on fertilizer application intensity at the 5%

significant level, i.e., the more risk appetite farmers are, the lower the fertilizer application intensity is, which is consistent with the previous theoretical analysis.

Second, the effect of farmers' operation characteristics. The scale of operation has a negative effect on the farmers' fertilizer application intensity at the 5% significance level, which is consistent with the previous theoretical analysis and with the conclusion reached by Zhang and Luo (2020). Planting structure (the share of food crop output value in household agricultural output value) has a negative effect on fertilizer application intensity at the 1% significance level. For each 1% increase in the share of food crop output value, the farmers' fertilizer application intensity decreases by 0.1% on average. This indicates that overall fertilizer application intensity is higher for cash crop cultivation than for food crop cultivation. This is confirmed by statistical analysis of the sample (the mean value of fertilizer input intensity is RMB 5704.43/ha for farmers who mainly grow food crops, while the mean value of fertilizer input intensity is RMB 9554.59/ha for farmers who mainly grow cash crops). The commodity rate of farmers' production has a positive effect on fertilizer application intensity at the 1% significance level. Each 1% increase in commodity rate increases the fertilizer application intensity by 0.1% on average, which is consistent with the previous theoretical analysis.

Third, the effect of farmers' resource characteristics. Confirmation of land right has a negative but non-significant effect on the farmers' fertilizer application intensity. Whether farmers transfer into farmland has a positive effect on the fertilizer application intensity of farmers at the 1% significance level. Compared with the farmers who manage their own land, the fertilizer application intensity of the farmers who have transferred into the land management rights increased by 21.3% on average, which is consistent with the previous theoretical analysis. Annual per capita household income has a negative effect on fertilizer application intensity at 10% significance. For each 1% increase in household per capita income, fertilizer application intensity decreases by 0.01% on average. This may be due to the increased environmental awareness and ability to invest in green production (e.g., replacing chemical fertilizers with organic fertilizers; adopting environmentally friendly fertilizer application methods such as fertilization by soil testing) as the income of farmers increases. The value of owning farm machinery (farm machinery inputs) has a positive effect on fertilizer application intensity at 1% significance level. For each 1% increase in the value of farm machinery owned, fertilizer application intensity increases by 0.008%. This may be due to the fact that more farm machinery inputs imply more mechanization of farming, which is more extensive compared to traditional farming, resulting in more fertilizer application.

TABLE 3 Effect of agricultural subsidies on fertilizer application intensity: heterogeneity analysis.

	(1)	(2)
ln(subm)	−0.019*** (−2.905)	−0.018*** (−2.667)
ln(scale)	−0.036* (−1.908)	
[ln(subm)-mean$_s$]#		
[ln(scale)-mean$_c$]	0.025** (2.029)	
stru		−0.001** (−2.546)
[ln(subm)-mean$_s$]#(stru-mean$_t$)		0.001*** (2.736)
Control variable	Control	Control
_cons	3.663*** (45.199)	3.645*** (45.037)
N	4,202	4,202
Prob> chi2	0.000	0.000
R^2	0.065	0.066

Note: ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively.

4.4.2 Robustness test

The model may have some endogenous problems that cause the results to be unrobust. In this paper, the dummy variable of whether farmers received agricultural subsidies *sub* (for receiving subsidies, $sub = 1$; otherwise, $sub = 0$) was used to replace the continuous variable of agricultural subsidy amount (*subm*) for robustness testing (see the second column in Table 2). It was found that agricultural subsidies had a significant negative effect on the farmers' fertilizer application intensity, which was consistent with the results of the baseline regression. The signs, coefficient magnitudes and significance of other variables were also generally consistent with the baseline regression results. Therefore, the estimation results of this paper are robust.

4.5 Heterogeneity analysis and mediating mechanism test

4.5.1 Heterogeneity analysis

This paper examined the differences in the effect of agricultural subsidies on heterogeneous farmers by introducing interaction terms. To avoid multicollinearity, a centering strategy was used for continuous variables. It was found that there was significant interaction effect of agricultural subsidies ln (subm) with operation scale *ln(scale)* and planting structure *stru*. Therefore [*ln(subm)-mean$_s$*]# [*ln(scale)-mean$_c$*] was introduced in Eq. 1 of Table 3; [*ln(subm)-mean$_s$*]#(*stru-mean$_t$*) was introduced in Eq. 2, where *mean$_s$*, *mean$_c$*, and *mean$_t$* denote means of *ln*(*subm*), *ln(scale)* and *stru*.

In Eq. 1, both agricultural subsidies and scale of operation have a significant negative effect on the farmers' fertilizer application intensity (significance levels of 1% and 10%, respectively). From the interaction term of the two, there is a significant difference in the effect of agricultural subsidies on the farmers' fertilizer application intensity with different operation scales. At the mean level of Ln (scale) (about −0.39, i.e., the operation scale of about 0.68 ha), each 1% increase in agricultural subsidies decreases fertilizer application intensity by 0.019% (1% significance level). The positive coefficient of the interaction term indicates that the fertilizer reduction effect of agricultural subsidies is weakened by the increase in operation size, i.e., the fertilizer reduction effect of agricultural subsidies is greater for farmers with smaller operation scale. This is because the scale of operation itself has a negative effect on the farmers' fertilizer application intensity, i.e., in the absence of agricultural subsidies, the fertilizer application intensity of larger farmers is lower than that of smaller farmers, so that agricultural subsidies have less room to stimulate larger farmers to further reduce their fertilizer application intensity than smaller farmers.

In Eq. 2, both agricultural subsidies and planting structure have a significant negative effect on fertilizer application intensity (significance level of 1% and 5%, respectively). From the interaction term of the two, there is a significant difference in the effect of agricultural subsidies on the farmers' fertilizer application intensity with different planting structures. At the mean value of the share of food crop output (about 86.65%), each 1% increase in agricultural subsidies decreases fertilizer application intensity by 0.018%. The coefficient of the interaction term is positive, indicating that the increase in the share of food crop output diminishes the fertilizer reduction effect of agricultural subsidies. That is, the fertilizer reduction effect of agricultural subsidies on cash crop cultivation is more significant relative to food crop cultivation. This is because, as mentioned earlier, the overall fertilizer application intensity of cash crops is higher than that of food crops (Zhang et al., 2021), and thus there is more room for agricultural subsidies to reduce the fertilizer application intensity of cash crops than that of food crops.

4.5.2 Mediating mechanism test

As mentioned earlier, the operation scale, planting structure and the degree of mechanized farming (substituted by farm machinery inputs) may be important mediating variables for agricultural subsidies to affect the farmers' fertilizer application intensity. The three-step approach of Baron & Kenny (1986) is used below to test the mediating effect of these variables, and the specific model is as follows.

Step 1. test the effect of agricultural subsidies on fertilizer application intensity.

$$ln\ (fertil_i) = \beta_0 + \beta_1\, ln\ (subm_i) + \beta_2 X_i + \mu_i \tag{2}$$

Step 2. examine the impact of agricultural subsidies on the operation scale, planting structure and farm machinery inputs.

$$ln\ (scale_i) = \alpha_0 + \alpha_1\, ln\ (subm_i) + \alpha_2 X_i + \mu_i \tag{3}$$

$$stru_i = \alpha_0 + \alpha_1\, ln(subm_i) + \alpha_2 X_i + \mu_i \tag{4}$$

$$ln\ (machine_i) = \alpha_0 + \alpha_1\, ln\ (subm_i) + \alpha_2 X_i + \mu_i \tag{5}$$

Step 3. examine the mediating effect of the operation scale, planting structure and farm machinery inputs in the influence of agricultural subsidies on the farmers' fertilizer application intensity.

$$ln\ (fertil_i) = \theta_0 + \theta_1\, ln\ (subm_i) + \theta_2 ln\ (scale_i) + \theta_3 X_i + \mu_i \tag{6}$$

$$ln\ (fertil_i) = \theta_0 + \theta_1\, ln\ (subm_i) + \theta_2 stru_i + \theta_3 X_i + \mu_i \tag{7}$$

$$ln\ (fertil_i) = \theta_0 + \theta_1\, ln\ (subm_i) + \theta_2 ln\ (machine_i) + \theta_3 X_i + \mu_i \tag{8}$$

where $scale_i$, $stru_i$, and $machine_i$ denote operation scale, planting structure, and farm machinery inputs, respectively, and μ_i is random disturbance terms.

The estimation results are shown in Tables 4,5,6. First, the mediating effect of farmer operation scale is shown in Table 4. Column 1) is the first step. The results show that agricultural subsidies reduce the farmers' fertilizer application intensity at the 1% significance level. Column 2) tests the effect of agricultural subsidies on farmer operation scale. The results show that agricultural subsidies promote farmers to expand their business scale at the 1% significance level. Column 3) includes both agricultural subsidies and operation scale in the regression equation. According to the results, it is found that operation scale has a negative effect on farmers' fertilizer application intensity at the 1% significance level. However, the coefficient of agricultural subsidy becomes larger (from −0.022 to −0.019). This indicates that there is a significant mediating effect of farm scale in the effect of agricultural subsidies on farmers' fertilizer application intensity, i.e., agricultural subsidies play a role in reducing farmers' fertilizer application intensity by motivating farmers to expand their operation scale.

Second, the mediating effect of farmer planting structure is shown in Table 5. Column 1) shows that agricultural subsidies reduce the farmers' fertilizer application intensity at the 1% significance level. Column 2) shows that agricultural subsidies increase the share of food crops planted by farmers at the 1% significance level. Column 3) includes both agricultural subsidies and planting structure in the regression equation, and it is found that the intensity of fertilizer application decreases (1% significance level) as the share of food crops grown by farmers increases, but the coefficient of agricultural subsidies becomes larger (from -0.020 to -0.019). This indicates that there is a significant mediating effect of farming structure in the fertilizer application intensity of agricultural subsidies acting on farmers, i.e., agricultural subsidies (subsidies for food crop cultivation) play a role in fertilizer reduction by motivating farmers to increase food crop cultivation.

TABLE 4 Mediating effect of operation scale.

	(1)	(2)	(3)
	fertil	*ln(scale)*	*fertil*
ln(subm)	−0.022*** (−3.345)	0.073*** (11.582)	−0.019*** (−2.844)
ln(scale)			−0.038** (−2.021)
Control variable	Control	Control	Control
_cons	3.714*** (48.553)	−1.458*** (−20.469)	3.658*** (45.158)
N	4,202	4,202	4,202
Prob> chi2	0.000	0.000	0.000
R^2	0.044	0.351	0.064

Note: ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively.

TABLE 5 Mediating effect of planting structure.

	(1)	(2)	(3)
	fertil	*stru*	*fertil*
ln(subm)	−0.020*** (−3.003)	1.276*** (3.117)	−0.019*** (−2.844)
stru			−0.001*** (−2.823)
Control variable	Control	Control	Control
_cons	3.557*** (48.594)	114.946*** (25.319)	3.658*** (45.158)
N	4,202	4,202	4,202
Prob> chi2	0.000	0.000	0.000
R^2	0.044	0.070	0.064

Note: ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively.

TABLE 6 Mediating effect of farm machinery inputs.

	(1)	(2)	(3)
	fertil	*ln(machine)*	*fertil*
ln(subm)	-0.018*** (-2.647)	0.165*** (3.024)	-0.019*** (-2.844)
ln(machine)			0.008*** (4.259)
Control variable	Control	Control	Control
_cons	3.701*** (46.296)	5.455*** (8.469)	3.658*** (45.158)
N	4,202	4,202	4,202
Prob> chi2	0.000	0.000	0.000
R^2	0.059	0.179	0.064

Note: ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively.

Third, the mediating effect of the degree of mechanized farming (substituted by farm machinery inputs) of farmers is shown in Table 6. Column 1) indicates that agricultural subsidies reduce the farmers' fertilizer application intensity at the 1% significance level. Column 2) shows that agricultural subsidies (e.g., agricultural machinery purchase subsidies) have a positive effect on the farm machinery inputs of farmers at the 1% significance level, i.e., agricultural subsidies motivate farmers to purchase farm machinery and promote agricultural mechanization. Column 3) incorporates both agricultural subsidies and the farm machinery inputs into the equation, and it is found that the fertilizer application intensity increases with the increase of farm machinery inputs and mechanization (1% significance level), but the coefficient of agricultural subsidies decreases (from −0.018 to −0.019). This indicates that there is a significant mediating effect of the degree of mechanized farming (reflected by the farm machinery inputs) in the effect of agricultural subsidies on farmers' fertilizer application intensity, i.e., agricultural subsidies increase the farmers' fertilizer application intensity by motivating them to acquire farm machinery and mechanized farming. This suggests that in the process of agricultural mechanization, farmers should be encouraged to cultivate more intensively in order to reduce the fertilizer application intensity.

5 Conclusion and suggestions

Agricultural subsidies have an important effect on farmers' fertilizer application behavior, but the differences in the effect on different farmers and its mediating mechanism have not been sufficiently studied. Using relevant data from the CFHS database in 2015, this paper focused on the differences in the impact of agricultural subsidies on the farmers' fertilizer application intensity with different operation scales and planting structures, and the mediating mechanism of agricultural subsidies acting on the farmers' fertilizer application intensity. According to the results, it was found that the agricultural subsidies in general helped farmers reduce fertilizer application. This finding still held after replacing the subsidy amount (continuous variable) with whether or not the subsidy was received (dummy variable). However, the effect of agricultural subsidies on the farmers' fertilizer application intensity with different operation scales and planting structures differed significantly. The fertilizer reduction effect of agricultural subsidies was weakened by the increase in the scale of operation, i.e., the fertilizer reduction effect of agricultural subsidies was greater for farmers with smaller scale of operation. This might be because in the absence of agricultural subsidies, larger-scale farmers were generally more likely to adopt fertilizer reduction technologies (determined by the economies of scale in adopting fertilizer reduction technologies) than smaller-scale farmers, and fertilizer application intensity was relatively lower, so that agricultural subsidies had less room to stimulate larger-scale farmers to further reduce fertilizer application intensity than smaller-scale farmers. The increase in the share of food crop cultivation weakened the fertilizer reduction effect of agricultural subsidies, i.e., the fertilizer reduction effect of agricultural subsidies on cash crop cultivation was more significant than that on food crop cultivation. This might be because, in general, the fertilizer application intensity of cash crops was higher than that of food crops, and thus there was more room for agricultural subsidies to reduce the fertilizer application intensity of cash crops than that of food crops. The farmers' operation scale, planting structure and farm machinery inputs are important mediating variables for the effect of agricultural subsidies on farmers' fertilizer application intensity. The agricultural subsidies acted to reduce fertilizer application intensity by encouraging farmers to expand the scale of operation and increase the cultivation of food crops, and increased fertilizer application intensity by incentivizing farmers to purchase farm machinery and adopt mechanical farming. This might be due to the fact that farm machinery farming was more extensive compared to traditional farming, resulting in the application of more fertilizer. In addition, farmers' risk preference had a significant negative effect on fertilizer application intensity; age of household head and annual per capita household income also had a negative effect on fertilizer application intensity, but the significance level was low; product commodity rate and land transfer-in had a significant positive effect on fertilizer application intensity.

To promote the reduction of chemical fertilizer application, the following suggestions can be made based on the above research findings.

First, increase agricultural subsidies and adjust the subsidy structure. Increase the proportion of subsidies for green production behaviors to motivate farmers and other agricultural producers to return straw to the fields, plant green manure crops, replace chemical fertilizers with organic fertilizers, and actively adopt efficient and environmentally friendly fertilization methods such as soil testing to determine formula fertilization, water and fertilizer integration, side-deep fertilization, foliar fertilization, and cropland rotation and compound planting that are conducive to chemical fertilizer reduction and efficiency increase. In addition, in the government funds to support agriculture, it should increase the investment in green agricultural research and development such as fertilizer and pesticide reduction and efficiency increase, and provide more technical support for fertilizer reduction and efficiency increase.

Second, pay attention to the fertilizer reduction effect of agricultural subsidies on small farmers. Support agricultural service enterprises, farmers' cooperatives and rural collective economic organizations to carry out fertilizer reduction technical services, direct advanced and applicable fertilizer reduction technologies and farming methods to small farmers, and motivate small farmers to replace chemical fertilizers with organic fertilizers and adopt fertilizer reduction technologies and farming methods through subsidies, so as to give full play to the fertilizer reduction effect of agricultural subsidies on small farmers.

Third, promote the transfer of agricultural land and moderate scale operation to give full play to the positive effect of operation scale on chemical fertilizer reduction. Improve the rural land transfer market, strengthen transfer services, continuously explore and enrich rural land transfer methods, provide moderate subsidies for rural land transfer, and promote agricultural land transfer and moderate operation scale; strengthen the protection of land rights, encourage longer-term transfers, and enhance the incentives for farmers and other land operators who carry out large-scale operations through inflow of land to protect the long-term productivity of land and reduce fertilizer application.

Fourth, reduce fertilizer application by adjusting planting structure, incentives and constraints in both directions. The research in this paper shows that different types of crops have different fertilizer application rates and agricultural subsidies have different fertilizer reduction effects on different types of crops. Therefore, in order to exert the fertilizer reduction effect of agricultural subsidies, the following two measures can be taken: first, to use agricultural structure adjustment subsidies to encourage agricultural producers to reduce the cultivation of high fertilizer-consuming crops and increase the cultivation of low fertilizer-consuming crops; second, to adopt a two-way policy of incentive and constraint for the cultivation of high fertilizer-consuming crops. On the one hand, apply green subsidies to stimulate agricultural producers to take the initiative to replace chemical fertilizers with organic fertilizers, the use of chemical fertilizer reduction technology and farming methods to reduce the amount of chemical fertilizers; on the other hand, implement a policy of limited application of chemical fertilizers and pesticides, and decide whether to subsidize and the number of subsidies according to the actual situation of operators to reduce the amount of chemical fertilizers and pesticides. For the farmers with reduction in output caused by the limited application of fertilizers and pesticides, appropriate compensation within the scope of the "green box policy" can be given.

Fifth, link agricultural mechanization subsidies to the reduction of fertilizers and pesticides. This paper shows that in China, agricultural subsidies have promoted the mechanization of farm production, but mechanization has increased the farmers' fertilizer application intensity. This may be due to the fact that currently in China, in general, farmer mechanized farming is less intensive than traditional farming. Therefore, in order to exert the fertilizer reduction effect of agricultural subsidies, a regime linking subsidies aimed at promoting agricultural mechanization, such as agricultural machinery purchase, to green production behaviors, such as fertilizer and pesticide reduction, can be implemented to assess the fertilizer and pesticide reduction of producers applying for subsidies for agricultural machinery purchase and other subsidies, and determine whether to subsidize and the amount of subsidies based on the actual situation of reduction, so as to motivate farmers to cultivate intensively and adopt technologies such as mechanical side-deep fertilizer application to reduce the application of chemical fertilizers.

Sixth, improve the agricultural insurance policy, and subsidize a certain percentage of the insurance premiums for agricultural producers who participate in agricultural insurance, so as to motivate them to participate in agricultural insurance and improve their ability to bear risks; support insurance institutions to develop green agricultural insurance to promote green production by farmers and other agricultural producers and reduce the application of chemical fertilizers.

Seventh, strengthen the publicity and technical training on fertilizer reduction and efficiency increase, summarize and promote the experience of fertilizer reduction and efficiency increase in a timely manner, and improve the awareness and technical level of farmers and other agricultural producers on fertilizer reduction and efficiency increase. Continuously improve training contents, innovate training methods, and incorporate technical innovations and experiences in fertilizer reduction and efficiency increase into rural vocational education and training in a timely manner through flexible and diverse forms such as media publicity, organizing regular experience exchange meetings, establishing training schools, and entrusting training to relevant organizations (such as farmers' cooperatives, government agricultural technology departments, agricultural colleges and universities, etc.). To motivate farmers and other agricultural producers to actively participate in training, the government can arrange a certain amount of funds for subsidies for participation in training.

Since there was no disaggregated data on agricultural subsidies in the data source of this paper, this paper did not test the effect of different types of agricultural subsidies on farmers' fertilizer application. This is a shortcoming of this paper and a problem that needs to be addressed in subsequent studies on this topic.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://chfs.swufe.edu.cn/.

Author contributions

GH: conceptualization, investigation, methodology, project administration, resources, formal analysis, validation, visualization, writing-original draft, and funding acquisition. JF: data curation, writing-review, and editing, supervision. TX: software, writing-review, and editing.

Funding

The research was financially supported by the National Social Science Fund of China (project number 18BJY123).

Acknowledgments

These authors also thank the China Household Finance Survey Database (CHFS).

Conflict of interest

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

Publisher's note

Supplementary Material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.1043434/full#supplementary-material

References

Baron, R. M., and Kenny, D. A. (1986). The moderator-mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *J. Pers. Soc. Psychol.* 51 (6), 1173–1182. doi:10.1037/0022-3514.51.6.1173

Chen, C., Wang, Y., and Zhai, Q. Q. (2019). Risk preference, perception and fertilizers, pesticides application. *J. J. Agro-Forestry Econ. Manag.* 18 (04), 472. doi:10.16195/j.cnki.cn36-1328/f.2019.04.51

Cui, G., and Liu, Z. C. (2022). The impact of environmental regulations and social norms on farmers' chemical fertilizer reduction behaviors: An investigation of citrus farmers in southern China. *Sustainability* 14 (13), 8157. doi:10.3390/su14138157

Dou, Y., Deng, Y. J., and Cheng, S. (2016). China's agricultural environment pollution present situation and the technological innovation path. *J. Sci. Manag. Res.* 34 (04), 76. doi:10.19445/j.cnki.15-1103/g3.2016.04.020

Eba, N., and Bashargo, G. (2014). Factors affecting adoption of chemical fertilizer by smallholder farmers in guto gida district, oromia regional state, Ethiopia. *Sci. Technol. Arts Res. J.* 3 (2), 237. doi:10.4314/STAR.V3I2.31

Fort, R. (2008). The homogenization effect of land titling on investment incentives: Evidence from Peru. *NJAS Wageningen J. Life Sci.* 55 (4), 325–343. doi:10.1016/S1573-5214(08)80024-3

Gong, Q. W., Mu, X. L., and Tian, H. Z. (2010). Analysis on influencing factors of farmers' risk cognition and avoidance ability in excessive fertilization-based on the questionnaire survey of 284 farmers in the jianghan plain. *J. Chin. Rural. Econ.* (10), 66. Available at: https://kns.cnki.net/kcms/detail/detail.aspx?FileName=ZNJJ201010010&DbName=CJFQ2010

Grunt, M., Błażejewski, A., Pecolt, S., and Królikowski, T. (2022). BelBuk system—smart logistics for sustainable city development in terms of the deficit of a chemical fertilizers. *Energies (Basel).* 15 (13), 4591. doi:10.3390/EN15134591

Guo, L., Li, H., Cao, X., and Cao, A. (2021). Effect of agricultural subsidies on the use of chemical fertilizer. *J. Environ. Manage.* 299 (2), 113621. doi:10.1016/J.JENVMAN.2021.113621

Guo, Q. H., Li, S. P., and Li, H. (2018). Study on the adoption behavior of farmers' chemical fertilizer reduction measures from the perspective of social norms. *J. J. Arid Land Resour. Environ.* (10), 50. doi:10.13448/j.cnki.jalre.2018.298

Han, H., and Zhao, L. (2009). Farmers' character and behavior of fertilizer application -evidence from a survey of xinxiang county, henan province, China. *Agric. Sci. China* 8 (10), 1238–1245. doi:10.1016/S1671-2927(08)60334-X

He, H. R., Zhang, L. X., and Li, Q. (2006). Study on farmers' fertilization behavior and agricultural non-point source pollution. *J. J. Agrotechnical Econ.* (06), 2. Available at: https://kns.cnki.net/kcms/detail/detail.aspx?FileName=NYJS200606000&DbName=CJFQ2006

Hou, L. L., Sun, Q., and Mu, Y. Y. (2016). Impact of agricultural subsidy policy on agricultural non-point pollution: From the perspective of fertilizer demand. *J. J. China Agric. Univ.* 17 (04), 173. Available at: https://kns.cnki.net/kcms/detail/detail.aspx?FileName=NYDX201204031&DbName=CJFQ2012

Kharbach, M., and Chfadi, T. (2021). General trends in fertilizer use in the world. *Arab. J. Geosci.* 14 (23), 2577. doi:10.1007/S12517-021-08889-0

Leake, G. (2015). Factors influencing application of fertilizer by smallholder farmers of northern Ethiopia. *J. J. Econ. Sustain. Dev.* 6 (3), 202–207. https://schlr.cnki.net/zn/Detail/index/GARJ2015/SJEE099A8CCCCA2C7C030F2B2AA1C7C12886.

Li, B. W., and Zeng, Q. Y. (2022). The effect of land right stability on the application of fertilizer reduction technologies—evidence from large-scale farmers in China. *Sustainability* 14 (13), 8059. doi:10.3390/SU14138059

Liu, L. Z., Ma, S. H., Li, X. L., An, T. T., and Wang, J. K. (2020). Effects of long-term fertilization on soil ammonia-oxidizing microorganisms. *J. J. Appl. Ecol.* 31 (5), 1459–1466. doi:10.13287/j.1001-9332.202005.024

Lu, H., Chen, Y. J., Huan, H. T., and Duan, N. (2022). Analyzing cultivated land protection behavior from the perspective of land fragmentation and farmland transfer: Evidence from farmers in rural China. *Front. Environ. Sci.* 10, 901097. doi:10.3389/fenvs.2022.901097

Luan, H., and Qiu, H. G. (2013). An empirical study on excessive application of chemical fertilizers in China: Data from farmer household surveys in four provinces. *J. Agric. Sci. Technol.* 14 (01), 193–196. doi:10.16175/j.cnki.1009-4229.2013.01.016

Luo, X. M., Zhang, W., and Tan, Y. (2016). Environmental effects of policy-oriented agricultural insurance and green subsidy model. *J. Rural. Econ.* (11), 13. Available at: ttps://kns.cnki.net/kcms/detail/detail.aspx?FileName=NCJJ201611003&DbName=CJFQ2016

Lv, J., Liu, H., Xue, Y., and Han, X. Y. (2021). Study on risk aversion, social network and farmers' overuse of chemical fertilizer—based on survey data from maize farmers in three provinces of northeast China. *J. J. Agrotechnical Econ.* (07), 4. doi:10.13246/j.cnki.jae.2021.07.001

Ma, W. L., Abdulai, A., and Ma, C. (2009). The effects of off-farm work on fertilizer and pesticide expenditures in China. *Rev. Dev. Econ.* 22 (2), 573–591. doi:10.1111/rode.12354

Ma, X. L. (2009). Empirical analysis of the influence of farmland property right System on farmers' soil conservation investment at present -Taking rice production in hilly areas as an example. *J.Chinese Rural. Econ.* (10), 31. Available at: https://kns.cnki.net/kcms/detail/detail.aspxFileName=ZNJJ200910006&DbName=CJFQ2009

Mao, H., and Cao, G. Q. (2020). Subsidy policy and green ecological agricultural technology adoption behavior of farmers. *J. China Popul. Resour. Environ.* 30 (01), 49. doi:10.12062/cpre.20190819

Niu, Z. H., Yi, F., and Chen, C. (2022). Agricultural insurance and agricultural fertilizer non-point source pollution: Evidence from China's policy-based agricultural insurance pilot. *Sustainability* 14 (5), 2800. doi:10.3390/SU14052800

Qiao, F. B., and Huang, J. K. (2021). Farmers' risk preference and fertilizer use. *J. Integr. Agric.* 20 (7), 1987–1995. doi:10.1016/S2095-3119(20)63450-5

Shi, C. L., Zhu, J. F., and Luan, J. (2015). Fertilizing technical efficiency and its determinants: Based on rice farmers' data in four provinces. *J. J. Agro-Forestry Econ. Manag.* 14 (03), 234. doi:10.16195/j.cnki.cn36-1328/f.2015.03.004

Su, Y. Q., and Wang, Z. G. (2014). Effects of testing and formulated fertilization and farmers' satisfactio: Evidence from rural household survey in pingyuan county, shandong province. *J. J. Hunan Agric. Univ. Soc. Sci.* 15 (06), 25. doi:10.13331/j.cnki.jhau(ss).2014.06.006

Tang, Y. (2019). Analysis of Factors Affecting Farmers' Intention to Reduce Fertilization under Organic Certification System. *J. J. Arid Land Resour. Environ.* 33 (10), 29–34. doi:10.13448/j.cnki.jalre.2019.283

Wang, Y., Zhu, Y., Zhang, S., and Wang, Y. (2018). What could promote farmers to replace chemical fertilizers with organic fertilizers? *J. Clean. Prod.* 199 (PT.1-1130), 882–890. doi:10.1016/j.jclepro.2018.07.222

Wu, H. X., and Ge, Y. (2019). Excessive application of fertilizer, agricultural non-point source pollution, and farmers' policy choice. *Sustainability* 11 (4), 1165. doi:10.3390/su11041165

Wu, J. Q., Wen, X., Qi, X. L., Fang, S. L., and Xu, C. X. (2021). More land, less pollution? How land transfer affects fertilizer application. *Int. J. Environ. Res. Public Health* 18 (21), 11268. doi:10.3390/IJERPH182111268

Wu, Y. H., and Miao, C. H. (2017). Research on the environmental effects of agricultural support policies in China: Theory and demonstration. *J. Mod. Econ. Res.* (09), 101. doi:10.13891/j.cnki.mer.2017.09.013

Wu, Y. H., Wang, E. R., and Miao, C. H. (2019). Fertilizer use in China: The role of agricultural support policies. *Sustainability* 11 (16), 4391. doi:10.3390/su11164391

Xiang, Z. Y., Tian, Q. S., and Li, Q. L. (2021). Perceived risk, environmental attitude and fertilizer application by vegetable farmers in China. *J. Int. J. Low-Carbon Technol.* 16 (3), 683–690. doi:10.1093/IJLCT/CTAA101

Yang, X. Y., and Qiao, C. X. (2018). Impacts of agricultural subsidies on ecological environment-from the perspective of fertilizer use. *J. Chin. J. Agric. Resour. Regional Plan.* 39 (07), 47. doi:10.7621/cjarrp.1005-9121.20180707

Yang, Y., He, Y., and Li, Z. (2020). Social capital and the use of organic fertilizer: An empirical analysis of hubei province in China. *Environ. Sci. Pollut. Res.* 27 (13), 15211–15222. doi:10.1007/s11356-020-07973-4

Yang, Y., Li, Z., and Zhang, Y. (2021). Incentives or restrictions: Policy choices in farmers' chemical fertilizer reduction and substitution behaviors. *J. Int. J. Low-Carbon Technol.* 16 (2), 351–360. doi:10.1093/IJLCT/CTAA068

Yu, W. Y., Qi, Y. B., and Yu, H. (2017). Empirical study on the effect of agricultural subsidies on non-point source pollution of chemical fertilizer—based on provincial panel data. *J. Rural. Econ.* (02), 89. Available at: https://kns.cnki.net/kcms/detail/detail.aspx?FileName=NCJJ201702016&DbName=CJFQ2017

Zhang, H. (2020). Big country and small farmers: Structural contradiction and governance difficulty—take the management of agricultural ecological environment as an example. *J. J. China Agric. Univ. Soc. Sci.* 37 (01), 15. doi:10.13240/j.cnki.caujsse.20200303.002

Zhang, L., and Luo, B. L. (2020). Agricultural chemical reduction: the logic and evidence based on farmland operation scale of households. *J. Chin. Rural Econ.* (02), 81. Available at: https://kns.cnki.net/kcms/detail/detail.aspx?FileName=ZNJJ202002006&DbName=CJFQ2020

Zhang, Y. N., Long, H. L., Li, Y. R., Ge, D. Z., and Tu, S. S. (2020). How does off-farm work affect chemical fertilizer application? Evidence from China's mountainous and plain areas. *Land Use Policy* 99, 104848. doi:10.1016/j.landusepol.2020.104848

Zhang, Z. Y., Ning, Z. S., Gao, Y. L., and Wang, Z. G. (2021). What is the effect of agricultural subsidies on fertilizer inputs? - analysis based on panel data of major subsidized crops in provinces and regions. *J. J. Appl. Statistics Manag.* 40 (04), 720. doi:10.13860/j.cnki.sltj.20210625-002

Zhu, W., Qi, L. X., and Wang, R. M. (2022). The relationship between farm size and fertilizer use efficiency: Evidence from China. *J. Integr. Agric.* 21 (1), 273–281. doi:10.1016/S2095-3119(21)63724-3

Zou, W., Cui, Y. L., and Zhou, J. N. (2020). The impact of farmland transfer on farmers' fertilizer reduction: An analysis of transferability and security of land rights. *J. China Land Sci.* 34 (09), 48. doi:10.11994/zgtdkx.20200826.094939

Zuo, Z. Y., and Fu, Z. H. (2021). The environmental and economic effects of green agricultural subsidy policies: A regression of discontinuity design based on agricultural non-point source pollution control programs with the world bank's loan in guangdong province. *J. Chin. Rural. Econ.* (02), 106. Available at: https://kns.cnki.net/kcms/detail/detail.aspx?FileName=ZNJJ202102006&DbName=CJFQ2021