



# Improved economic and environmental outcomes from targeted fertilizer policy

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## Abstract

The overuse of nitrogen (N) fertilizer for wheat is a serious problem in China, and previous studies seldom distinguish between the use of basal and topdressing N fertilizer. Data from 225 households in Jiangsu Province, China (a wheat planting area), were collected through face-to-face interviews with each head of the household. Regression models were used to study factors affecting farmers' application of basal and topdressing N fertilizers separately. Fertilizer retailers proposed fertilizer application levels that were in opposition to their concern for the environment. Farmers' concern for the environment only affected their application of topdressing N fertilizer and had no significant influence for use of total N fertilizer. The farmland area and amount of experience planting wheat had negative effects on basal N fertilizer use, but not on topdressing fertilizer. In the study area, the optimal strategy for decreasing N fertilizer application is designing policies to rent more farmlands to farmers with the most experience first. These farmers with their higher farm income would decrease basal N fertilizer use and the basal-topdressing ratio to improve N fertilizer use efficiency and then decrease the N fertilizer leaching into the environment.

**Keywords** Farmer decision · Nitrogen overuse · Basal fertilizer · Soil erosion · Sustainability

## Introduction

A reliable supply of nitrogen (N) fertilizer for crop growth has allowed farmers to increase crop production, thus promoting economic development in China (Zhang et al. 2017; Foley et al. 2011). Notably, too little N fertilizer causes lower crop productivity, but too much N fertilizer causes environmental pollution and soil erosion (Sanchez and Swaminathan 2005; Yusuf et al. 2017; Xu et al. 2018). The overuse of N fertilizer has resulted in serious impacts to the aquatic environment because nitrate is leached from soils (Lu et al. 2015). While the government has implemented policies to reduce pollution

caused by the overuse of N fertilizer, the use of fertilizers has continued to increase in China (Cui et al. 2018).

China uses more N fertilizer than any other country, and the reasons for the overuse have not been fully understood and explained (Smith and Siciliano 2015; Yuan et al. 2021). In many cases, a myriad of social and economic factors that affect farmers' decision-making processes are critical for improving N fertilizer use efficiency (Davidson et al. 2015; Barbero-Sierra et al. 2016). Socio-demographic impediments, such as insufficient trust in the recommendations by agricultural agents and incorrect information on the overuse of fertilizers, often increase N fertilizer use by farmers (Perez 2015). The complexity of farmers' decisions on N fertilizer use has been described as an internal analysis of the positive and negative impacts of farmers' attitudes toward economic, environmental, social, and ethical aspects (Schneider and Francis 2006). Farmers' decision models are increasingly focused on the role of farmers' values, beliefs, and attitudes, which influence the decision-making process (Pan et al., 2017). These significant works on socio-demographic factors have not considered the differences between basal and topdressing fertilizers. The farmers in these studies had the same attitudes toward the use of basal and topdressing fertilizers.

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Farmers in China tend use more basal N fertilizer (Bai et al. 2021), consequently decreasing N fertilizer use efficiency (Shi et al. 2012). Many field experiments have been conducted to determine the optimal ratio of basal to topdressing N fertilizer, without considering socio-demographic factors (Liu et al. 2015). Documenting the factors that contribute to the decisions of basal and topdressing N fertilizers application separately is a necessary step in addressing the reason of N fertilizer overuse in the study area. Thus, this paper studies the impact of socio-demographic factors on the use of basal and topdressing N fertilizers, and proposes policies tailored to Jiangsu Province, China, to reduce basal and topdressing N fertilizer use.

## Materials and methods

### Study area and data collected

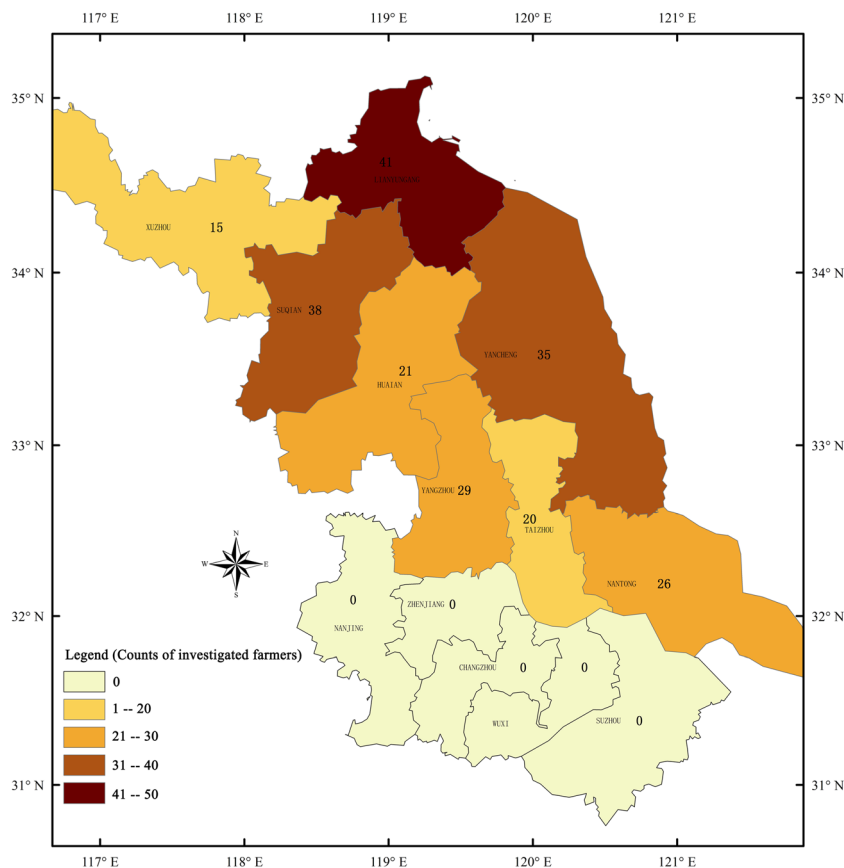
The study was conducted in a rural area of northern Jiangsu Province, China (Figure 1). We investigated 225 wheat farmers in the study area (Figure 1). Many college students from Jiangsu Province were hired to conduct the investigation on their winter holiday. Data were collected through face-to-face interviews with each householder. Wheat is a dominant summer crop in Jiangsu Province: 96% of farmlands are planted to wheat (Jiangsu Statistical Bureau 2019).

The total wheat output (2018) of Jiangsu Province was 9.8% of China's wheat output (Jiangsu Statistical Bureau 2019; National Bureau of Statistics of China 2019). The total wheat output (2018) of the investigated area (eight cites: Yangzhou, Yancheng, Xuzhou, Taizhou, Suqian, Nantong, Lianyungang, and Huai'an) was approximately 88% of that of Jiangsu Province. The wheat planting area of the eight investigated districts was 87% of the total wheat area in Jiangsu Province (Jiangsu Statistical Bureau 2019).

The five districts in the southern part of Jiangsu (the not-investigated area) represent the main industrial production area. The gross domestic product (2018) of the five cites was more than 58% of that of Jiangsu Province and more than 6% of that of China (Jiangsu Statistical Bureau 2019; National Bureau of Statistics of China 2019). Farmers have many opportunities to get off-farm income in the five districts.

In the study area, farmers mainly spread urea and compound fertilizer by hand for the planting of wheat. Farmers do not use soil testing and use N fertilizer based on their experience and social pressure. No commercial advisors help farmers calculate the amount of N fertilizer required for yields. The questionnaire was designed based on the literature on related topics (Atari et al. 2009; Tan 2014). The first part of the questionnaire included questions on the socio-demographic characteristics of farmers, such as age, education, household labor, wheat planting area, wheat planting experience, and farm and off-farm

**Fig. 1** Map of the study sites in Jiangsu Province, China



income. The second part included Likert-scale questions on the confidence of farmers in fertilizer retailers' suggestions (trust factor), attitudes toward prospective farm income, and perceptions of output reduction and environmental pollution caused by N fertilizer overuse. The amount and application frequency of basal and topdressing N fertilizers were covered in the third part of the questionnaire. Limiting N accumulation in wheat season was a key to controlling N runoff losses from rice-wheat rotation (Zhao et al., 2009; Cao et al., 2017). This paper did not consider N loss after absorption by next crop (rice).

## Variables and measurement

Three dependent variables, *Basal N*, *Topdressing N*, and *Total N*, denote the use of basal N fertilizer, topdressing N fertilizer, and all inputted N fertilizer, respectively. The relationship among the three variables is  $Total\ N = Basal\ N + Topdressing\ N$ .

The independent variables—*Education*, *Wheat-planting-experience*, *Farmland-area*, *Laborers*, *Farm-income*, *Off-farm-income*, *Trust-factor*, *Output-reduction-factor*, and *Environmental-pollution-factor*—were selected based on local farmers' practice and previous studies.

Years of education and planting experience played roles in the decisions for fertilizer use (Daberkow and McBride 2003; Huang et al. 2020). *Education* and *Wheat-planting-experience* describe the education level and wheat planting experience, for example, of the household head.

Exogenous variables were also critical factors that affected farmers' behavior in the use of fertilizer, such as farmland area, number of family laborers, and farm and off-farm income (Zbinden and Lee 2005). This paper used *Farmland-area*, *Labors*, *Farm-income*, and *Off-farm-income* as the exogenous variables.

Farmers' attitudes and beliefs were considered when examining fertilizer use behavior (Uthes and Matzdorf 2013). The importance of farmers' perceptions has been widely recognized (Hashemi and Damalas 2011). Farmers' perceptions of fertilizer use are a key influencing factor of the excessive use of N fertilizer in China. Confidence in retailers and perceptions of fertilizer overuse influence the application of fertilizer (Adrian et al. 2005). In this study, *Trust-factor* denotes whether the farmer trusts the retailers' information on the use of N fertilizer. *Environmental-pollution-factor* denotes farmers' perceptions of environmental pollution caused by N fertilizer overuse. Increased use of fertilizers has contributed to the increased gain in productivity since 1978 (Carter et al. 2012), but much evidence now indicates that fertilizer use could be reduced in many cropping situations with minimal loss of crop yields (Zhan and Powlson 2010). *Output-reduction-factor* denotes

the investigation of farmers' attitudes toward the yield reduction caused by N fertilizer overuse.

SPSS (24.0) was used to code and analyze the data from the 225 completed household survey questionnaires. Summary statistics and frequency distributions were used to describe and interpret data. Four regression models were used to examine the determining factors influencing farmers' decisions on basal and topdressing N fertilizer use. We used the data to analyze the differences in factors of influence on the use of basal and topdressing N fertilizer and thereby reached an improved understanding of the main drivers for basal and topdressing N fertilizer use. These characteristics can be used to design more efficient mechanisms for reducing N fertilizer use in China.

## Results

### Farmers' demographic profile

Many elderly farmers resided in the rural areas under investigation. Of the farmers surveyed, approximately 98% and 24% had at least 10 and 40 years of farming experience, respectively, with the average years of farming experience being 29 years in Figure 2c.

Based on educational attainment, the farmers (head of household) were grouped into five categories in Figure 2a: illiterate (9.3%), primary school (27.6%), middle school (49.8%), high school (11.1%), and college or bachelor's degree (2.2%). Notably, 9 years of education is compulsory in China.

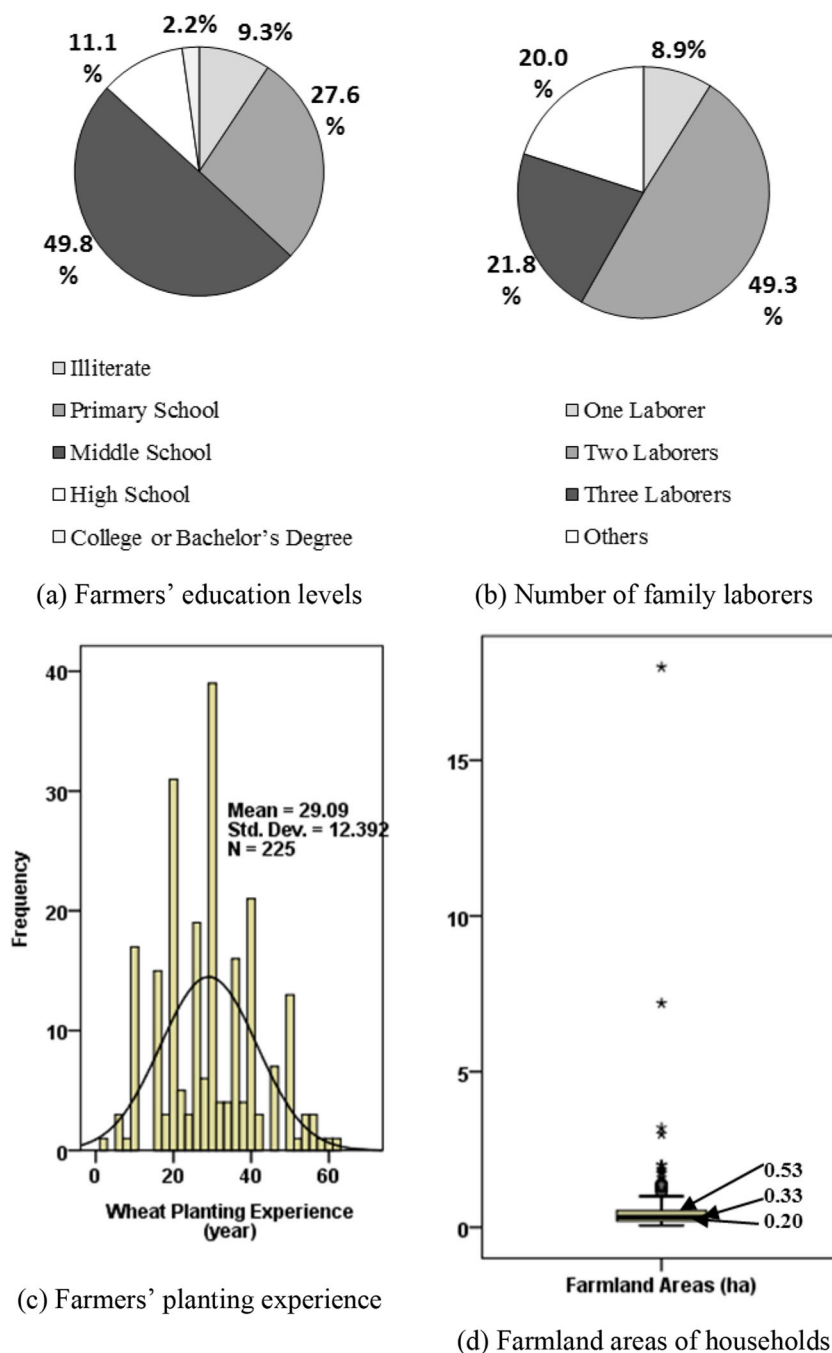
The average number of family laborers was 2.5. Because most of the respondents were working in districts, 49.3% of households had 2 laborers, 8.9% of households had 1 laborer, and 21.8% of households had 3 laborers (Figure 2b). Considering farmers' planting experience, we found that for most households, only elderly farmers remained in the villages as farmers.

The results of farming experience, education level, and number of family laborers demonstrate that many elderly individuals with a low education level work on farmlands in the study area. Rural–urban migration for employment, particularly by male able-bodied workers, reduced the potential for effective use of N fertilizers as it is hand spread.

### Fragmented farmlands

The typical size of the farmers' parcel of farmland was approximately 0.1 ha (Zhang et al. 2013). Considering the small scale and aging population, modern management practices for fertilizer use were less effective because of the high fixed costs of adoption (Foster and Rosenzweig 2010). Highly skewed farm size distribution in China was one possible explanation for the overuse of fertilizer (Ju et al. 2016).

**Fig. 2** Farmers' demographic profile. **a** Farmers' education levels. **b** Number of family laborers. **c** Farmers' planting experience. **d** Farmland areas of households



Most of the farmers owned the land under cultivation. Two households cultivated more than 3 ha of farmland by using rental arrangements. Except for these two households, the average area was 0.56 ha per household. Notably, 167 households (74.2%) had less than 0.5 ha. Figure 2 d illustrates the median value of farmland area is 0.33 ha per household.

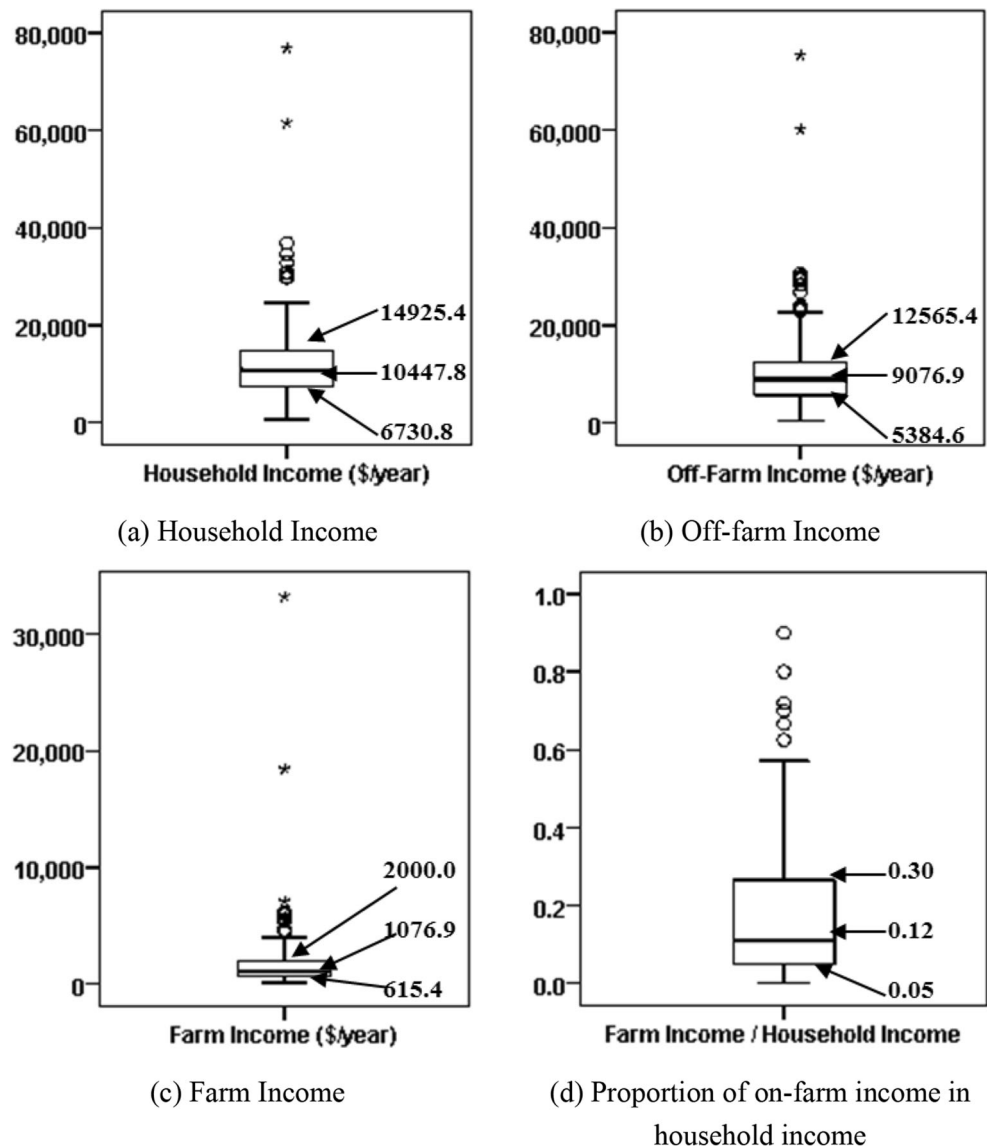
### Proportion of on-farm income in household income

The nature of fertilizer use was reflected in the total farm operation income, and earning a good income from farming

was still the main purpose of fertilizer application (Bosch et al. 1995). Household and off-farm incomes are presented in Figure 3 a and b (the exchange rate of USD to RMB is 6.5). The average values of household (11,855.19 USD/year) and off-farm income (10,423 USD/year) were similar. For most of the households, farming was a secondary occupation and on-farm income was 14% of off-farm income (average value).

Farm income was much lower than off-income in the study area. Fifty-four households' farm income was more than 2000 USD/year; 76% of households had a farm income of less than 2000 USD/year (Figure 3c). The proportion of farm income

**Fig. 3** Farmers’ income. **a** Household income. **b** Off-farm income. **c** Farm income. **d** Proportion of on-farm income in household income



(farm income/household income) was much lower in our study. The ratio was less than 0.3 for most of households 90.2%, and the 75th percentile is 0.3 in Figure 3d. Because of the wheat–rice rotation system, wheat income was approximately half of farm income.

**Farmers’ perceptions of N fertilizer application**

We investigated farmers’ perceptions of fertilizer use in four areas: prospective farm income, trust in N fertilizer retailers’ suggestions, reduction of productivity caused by N fertilizer overuse, and environmental pollution caused by N fertilizer overuse.

Due to the lower proportion of farm income in the households (Figure 3), we analyzed farmers’ confidence in the income derived from agriculture and found that 9.3% of farmers had a positive attitude toward prospective farm income

(Table 1), 24.9% of farmers predicted that their farm income would decrease, and the other farmers had no confidence that their farm income would increase. The farmers’ perception of farm income was defined as the prospective-farm-income-factor.

Trust in agronomic advice influences fertilizer use (Sherrif 2005). Farmers have many opportunities to obtain advice from fertilizer retailers. Our results demonstrate that 77.3% of farmers had confidence in retailers’ advice and 22.7% of farmers did not. “Does the farmer trust the retailers’

**Table 1** Farmers’ prospective farm income

	Decrease	Not change	Increase
Frequency	56	147	21
Percent	24.9%	65.3%	9.3%



information on the use of N fertilizer” was called the trust-factor in this study.

Excessive use of fertilizers can result in soil degradation (Stuart et al. 2014), and this scenario was defined as the *output-reduction-factor* in this study. According to our survey, 69.7% of the farmers realized that fertilizer overuse could reduce the yield of wheat (Table 2); 13.1% of farmers thought that fertilizer overuse could seriously decrease productivity, and 4.4% thought that excessive fertilizer use did not reduce wheat yield (Table 2).

In addition to the decrease in productivity, the majority of the farmers agreed that chemical fertilizers would cause serious environmental pollution and thus harm the environment. A small proportion of farmers (3.1%) thought that N fertilizers had no negative effect (Table 2). The environmental-pollution-factor was used to explain “What’s the farmers’ attitude to overuse of N fertilizer and environmental pollution?”

### Overuse and inappropriate ratio of basal and topdressing N fertilizer

Figure 4 illustrates the total use of N fertilizer in the study. Notably, the average use of N fertilizer (357.55 kg/ha) observed in our study was more than that of other countries’ applications (Figure 4).

The results of basal and topdressing N fertilizer use are presented in Table 3. The use of basal N fertilizer for 49.8% of farmers was less than the use of topdressing N fertilizer. A greater proportion of farmers (67.6%) used between 100 and 300 kg/ha of basal N fertilizer, and 79.1% of farmers used topdressing N fertilizer in the same amounts. Few farmers (20.9%) applied basal N fertilizer at a rate of less than 100 kg/ha. Additionally, 15.6% of farmers used topdressing N fertilizer at a rate of less than 100 kg/ha. Farmers habitually use excessive applications of basal N fertilizer and overuse a few of the topdressing N fertilizers. To manage N fertilizer more accurately, the use of basal and topdressing N fertilizer should be explained separately.

The basal-topdressing ratio was the index to demonstrate the structure of basal and topdressing fertilizer use and was calculated as (basal N fertilizer use)/(topdressing N fertilizer

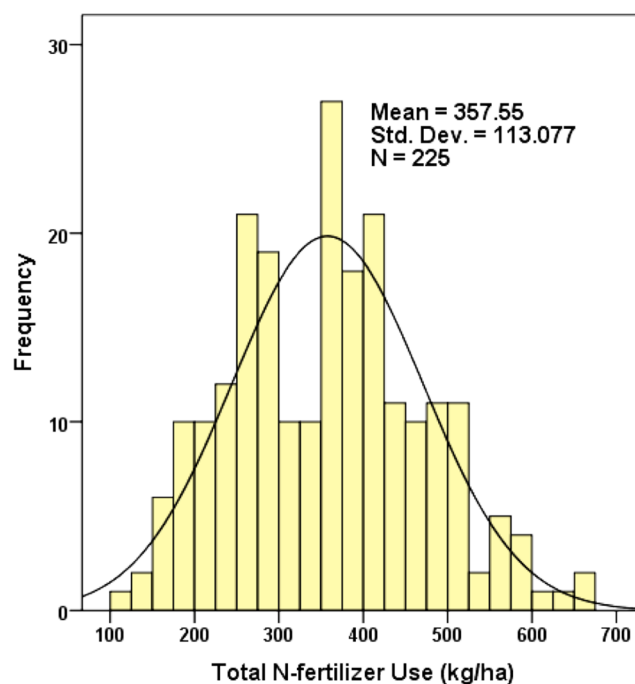


Fig. 4 Frequency analysis of total N fertilizer use

use). Based on researchers’ field experiments in our study area (Jiangsu Province), a smaller basal-topdressing ratio (less than 1) of N fertilizer would increase the productivity of wheat for all types of soils, including lower, middle, or higher fertility soils (Sui 2013). Other parts of the experiments conducted in China have proved that the basal-topdressing ratio should be less than 0.5 (Wang et al. 2015). Only 18.2% of farmers in our study managed basal and topdressing with a ratio of less than 0.5, and 33.8% of farmers applied a ratio between 0.5 and 1. The basal-topdressing ratios of 81.8% of farmers were higher than 0.5; thus, the basal-topdressing ratio was too high, and the basal N fertilizer was used too much. Much of the N fertilizer applied could not be used by the targeted plants and thus was leached or moved out of the soil profile. To achieve higher productivity, farmers applied the poor choice (more N fertilizer with a higher basal-topdressing ratio) as a substitute for the good choice (lower N fertilizer with lower basal-topdressing ratio). There are two reasons why farmers

**Table 2** Perception of wheat production caused by excessive fertilizer application

	Strongly disagree	Disagree	No opinion	Agree	Strongly agree
<i>Perception of wheat yield reduction caused by excessive fertilizer application</i>					
Frequency	3	7	58	127	30
Percent	1.3%	3.1%	25.8%	56.4%	13.3%
<i>Perception of pollution caused by fertilizer overuse</i>					
Frequency	7	20	75	103	20
Percent	3.1%	8.9%	33.3%	45.8%	8.9%

**Table 3** Basal and topdressing N-fertilizer using (kg/ha)

	N	Minimum	Maximum	Mean	Std. deviation
Basal N (kg/ha)	225	31.50	483.00	188.12	105.82
Topdressing N (kg/ha)	225	27.45	452.40	169.87	75.26

apply a higher basal-topdressing ratio: the tradition of N fertilizer management is higher basal-topdressing ratio in the study area, and some farmers work in districts except during the busy farming season. They do not have enough holidays to spread topdressing N fertilizer; hence, they apply excessive amounts of basal N fertilizer.

### Factors affecting applications of basal and topdressing N fertilizers

To assess the effects of socio-demographic characteristics in farmers’ decisions on the amount of N fertilizer use, we performed regression analysis on the basal, topdressing, and all N fertilizer inputs. Table 4 presents our regression analysis results, namely insights into the effects of socio-demographic characteristics of basal and topdressing N fertilizer use.

For the total application of N fertilizer (basal and topdressing), *Trust-factor* (Trust of fertilizer retailer), *Farmland-area*, and *Wheat-planting-experience* showed significant effects (Table 4). However, the significant factors for basal and topdressing N fertilizer use were different from the factors for total N fertilizer application.

**Table 4** Regression results for socio-demographic characteristic effects on basal and topdressing N fertilizer use

	Basal N		Topdressing N		Total N	
	R square=0.104		R square=0.150		R square=0.119	
	F=2.490		F=3.813		F=2.923	
	Sig.=0.010		Sig.=0.000		Sig.=0.003	
	df=203		df=203		df=203	
	B	Sig.	B	Sig.	B	Sig.
(Constant)	283.554	<b>0.000</b>	149.609	<b>0.000</b>	424.816	<b>0.000</b>
<i>Trust-factor</i>	11.361	0.501	38.757	<b>0.001</b>	52.490	<b>0.004</b>
<i>Output-reduction-factor</i>	-5.054	0.631	7.224	0.326	2.837	0.799
<i>Environmental-pollution-factor</i>	0.401	0.964	-12.483	<b>0.044</b>	-11.998	0.200
<i>Farmland-area</i>	-11.531	<b>0.045</b>	-0.719	0.857	-12.260	<b>0.044</b>
<i>Wheat-planting-experience</i>	-1.453	<b>0.015</b>	-0.768	0.065	-2.187	<b>0.001</b>
<i>Education</i>	-3.203	0.691	2.167	0.700	-0.413	0.961
<i>Laborers</i>	-5.614	0.455	3.380	0.519	-2.086	0.793
<i>Farm-income</i>	-0.006	<b>0.041</b>	0.006	<b>0.001</b>	0.001	0.815
<i>Off-farm-income</i>	0.000	0.855	0.001	0.340	0.000	0.587

*Trust-factor* and *Farm-income* were positively significant for the use of topdressing N fertilizer. Farmers’ perceptions of environmental pollution caused by N fertilizer overuse (*Environmental-pollution-factor*) were negatively related to topdressing N fertilizer use. *Farmland-area*, *Wheat-planting-experience*, and *Farm-income* had negative effects on the use of basal N fertilizer. Other factors, such as *Output-reduction-factor*, *Education*, *Laborers*, and *Off-farm-income*, had no significant effects on the use of basal, topdressing, or total N fertilizer.

### Discussion

Farmers used more N fertilizer than wheat plant requires in the study area. However, farmers did not think this amount exceeded the crop requirements. Previous research have pointed to many reasons that affect farmers’ perception, such as their knowledge of fertilizer use (Pan et al., 2017), number of farm laborers (Zhang et al. 2021), farmland size (Bai et al. 2019), social pressure, and perception (Li et al. 2020). This study analyzed all the factors affecting the application of basal and topdressing N fertilizers separately.

### Non-significant factors

For the *Output-reduction-factor*, overuse of N fertilizer caused the soil pH to decrease, and soil acidification can severely impact Chinese agricultural production (Guo et al. 2010). However, the surveyed farmers were unaware of their overuse of fertilizers, despite their perception that the overuse of N fertilizer could cause decreased yield. Most households had their elderly members perform farm work. Because *Education* and *Laborers* were similar for these households, no significance based on these data was presented. Li et al. (2012) reported similar results for the laborers’ coefficient in their fertilizer overuse study. The influence of *Education* in this study was in agreement with that of Sun et al. (2019).

The largest proportion of the household income in this study was off-farm income, which had no significant relationship with agriculture (Figure 2). Because most households had a larger proportion of off-farm income than on-farm income, our result was the opposite of the result of Zhang et al. (2017).

## Effect of retailers' fertilizer advice

There was a strong positive relationship between the trust-factor and the application of N fertilizer, for topdressing N fertilizer and for total N fertilizer, but the trust-factor did not have a significant correlation with the basal-topdressing ratio and use of basal N fertilizer. Because of the low level of knowledge of fertilizers application in China, the trust in retailers' information on fertilizers influenced the widespread overuse of fertilizers (Yang and Fang 2015). Fertilizer retailers have established trust with farmers through one-on-one relationships with salespeople and wheat consultants. This study showed that trust increased the amount of topdressing N fertilizer used, but it did not affect the amount of basal N fertilizer applied. The increase in total N fertilizer use as a result of retailers' advice was in agreement with that of Yang and Fang (2015). However, we found that the increase in total N fertilizer use (affected by retailers' advice) was only influenced by the increase in N fertilizer use for topdressing. Thus, retailers' advice did not have a significant impact on reducing basal N fertilizer use that is considered more detrimental to the environment.

Retailers' eco-friendly view was that the lower basal-topdressing ratio would improve fertilizers' use efficiency and decrease the loss of N fertilizer into the environment. However, retailers suggested that farmers increase the use of topdressing N fertilizer to decrease the basal-topdressing ratio rather than suggesting a decrease in basal N fertilizer use. This type of advice increases the amount of basal and topdressing N fertilizer, although the basal-topdressing ratio decreased.

Considering the overuse of basal N fertilizer, it is not advisable to decrease the basal-topdressing ratio by increasing topdressing N fertilizer use, and even the lower basal-topdressing ratio can decrease the residue of N fertilizer in the environment. This finding may be one reason for the overuse of N fertilizer in the study area.

## Farmers' fertilizer application and concern over related environmental effects

Previous studies indicated when farmers realized that fertilizer overuse influenced the quality of the local environment; they reduced their fertilizer use (Han and Zhao 2009). Establishing an environmental extension system at the township level could also help prevent fertilizer overuse in China (Gong et al. 2011). Chhay et al. (2017) used FFS (farmer field school) to improve farmers' using efficiency of fertilizers in Cambodia. However, in our study, the recognition of environmental pollution (*Environmental-pollution-factor*) only reduced the application of topdressing N fertilizer. The impact was less because topdressing N fertilizer was applied at lower rates compared with basal N fertilizer. Farmers' concern over the environmental effects of excess fertilizer application did

not affect the use of the basal and total N fertilizer significantly. The significance of the *Environmental-pollution-factor* could not be established by the analysis of total N fertilizer.

Considering the retailers' advice, and the negative relationship between farmers' concern for the environment and topdressing N fertilizer use, education programs on the environmental degradation associated with N fertilizer might be more successful if they also involved retailers. This conclusion was the same as that of Stuart et al. (Stuart et al. 2018). Different from prior studies, our results demonstrated that education programs only encouraged farmers to reduce the use of topdressing N fertilizer, which then decreased total fertilizer use. This phenomenon may explain why the effects of the government's education programs were not significant in the study area.

## Effects of farmland area and planting experience on N fertilizer application

*Farmland-area* and *Wheat-planting-experience* had significantly negative effects on the amount of basal and total N fertilizer use. The positive relationship between the two factors and the total fertilizer use has been shown in prior studies (Wu et al. 2018; Barreiro-Hurlé et al. 2010). Because the farmland area and wheat planting experience did not show a significant correlation with the use of topdressing N fertilizer, the two factors could only be applied to the decrease in basal N fertilizer use in this study.

Different from the total N fertilizer use in prior studies (Wu et al. 2018; Barreiro-Hurlé et al. 2010), *Farmland-area* and *Wheat-planting-experience* affected the use of basal N fertilizer in our work and then decreased total N fertilizer use. Renting out more farmland to the farmers with more wheat planting experience was the best way to decrease basal N fertilizer use, and then decrease the total use of N fertilizer. Additionally, the decrease in basal N fertilizer could decrease the basal-topdressing ratio and then improve the efficiency of N fertilizer use. Designing policies for renting out more farmland to experienced farmers would decrease the application of N fertilizer in the study area.

## Different effects of on-farm income for basal and topdressing N fertilizer use

The nature of farming management is reflected by farm income (Bosch et al. 1995). In our study, *Farm-income* demonstrated a significantly opposite relationship with basal and topdressing N fertilizer use and showed no significant correlation with total N fertilizer use. The reasons for this finding might be that households with higher farm income had more scientific knowledge of fertilizers. Then, farming households decreased basal N fertilizer use and increased topdressing N fertilizer use to increase N efficiency. Households with higher



farm income made an informed decision (a smaller basal-topdressing ratio) on N fertilizer use.

*Farm-income* did not affect the total use of N fertilizer, which agrees with the results of Ju et al. (2016). They recognized that because the majority of households' incomes were from employment in urban areas, low fertilizer cost to their total income made the farmers less sensitive to the amount of fertilizer applied. In our paper, laborers in the households with higher off farm income worked in factories except for harvest and planting seasons. These households were not sensitive to the application of fertilizer and had no enough times for the effective application of topdressing N. However, we found that households with higher farm income improved the basal-topdressing ratio (fewer basal N and more topdressing N) to increase N fertilizer efficiency. More productivity and less environmental pollution could be a result of the higher N fertilizer efficiency; even the total use of N fertilizer did not decrease. Ahovi et al. (2021) found that reducing the inefficiency of fertilizer application will enable farmers to be competitive in The Netherlands.

### Approaches to alleviate N fertilizer overuse in the study area

Some alternative fertilizer practices would reduce the use of fertilizer and maintain wheat yields. These alternatives required greater knowledge of the efficient use of fertilizer application. An integration of socio-demographic characteristics could provide the basis for lower N fertilizer solutions (Matson et al. 1998). Researchers have proposed preventing N fertilizer overuse by considering all fertilizer as integration. For the use of chemical fertilizers in Italy and Denmark, Lehmann et al. (2020) showed that integrated food and non-food systems are less polluting compared to the conventional wheat production system. Gurluk (2015) suggested the environmental Kuznets curve to support agri-environmental fertilizer policies in N in The Netherlands and Germany.

The solution based on our study differed from that of previous research because we studied the decrease in basal N fertilizer use separately from topdressing N fertilizer. Spreading knowledge of environmental pollution to farmers was not necessary for fertilizer management, which seemed to only effect of topdressing N fertilizer application that did not contribute to environmental pollution.

Figure 5 illustrates the solution based on the basal N fertilizer use observed in this paper. Policy makers should devise

policies to transfer more farmland to farmers with the most wheat planting experience. These types of farmers are more than likely to decrease basal N fertilizer use and thus the total input of N fertilizer. Additionally, higher farm income encouraged these farmers to obtain more profit through improving N fertilizer use efficiency. Higher N fertilizer use efficiency could decrease the N fertilizer residue in the environment. Less basal N fertilizer use and higher N fertilizer use efficiency showed significance regarding the effect on environmental pollution caused by N fertilizer overuse (Dong et al. 2020).

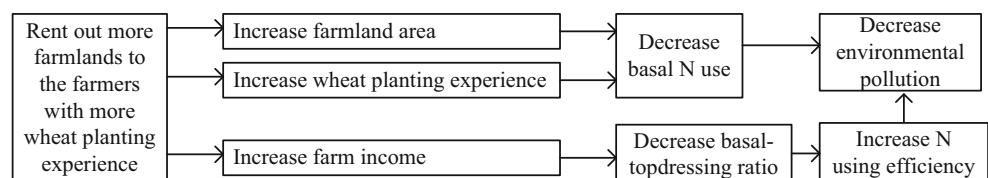
### Conclusion

The study provided essential information for fertilizer managers to understand how farmers' socio-demographic characteristics affect the basal and topdressing N fertilizer use separately. Fertilizer retailers' advice increased the application of N fertilizer even when they considered that was not the best option. Farmers' concern about the effect of N fertilizer application on the environment only affected the use of topdressing N fertilizer and had no significant influence on the amount of basal and total N fertilizer used. Government education programs on environmental degradation associated with N fertilizer may be more successful if they involved farmers and retailers together.

Farmland area and planting experience had a negative relationship with basal N fertilizer use, and that was why studies have concluded that these two characteristics affect fertilizer use. Additionally, a higher basal-topdressing ratio with greater N fertilizer overuse was found in the study area. Farm income had significant negative effects on the basal-topdressing ratio (less basal N and more topdressing N fertilizer use). The lower basal-topdressing ratio could improve N fertilizer use efficiency and then decrease the fertilizer leaching into the environment. Renting out farmlands to the farmers with the most wheat planting experience could decrease the use of basal N fertilizer and then decrease the total application of N fertilizer. Policies for factors to decrease basal N fertilizer application would be the optimal approach to alleviate N fertilizer overuse in the study area.

This study was the first step in analyzing the socio-demographic characteristics that affect basal and topdressing N fertilizer application. An application of the outcomes of the research could be a major step for further policies in N fertilizer management. Further studies of different crops

**Fig. 5** Solution of alleviating environmental pollution caused by N fertilizer overuse



that use basal and topdressing N fertilizer could be developed to find more effective policies that increase the sustainability of agriculture. Moreover, the results of this study could be used in farm simulation to build more accurate models.

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**Data Availability** The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethical approval** Not applicable.

**Consent to participate** Not applicable.

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