

Factors influencing farmers' decisions on nitrogen fertilizer application in the Liangzihu Lake basin, Central China

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Abstract Overuse of nitrogen (N) fertilizers in agriculture activities has caused severe water pollution in China. The lack of data at producer level hampers decision makers in the development and implementation of efficient policies to curb excessive N-fertilizer use. In a survey of 300 farm households in the Liangzihu Lake basin, we identified factors associated with farmers' decisions on N-fertilizer use and application rate. Household survey and multiple linear regression models indicate that the average application rate in the study region is 229 kg N ha^{-1} , which exceeds the recommended rate for maximum profit for cereal crops (maize, wheat, and rice) in China of $150\text{--}180 \text{ kg N ha}^{-1}$. High N-application rates are associated with low farmland productivity (coefficient = -15.66 , $p = 0.02$), a high share of off-farm income (coefficient = 27.14 , $p = 0.003$), and a low education level of the household head (coefficient = -10.83 , $p = 0.039$). Neither physical infrastructure nor access to input markets appears to be related to N-application rates. It may be concluded that excessive use of N in agriculture of Central China is mainly a problem of insufficient awareness and high share of off-farm income.

Keywords Chemical fertilizer · Farmers' behaviour · Fertilizer management · Nitrate pollution · Overuse

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1 Introduction

To satisfy the rapidly growing demand for food and other agricultural commodities during the past 40 years, Chinese farmers tend to apply on average 30–50 % more than the crops' requirement of mineral nitrogen (N) fertilizer (Ju et al. 2009). In China, 19.4–24.7 % of the applied N is lost through volatilization, 0.1–3.3 % through denitrification, and 2.7–12.1 % through leaching in wheat and maize rotation system (Ju et al. 2009). This is causing severe environmental problems at both local and global scales (Mueller et al. 2012). Typically associated with excessive N use at local scale are the eutrophication of the aquatic environment (Pedersen et al. 2009) and nitrate pollution of groundwater (Almasri and Kaluarachchi 2007). On a large scale, disturbance of the global N cycle (Galloway et al. 2008) and the enhanced emission of climate-relevant trace gases (Mosier et al. 1998) are associated with N overuse. Policy makers in the country are becoming increasingly aware of the problems associated with N overuse, and new policies are being developed to sustain on the one hand the increasing demand for food, while on the other hand minimizing negative environmental impacts of excessive N-fertilizer consumption. Thus, an “N-testing” project basing application rates on soil-N values and target yield levels was approved in China in 2005 as a strategy proven to be beneficial in other countries (Bosch et al. 1995). However, its implementation largely failed due to a lack of extension capacity and of other incentives to support an upscaling to the national level. To date, it remains unclear why Chinese farmers consistently exceed recommended N-application rates despite widely recognized environmental problems and a generally low use efficiency of the inputs. A commonly mentioned reason is the relatively low cost of about € 200 per ton of subsidized mineral fertilizer N which is below the world market price of about € 300 per ton of N (Huang et al. 2011).

Past research on possible factors influencing N-fertilizer use in China is contradictory and appears to be location specific. For example, a negative relationship between farm size and N use was reported for the Chaobai watershed in Northern China (Zhou et al. 2010), while no such link was observed in the Songhuaba watershed in Yunnan Province (Yunju et al. 2012). Other authors found that, depending on the study area, seasonal labour migration tends to affect N-fertilizer use both positively and negatively (Zhou et al. 2010). This evidence of a high location specificity of the factors governing N overuse suggests a more differentiated approach that should consider site-specific differences in ecological, economical, and cultural factors (Huang et al. 2011).

The Liangzihu Lake basin in Hubei Province of Central China is particularly affected by N pollution, and the quality of the aquifers has been declining particularly as a result of high nitrate concentrations in the water (Qiu et al. 2001). The water pollution, especially the N pollution problem, is likely to affect regional development in the long run (Kuangfei et al. 1999; Li et al. 2009). To reduce agricultural N pollution, it is necessary to determine the factors driving farmers' excessive use of N-fertilizer. Accordingly, the objectives of this study were: (1) to determine the factors that influence farmers' behaviour with respect to use of N-fertilizers in Central China and (2) to provide suggestions to reduce excessive N application in the study region. The results of this research are seen to provide information required for facilitating policies for better N-fertilizer management in Central China.

2 Materials and methods

2.1 Site description

A household survey was conducted in the Liangzihu Lake drainage basin, Hubei Province, from April to June 2013. The drainage basin is located in the south-east of the Jiangnan Plain in Hubei Province and covers an area of 2085 km², belonging to the counties of Jiangxia, Liangzihu, Daye and Xian'an (Fig. 1). The main characteristics of these four counties are listed in Table 1. Liangzihu Lake has a surface area of 271 km² and an average lake water depth of 2.54 m (Li et al. 2009); the lake is connected with the Yangtze River in the east. The drainage basin is very rich in water resources. For instance, there are many lakes spread throughout the region, all being interconnected by rivers or creeks. The research area has a subtropical monsoon climate with an annual average precipitation of 1100 mm and an annual average temperature of 16 °C (Li and Sun 2009). The dominant crops are rice, maize, wheat, and cotton, with cotton and wheat growing in the cold season, and rice and maize in the hot season. Oilseed rape and groundnuts are also occasionally

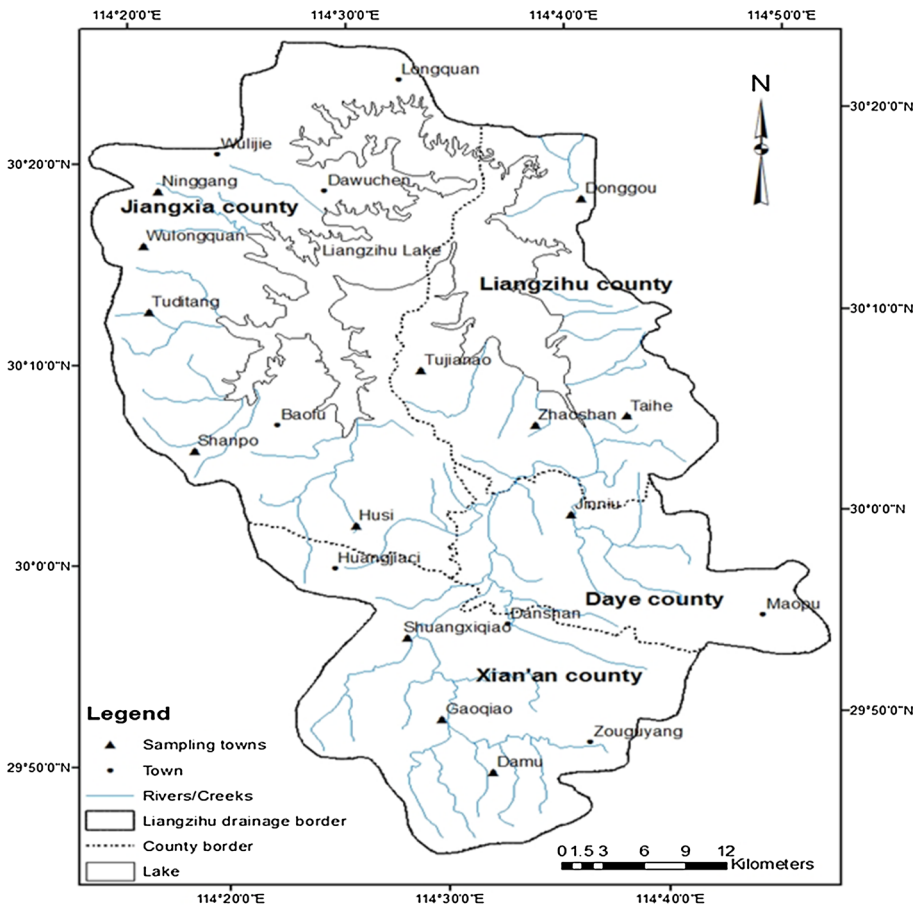


Fig. 1 Location of the surveyed towns in Liangzihu Lake basin

Table 1 Characteristics of the survey counties in the study region

Characteristics	Liangzihu	Jiangxia	Xian'an	Daye
Surveyed households	95	95	47	46
Area (km ²)	500	2010	1502	1566
Arable farmland (km ²)	127	355	355	362
Population	164,846	351,200	393,300	662,500
Households	44,319	97,000	97,900	169,800
Income per capita (Yuan)	7010	9898	6588	8079

cultivated in the region. Most farmers in the study area are small-scale farmers who practise a very intensive crop production with high yields and 1–2 crops per year. The predominant soil in the study region is ferric Acrisols (FAO classification system—WRB; FAO 2003). With an average farm size of only 0.23 ha per household (Hubei Provincial Bureau of Statistics 2008), farmers commonly cultivate two crops per year. The main crops are rice and maize during the summer season and wheat and rapeseed during the winter season. The mean yields are 7.5 Mg ha⁻¹ for paddy rice, 6.0 Mg ha⁻¹ for wheat, 2.3 Mg ha⁻¹ for rapeseed, and 6.5 Mg ha⁻¹ for maize (National Bureau of Statistics of China 2010).

2.2 Sampling methods

To ensure the confidence level at 95 %, a sample of 300 households was selected among the clusters of settlement in whole Liangzihu Lake drainage basin (Levy and Lemeshow 1999). Each settlement cluster consists of several villages. Stratified randomized sampling methods considered the following approach: (1) one settlement cluster from each group was randomly selected, and the villages in the cluster were stratified into two groups according to per capita income (high income >6000 yuan¹ per year and low income ≤6000 yuan per year), (2) several villages from each group were selected for the household survey, (3) households were randomly selected from the sample frame provided by the village head, and (4) face-to-face interviews using structured questionnaires were conducted with the household head or the person who was the major decision maker and manager of the farming activities. As farmers tend to apply large amounts of different types of organic manure to fruits and vegetables, and as their N contribution is difficult to quantify (Ju et al. 2004), such production systems were excluded from the analysis. Thus, from the initially selected 300 households, 17 were excluded because these farmers grew only fruit trees and vegetables. Accordingly, the results are based on the information of 283 sample households. In the study area, mineral N-fertilizer is manually applied twice in one crop season: first time at sowing and second time at tillering. The N-fertilizer is usually applied as urea or ammonium bicarbonate. The number of samples and descriptions of the surveyed households are listed in Tables 1 and 2, respectively. Investigator training and pilot survey were used to ensure the quality of the questionnaire procedure. Investigators received 3-day training to ensure that questions were asked in a standardized way; a pilot

¹ Average currency exchange rate 2012: 1 US \$ = 6.3125 yuan.

Table 2 Variables selected in the questionnaire and household description

Category	Variable	Unit	N	Mean	Std.dev	Min	Max
Characteristic	N-fertilizer application rates	kg N ha ⁻¹	283	229.22	106.21	40.91	637.5
	Age of household head	Years	283	55	11.27	15	83
	household size	Number of persons	283	5.19	2.25	1	13
	Labour availability	Number of person/HH	283	2.62	1.39	1	9
	Education level of household head	^a	283	1.27	1.1	0	5
	Farmland area	Ha	283	0.58	0.71	0.33	6.67
	Disaster	1 = with, 0 = without	283	0.69	0.46	0	1
	Total income	10,000 Yuan	283	2.74	2.49	0.15	23
	Off-farm income (10,000 yuan)	Continuous variables	283	1.37	2.13	0	22
	Fertilizer quality evaluation	0 = don't know; 1 = know	283	0.15	0.36	0	1
Knowledge	Farmland fertility evaluation	^b	283	2.9	0.57	1	4
	Technical training	1 = yes; 0 = no	283	0.17	0.37	0	1
	Ways to access knowledge	dummy variables → ^c	1 (69 %)				
	Distance to farmland	km	283	1.19	3.65	0.1	60
Infrastructure	Distance to fertilizer market	km	283	2.71	4.22	0	60
	Distance with water resources	km	283	0.44	0.74	0	6
	Road conditions	^d	283	1.75	0.74	1	3
	Fertilizer transportation method	dummy variables → ^e	1 (12 %)				

^a 0 = without; 1 = less than 6 years; 2 = between 6 to 9 years; 3 = between 9 and 12 years; 4 = more than 12 years

^b 1 = very fertile; 2 = fertile; 3 = normal; 4 = poor

^c 1 = experience; 2 = discuss with other farmers; 3 = books; 4 = TV/Internet; 5 = other ways; 6 = more than one way

^d 1 = village level; 2 = county level; 3 = provincial level; 4 = national level

^e 1 = truck; 2 = labour; 3 = motorbike; 4 = home delivery service

survey was conducted to make the questionnaires more clearly and easily understood by farmers.

2.3 Variable selection

There are lots of variables influencing the N-fertilizer application. While, referring to the similar researches in China, the farmers first consider the input–output balance when thinking about the amount of N-fertilizer application, thus economic variables were selected (Zhi-wei et al. 2013). Other variables that may influence N-fertilizer application were selected based on previous research (Kormawa et al. 2003). Meanwhile, considering the study area is located in the Liangzihu Lake basin which was characterized with rich water resources, relatively low average income, and limited infrastructure conditions, thus, the variables related to infrastructure were also selected (Wu Weiju et al. 2015). The selected variables were classified into four sections as follows:

- Section 1: Characteristics (age of household's head, household size, yields, occurrence of disasters in the past 5 years);
- Section 2: Economic (farmland area, labour availability, off-farm income);
- Section 3: Knowledge (education level, ways to access knowledge, ability to evaluate the quality of fertilizer and the fertility of farmland, access to and use of training measures);
- Section 4: Infrastructure (distance to the market, distance to water bodies, road conditions, and transport facilities).

Twenty percentage surveyed households cultivate two seasons per year; thus, the multiple cropping index (MCI) was used as follows:

$$\text{MCI} = \frac{\text{Sowing area}}{\text{Farmland area}} \times 100\% \quad (1)$$

The percentage share of off-farm income was transformed into an index to estimate its impact on the amount of fertilizer N applied. To allow comparisons of yield between commodities, the farmland productivity was calculated.

$$\text{Agricultural output value (yuan)} = \sum_{i=1}^{i=n} c_i \times p_i \quad (2)$$

$$\text{Farmland productivity (yuan ha}^{-1}\text{)} = \frac{\text{Agricultural output value}}{\text{Farmland area}} \quad (3)$$

$$\text{Off-farm income percentage (\%)} = \frac{\text{Off-farm income}}{\text{Total income}} \times 100 \quad (4)$$

$$\text{N-fertilizer application density (kg N ha}^{-1}\text{)} = \frac{\text{N fertilizer applied} \times \text{fertilizer-N content}}{\text{Farmland area}} \quad (5)$$

$$\text{N-fertilizer application rates (kg N ha}^{-1}\text{)} = \frac{\text{N-fertilizer application density}}{\text{MCI}} \quad (6)$$

where c_i is the yield of crop i and p_i is the suggested price of crop i given by the provincial government.

2.4 Statistical analysis

Pearson analysis established the correlations between the surveyed variables. A multiple linear regression model was used to identify and estimate the drivers of mineral fertilizer use. Durbin–Wu–Hausman test was used to make sure the selected regression variables are exogenous (Cameron and Traivedi 2010). Bootstrapping (replication = 500) was introduced to test the stability of the results. Calculations were performed using Stata 12.1.

3 Results and discussion

3.1 General determinants of nitrogen application

Various factors appear to determine the amounts of mineral N-fertilizers used. The correlation analysis shows a positive relation between the amounts of N applied and the percentage share of off-farm income ($r = 0.1776$, $p = 0.004$; Table 3). Such relationships have been reported by Zhou et al. (2010). However, farmland productivity shows a highly significant negative correlation with amount of applied N ($r = -0.184$, $p = 0.003$), which is again supported by findings of other researchers in China (Jia et al. 2013). Different explanations were given for these findings. First, farmers tend to apply more N-fertilizer to the fields with unfavourable growing conditions, to compensate for reduced productivity that is perceived to be associated with such conditions (Ju et al. 2009). Another explanation is that excessive N-fertilizer may cause mutual shading, high competition and pest damage which can reduce yield (Peng et al. 2006). Therefore, the results can be interpreted in two ways: excessive N-fertilizer leads to lower yields, or lower yields lead to higher N-fertilizer application. The grain yield response to applied mineral N generally follows a quadratic response function (Meyer-Aurich et al. 2010). Thus, yield increments get smaller with increased N-application rates and may even decline at very high doses (Zhu and Zhang 2010). Most of the surveyed households (82 %) apply N-fertilizer rates above 150 kg N ha^{-1} which is the rate required to reach the maximum profit for cereal crops (maize, wheat, and rice) in China (Zhu and Chen 2002). Thus, it is assumed that the negative correlation in our result between farmland productivity and the N-application rate was caused by excessive use of N-fertilizer.

The distance between farmland and water bodies shows positive correlations with N-application rate ($r = 0.1031$, $p = 0.092$), which indicates that the farther away the farmland was from water resources the more N was applied. The mean distance between farmland and water was $<500 \text{ m}$, and nearly all farmlands were located at a distance of $<2 \text{ km}$ from the water resources (Table 2). Two reasons may explain this positive correlation. First, the farmlands that are located farther from water resources have lower productivity, which is indicated by the negative correlation between these two variables ($r = -0.019$, $p = 0.092$). Therefore, to pursue higher yield, farmers are likely to apply more fertilizer to these fields as compensation. Second, as farmers share irrigation equipment in the study region, they tend to over-irrigate large amount of “insurance water” to the farmland that far away from the water resources when they have the right to use the equipment. The excessive irrigation could cause N-fertilizer losses through leaching; therefore, over-irrigation could motivate farmers to apply even more N-fertilizer (Cameron, Di, and Moir 2013).

Table 3 Correlation between surveyed variables

	Age	HHS	La	Edu	DFI	DFe	DW	RC	%OF	FProd	Napp	FArea
Age	1.0000											
Household size (HHS)	0.1950***	1.0000										
Labour availability (La)	-0.0586	0.4244***	1.0000									
Education level (Edu)	-0.3978***	-0.1465**	0.0943	1.0000								
Distance to farmland (DFI)	-0.0419	0.0879	0.1309	0.0134	1.0000							
Distance to fertilizer (DFe)	0.0041	-0.0131	0.0677	0.0715	0.0094	1.0000						
Distance to water resources (DW)	-0.0726	-0.0190	-0.0507	-0.0232	0.0303	0.0243	1.0000					
Road conditions (RC)	0.0017	0.0922	0.0548	-0.0548	-0.0535	-0.0041	0.1246	1.0000				
Off-farm income percentage (% OF)	-0.3235***	0.1073*	0.2540***	0.2297***	-0.0697	-0.0905	0.0044	0.0891	1.0000			
Farmland productivity (FProd)	0.0721	-0.0147	0.0456	-0.0095	0.0675	-0.0059	-0.0190	-0.0135	-0.2143***	1.0000		
N-fertilizer application rates (Napp)	-0.0404	0.0199	-0.0254	-0.1002	-0.0260	-0.0890	0.1031*	-0.0078	0.1776***	-0.1842***	1.0000	
Farmland area (FArea)	-0.0171	0.0902	0.0667	-0.0012	0.0250	0.0617	0.0171	0.0989	-0.3058***	0.0176	-0.1682***	1.0000

Significant at * 10 % level, ** 5 % level, *** 1 % level

The amount of applied mineral N was negatively correlated with farm size ($r = -0.1682$, $p = 0.0058$), as households with more farmland area tend to rely more on agricultural income and less on off-farm revenues. This can be seen from the negative correlation between off-farm income and farmland area ($r = -0.3058$, $p = 0.000$). Thus, we suppose that farmers with less farmland tend to be employed as an off-farm worker who tend to spend less time on farm work and are more reluctant to spend time on adopting improved N-management techniques, which lead to higher N-application rates. In research from Northern China, a similar correlation between farmland size and N-fertilizer use was observed. The trend was explained by an increase in N-fertilizer use efficiency as farms became larger (Zhou et al. 2010).

3.2 Farmer-specific determinants of nitrogen use

Multivariate linear regression gives a depth analysis of the extent of selected factors influencing the rates of mineral N-fertilizer application (Table 4). The adjust R^2 is higher than 0.7 which means the good quality of the estimation. The raw bivariate correlation associations (Sect. 3.1) were adjusted for the influence of other involved variables. Three variables, i.e. education level, farmland productivity, and off-farm income percentage, were found to be significantly associated with the amount of mineral N used with coefficient of -11 ($p = 0.039$), -16 ($p = 0.02$), and 27 ($p = 0.003$), respectively.

With the off-farm labour wages increasing in China since the early 2000s, farmers pay more attention to their off-farm work rather than to farm work, which has caused an increase in fertilizer use (Brauw and Giles 2008, Wang et al. 2011). Increasing labour wages are reportedly the reason for the Chinese farmers' preference for high N-input management rather than the traditional N management, which demands higher labour input (Jia et al. 2013). Accordingly, as skills for improving fertilizer management require additional labour input, it is a challenge to persuade farmers engaged in off-farm

Table 4 Factors influencing farmers' N-fertilizer application

Category	Factor	Coefficient	Std. Err	p value	p value bootstrap
Characteristic	Education level of household head	-10.83	5.21	0.039**	0.016
	Age of household head	-0.27	0.52	0.606	0.669
	Disaster	6.02	11.16	0.59	0.627
	Household size	0.64	2.68	0.812	0.747
	Labour availability	-1.67	4.39	0.704	0.636
Economic	Farmland productivity	-15.66	6.61	0.02**	0.012
	Off-farm income percentage	27.14	16.89	0.003***	0.002
Knowledge	Farmland fertility evaluation	3.25	9.12	0.72	0.861
	Technical training	-12.31	15.09	0.416	0.305
	Fertilizer quality evaluation	6.2	14.79	0.68	0.585
Infrastructure	Distance to fields	0.25	1.39	0.86	0.954
	Distance to fertilizer market	-1.22	1.19	0.308	0.377
	Distance to water resources	12.26	6.93	0.078*	0.153
	Road conditions	-1.19	7.22	0.869	0.868

Significant at * 10 % level, ** 5 % level, *** 1 % level. Adjusted $R^2 = 0.748$

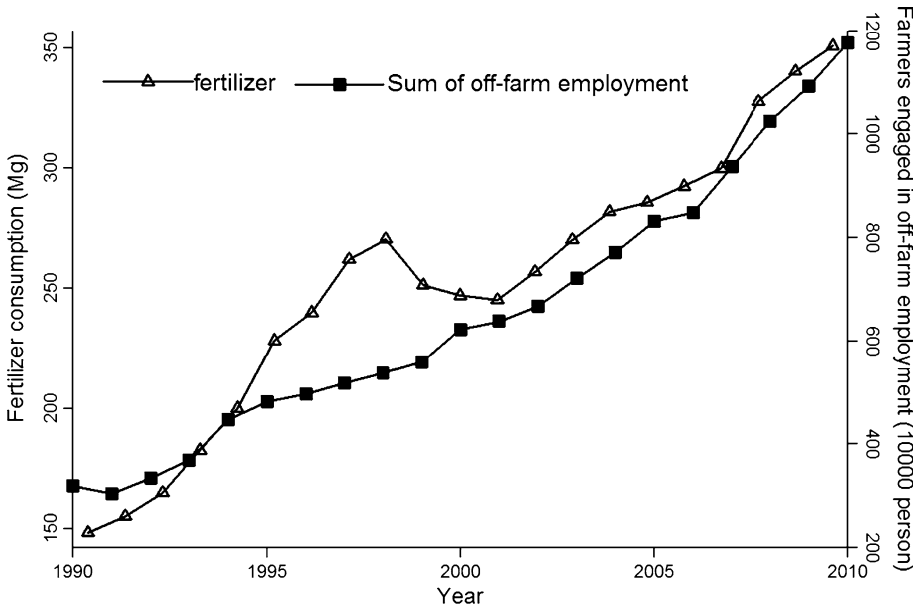


Fig. 2 Fertilizer consumption and off-farm employment in Hubei Province 1990–2010. *Source:* Hubei agricultural yearbook (1991–2011)

employment to adopt them. Figure 2 shows the number of farmers employed as off-farm workers and fertilizer consumption in Hubei Province from 1990 to 2010. Data indicate that fertilizer consumption increased with the number of farmers engaged in off-farm employment in Hubei Province. Similarly, the regression results in the current study indicate that the share of off-farm income was positively associated with the rate of N applied ($r = 0.1776$, $p = 0.004$). This can be for two reasons. First, farmers engaged in off-farm work have more cash to buy more fertilizer (Waithaka et al. 2007). Second, the households that rely more on off-farm income are busier with their off-farm work, and more N-fertilizer is applied to their farmland as a compensation for less farm work (Han and Zhao 2009; Waithaka et al. 2007). The comparison of Chinese farmers' behaviour with respect to N-fertilizer application from the 1940s to 2000s by Giampietro and Pastore (2001) provides a clear explanation of this issue from an economical perspective. They found that Chinese farmers used about 30 % of their farmland to cultivate green manure to produce organic fertilizer in the 1940s; however, farmers used the same amount of farmland to cultivate cash crops and bought synthetic fertilizer with the income from these crops in the 2000s. The farmers then had more free time to do other work and had higher profits. Accordingly, the increase in off-farm employment could cause farmers to spend less time on farm work and to be reluctant to accept proper N-fertilizer management skills. This could be the main reason for the increase in N-fertilizer application rates.

Lack of knowledge and information on required amounts of fertilizers and on crop response to applied N are the main reasons for the Chinese farmers' overuse of fertilizer (Huang et al. 2008). Although no statistically significant correlation was found between knowledge and the amount of N applied, results indicate that the surveyed households have a lack of knowledge on N-fertilizer. In our study, only 16 % of the interviewees knew how to judge the quality of fertilizer, while 72 % estimated their farmland as having normal

Table 5 Farmers' N-fertilizer behaviour based on education level and technical training

Items	Ways to access knowledge (%)						Knowledge on fertilizer quality (%)	N-fertilizer application rates (kg N ha ⁻¹)
	Experience	Discussion	Books	Internet/ TV	Others	Multiple		
<i>Education level</i>								
Without	81.61	3.45	0.00	0.00	0.00	14.94	13.79	225.02
≤6 years	70.59	2.94	0.00	1.47	2.94	22.06	10.29	223.98
6–9 years	56.99	8.60	1.08	3.23	3.23	26.88	19.35	210.81
9–12 years	63.64	0.00	0.00	0.00	9.09	27.27	18.18	206.98
>12 years	87.50	12.50	0.00	0.00	0.00	0.00	25.00	189.61
<i>Technical training</i>								
Not trained	75.43	3.88	0.43	1.29	1.29	17.67	14.22	220.96
Trained	39.13	10.87	0.00	2.17	8.70	39.13	21.74	201.28

fertility, but were not able to give any reasons for this assessment. Regarding the impact of technical training on the amount of N-fertilizer used, other studies show different results. Thus, Huang et al. (2009) observed that technical training can improve N-management strategies and reduce amount of N-fertilizer applied by 20–30 %, while other researchers argue that technical training has only a limited impact, because most of the techniques presented by the training were only reluctantly adopted by the farmers (Wang et al. 2011). The impact of technical training on N-fertilizer use was not significant in the current study. However, the trained and untrained farmers behaved differently with respect to N-fertilizer use (Table 5). Trained farmers tended to apply less N-fertilizer, had more ways to obtain knowledge, and were more likely to know how to evaluate fertilizer quality. Technology adoption in agriculture is a complicated process, which depends on various factors and takes time (Jia et al. 2013). In the current study, only a small percentage (16 %) of interviewees had received technical training in the previous 5 years; all of them received training only once, which is not enough to have a significant influence on amount of N-fertilizer applied. Therefore, the lack of evidence in our analyses regarding the link between technical training and amount of N-fertilizer used should not lead to the conclusion that training is in general of no impact.

The regression shows that education level was negatively correlated with amount of N-fertilizer applied with a coefficient of -11 ($p = 0.039$). This is in line with the findings that N-fertilizer application rates decreased from 225 kg N ha⁻¹ to 190 kg N ha⁻¹ with increasing education level (Table 5). The farmers with both the lowest and highest education levels clearly rely on their experience with respect to the rate of N-fertilizer application. We assume this is because most of the illiterate farmers had done farm work for a long time and were reluctant to accept new information due to lack of basic knowledge. In contrast, the farmers with the highest education are very self-confident and therefore hesitate to learn N-fertilizer management techniques except in discussions about their experience with others. Regarding the negative association between education level and fertilizer application rates, two reasons could explain this. First, although the decisions of both groups of farmers on N-fertilizer use rely on experience, educated farmers can get more useful information through reading the instruction about fertilizer

application on the fertilizer package and through discussions with other farmers. Furthermore, education can help farmers to know how to evaluate fertilizer quality, which can reduce N-fertilizer application rates (Yang and Sun 2008). Our study results reveal that farmers with more than 6 years education have better knowledge on how to evaluate fertilizer quality.

The variables referring to fertilizer transportation in our study did not show any statistically significant correlation with N-fertilizer application rates, which differs from the results in other research. Previous results indicate that the distance from home to the fertilizer market and fields are factors that have a negative impact on N-fertilizer application rates (Kormawa et al. 2003; Zhou et al. 2010). The insignificant correlation between fertilizer transportation and N-fertilizer application rates in our study could be explained by the advanced development of transportation infrastructure in the study region. First, the impact of fertilizer transportation could be weakened with improved road conditions. In the surveyed region, all fertilizer transportation roads are concrete roads, which are convenient for the vehicles. Second, the factors relating to fertilizer transportation did not play an important role in changing the amount of N-fertilizer applied when cars, trucks, or motor bikes were used to transport fertilizer. In our study, 88 % of the surveyed households transported their fertilizer in vehicles. Third, extensive development of fertilizer markets and services could compensate the transportation influence. For instance, 99 % of the households lived <10 km from a fertilizer market, which can be easily reached in vehicles. Meanwhile, 40 % of the surveyed household had a free home delivery service.

4 Conclusions and policy implications

Compared to the crops' requirement, N-fertilizer was overused in the Liangzihu Lake basin. Moreover, large-scale farmers show lower application rates than small-scale farmers. Thus, it is necessary to provide technical support to small-scale farmers. Moreover, policies encouraging "family farms" with large farmland and sustainable intensified agriculture should be facilitated. The high rent, low education level of labour, lack of law system, and bad management are the factors that obstacle the development of "family farms" (Juan and Quan-quan 2015). Thus, these problems should be solved when promoting the "family farms" policies.

Farmers with higher off-farm income percentage tend to apply more N-fertilizer, because off-farm employment could restrict farmers' working time. Accordingly, two ways may curb the overuse of fertilizer. First, appropriate policies targeting macroeconomic adjustment should be implemented to increase farmers' agricultural income percentage. This could encourage farmers to spend more time on farm work and raise their willingness to learn advanced N-fertilizer management skills. Second, other policies that promote the mechanization to substitute labour force can also compensate the labour shortage, thus curbing the excessive N-fertilizer application (Yong-jun and Man-de 2014).

Higher education could help the farmers to access knowledge and properly evaluate the quality of the N-fertilizer, thus reducing N-fertilizer application rate. Accordingly, policy makers should offer more opportunities to the farmers to finish their basic education (9 years), which could help them to reduce N use.

Furthermore, with the development of fertilizer markets and transportation infrastructure in the surveyed region in last years, factors relating to fertilizer transportation did not show a significant correlation with N-fertilizer application rates (Fu-liang and Gu-cheng

2012). Although rich of water resources in the study region, lack of irrigation equipment is still a factor that may increase the N-fertilizer application rate in the farmland that far away from water resources.

Nevertheless, farmers' N-fertilizer practice is a complex system, which cannot be explained adequately by a single theory or several factors (Kung and Cai 2000). Although factors significantly related to N-fertilizer application rates at household level were determined in this study, analysis on other factors such as policy factors at the government level, fertilizer market distribution, and cost–benefit factors at the market level is urgently needed to deepen the insight on the complete picture of factors that are associated with excessive N use (Ma Li-heng et al. 2011). Moreover, time series data from household surveys would be helpful to prove and estimate factors which are driving N-fertilizer overuse.

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