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Impacts of training on farmers' nitrogen use in maize production in Shandong, China

J. Huang, C. Xiang, X. Jia, and R. Hu

Abstract: Inorganic fertilizer plays an important role in increasing Chinese food production. However, recent studies showed that Chinese farmers have been significantly overusing nitrogen (N) fertilizer. The overall goal of this study is to investigate the impact of delivering information and knowledge regarding appropriate N fertilizer use in maize production. Based on an experimental study, which provided training to farmers in maize production in the North China Plain, the present study finds that training does have a positive impact on farmer practices. Indeed, the training was effective in reducing overall N fertilizer use by 22%, though the N application after training was still higher than the level recommended by scientists. These findings have important implications for China's extension system, as well as its efforts to reduce nonpoint pollution and greenhouse gas emissions.

Key words: China—fertilizer—knowledge training—maize—nitrogen

While inorganic fertilizer is important for China's crop production, there have been concerns raised about its intensive use and environmental consequences. Inorganic fertilizer application per hectare grew rapidly after 1960s in China and has surpassed average level in the industrialized countries since 1980 (Heisey and Norton 2007). By 2000, the average fertilizer nutrient application in China was more than 200 kg ha^{-1} (178 lb ac^{-1}), which was much larger than average application in India (less than 100 kg ha^{-1} [89 lb ac^{-1}]) and the industrialized countries (about 120 kg ha^{-1} [107 lb ac^{-1}]) (Heisey and Norton 2007). Ju et al. (2009) showed that intensive nitrogen (N) fertilizer use in China's major agricultural areas has resulted in serious environmental problems. The high rate of N fertilizer use has led to large N losses in the form of ammonia (NH_3) volatilization and N leaching into ground water and lakes (Zhu and Chen 2002). Moreover, it is estimated that the manufacture and use of N fertilizer contributed to approximately 30% of agricultural greenhouse gas (GHG) emissions and more than 5% of China's total GHG emission in 2007 (SAIN 2010). Improved N management is of great importance in both the mitigation of climate change and sustainability of agricultural production (IPCC 2007).

Recent studies have also shown that there have been excessively high uses or overuses of N fertilizer by Chinese farmers. For wheat, the average amount of N fertilizer use was 270 kg ha^{-1} (241 lb ac^{-1}) in 2002 in the North China Plain (NCP), which is the major wheat and maize production region in China (Chen 2003). Cui (2005) also observed an average application of 249 kg ha^{-1} (222 lb ac^{-1}) of N fertilizer for maize in the NCP in 2004. Wang et al. (2007) found that rice farmers in Zhejiang applied 180 kg ha^{-1} (161 lb ac^{-1}) of N fertilizer for double rice crops and 240 kg ha^{-1} (214 lb ac^{-1}) of N fertilizer for single late season rice in early 2000. Peng et al. (2006) found that the same yield can be maintained by applying 60 to 120 kg ha^{-1} (54 to 107 lb ac^{-1}) of N fertilizer in rice production in China, which is significantly lower than rice farmers' practices of 180 to 240 kg ha^{-1} (161 to 214 lb ac^{-1}). Hu et al. (2007) found that farmers used 177 kg N fertilizer ha^{-1} (158 lb ac^{-1}) in major rice production regions in China, and with appropriate N fertilizer use technology, N fertilizer could be reduced by more than 30% without lowering (and even increasing) rice yield.

If farmers have been overusing N fertilizer, understanding the reasons for such overuse is important for policy-makers to implement appropriate interventions to reduce farmers' fertilizer use and raise their income. Some scientists believe that there is a lack of technology to improve the efficient use of N fertilizer for farmers as substantial efforts have been made to identify efficient N fertilizer use methods in the field (Chen et al. 2006; Cui et al. 2008a, 2008b; Zhao et al. 2006). For example, to optimize the N management of winter wheat in NCP, Chen et al. (2006) developed new approaches by synchronizing N fertilizer application and N fertilizer demand over different wheat growth periods; they found that 60% of N fertilizer could be reduced without affecting wheat yield when compared with conventional N fertilization practices.

Scientists have also studied technologies for reducing N fertilizer use for maize in NCP. Based on year-round research on summer maize production, Cui et al. (2008a) found that using improved N management technologies could reduce N fertilizer use by 40% without reducing maize yield, compared with farmers' present practices (263 kg ha^{-1} [235 lb ac^{-1}] of N fertilizer). Such a reduction in N fertilizer use can increase crop profits by US$202 ha^{-1} (US$82 ac^{-1}). Improved N management in maize production can also significantly reduce environmental stress (e.g., nonpoint pollution) resulting from excessive N fertilizer use in China (Cui et al. 2008b).

However, despite great efforts made by scientists to improve the efficiency of fertilizer use, N fertilizer use continues to rise while its efficiency remains low, which has brought economists' attention to the rationality of overusing N fertilizer. Huang et al. (2008) argued that farmers' lack of knowledge and information on crop responses to N fertilizer are the primary reason for its overuse. Chinese farmers have been used to their experience from the previous Green Revolution (in the 1960s to the 1970s)

Jikun Huang is director and professor, **Cheng Xiang** is a PhD student, and **Xiangping Jia** (corresponding author) is a senior research fellow at the Center for Chinese Agricultural Policy, Institute for Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China. **Ruifa Hu** is a professor at the Beijing Institute of Technology, Beijing, China.

that significantly increased agricultural productivity through adoption of high-yield varieties and the use of highly responsive inorganic fertilizer. The Huang et al. (2008) study shows that through training and a scientist-guided, on-farm pilot experiment, N fertilizer could be reduced by about 20% to 30% in rice production in China without compromising yield.

If the above arguments are valid for N fertilizer use in rice production, several questions are raised. Can N fertilizer use also be reduced significantly in other major crops such as maize in China? Will reducing N fertilizer in crop production lead to declines in crop yields? How can the appropriate knowledge and information on the efficiency of fertilizer use be delivered to millions of small farmers in China? These questions are crucial, not only for the fertilizer industry (given the size of China's fertilizer market) but also for China's public agricultural extension system, which has a mandate to deliver technologies but has faced great challenges in offering appropriate technology and knowledge to millions of farmers (Hu et al. 2009; Huang et al. 2009).

The overall goals of this study are to provide empirical evidence for the above-raised questions by investigating the impacts of delivering information and knowledge on the efficiency of N fertilizer use in maize production through training. Maize is selected for this study for four reasons. First, maize is the number one crop in terms of sown area in China, reaching 31.2 million ha (77.1 million ac) in 2009 (NBSC 2010). Second, maize is the only cereal that has been expanding its area sown in the past decade, increasing by more than 35% in 2000 to 2009, while the area of sown rice recorded zero growth and wheat declined by about 9% over the same period (NBSC 2010). Third, as discussed above, farmers likely overuse N fertilizer in maize production. Finally, previous studies at the farm level have mainly focused on the rice sector (Huang et al. 2008; Wang et al. 2007), and little information is available on the potential reduction of N fertilizer use by farmers in maize production.

Materials and Methods

Study Sites. Experimental research was conducted in the Huimin (HM) and Shouguang (SG) Counties of the Shandong province in the NCP in 2009. These two counties were selected for two reasons. First, maize is one of the major crops produced by local farmers. Second, large-scale research experiments of N fertilizer optimization management were conducted for several years by soil scientists in the same region where these two counties are located (Cui et al. 2008a; Ju et al. 2009), which provides useful information for this study on appropriate methods to reduce N fertilizer application.

Maize in Shandong is mainly planted in the middle of June (after winter wheat harvest) and is harvested at the end of September. As 70% to 80% of the annual precipitation falls during the maize growing season, and most nitrate-N (NO_3-N) flow also occurs in this period, maize is a very important crop for capturing excessive soil NO_3-N and limiting its movement out of the root zone. However, the average N fertilizer use by farmers in maize production in the NCP was high, more than 40% higher than the amount recommended by scientists based on N fertilizer optimization use technology in 2005 (Cui et al. 2008a).

Sampling Method and Experiment Design. In both HM and SG Counties, 3 townships, and 5 villages from each township were randomly selected. In total, 6 townships and 30 villages were selected from two counties. In each township, the 5 villages were divided into 2 groups: 3 treated villages and 2 nontreated villages. In total, there were 18 treated villages and 12 nontreated villages from HM and SG. Villages were randomly selected to ensure these two groups of villages were comparable before the N fertilizer use training course was conducted in the treated villages.

For each of the treated villages, a training course on N fertilizer use in maize production was offered to farmers by the trained extension staff in May of 2009, prior to maize being planted. The extension staff was selected from local townships and was trained by the China Agricultural University. Extension staff came to each of the treated villages and randomly selected a group of farmers for training. For each training course, extension staff selected a group consisting of approximately 30 farmers who lived in the neighborhood. All farmers in the group were invited to attend the training course. Based on this approach, potential bias was minimized in sample selection within treated villages. After farmers were selected, the extension staff offered one-hour training courses to 20 to 30 farmers; hereafter, these farmers are referred to as the trained farmers in the treated villages.

Key information delivered in the training course was provided by soil scientists. Information provided during the training was based on the local soil situation and the results of N fertilizer management experiments in maize production conducted by soil scientists from the China Agricultural University in HM and SG. Farmers were advised to use N fertilizer in the following ways: (1) controlling the total amount of N fertilizer use between 150 and 180 kg ha^{-1} (134 to 161 lb ac^{-1}); and (2) applying N fertilizer during maize growing season twice—once before the 10-leaf stage and once after the 10-leaf stage.

For comparison, there were two types of nontrained farmers: nontrained farmers in treated villages and farmers in nontreated villages. These two types of farmers were used for comparison in order to see whether there could be any technology diffusion from the trained farmers to other farmers in the treated villages.

In November 2009 after the maize was harvested, farmers were randomly selected from both treated and nontreated villages for a face-to-face, questionnaire-based household survey. In each of the treated villages, about 30 farmers who planted maize were randomly selected. During the survey, the sample size in the treated village slightly varied according to the village size. In total, 577 farmers were selected from treated villages. By asking whether the households participated in the training course offered by this study in treated villages, trained farmers and nontrained farmers were identified. Among 577 farmers, there were 103 farmers who participated in the training course on N fertilizer use and 474 farmers who were not trained (table 1). The low share (18%) of trained farmers in the samples reflects the fact that there is a lack of extension services provided by extension staff to farmers in rural China (Huang et al. 2009).

The second type of farmers from nontreated villages was also randomly selected for comparison. In each of these villages, 20 farmers were randomly selected for a face-to-face questionnaire-based household survey, just as was done for those farmers from treated villages in November of 2009. At the end, a total of 236 farmers from nontreated villages were surveyed (table 1).

The survey covered both basic household information and maize production at the plot level. Because a typical farmer in the study sites normally had two to three plots of maize planted, in the survey one plot was selected with the largest maize area. For this plot, detailed information on maize production, particularly fertilizer use, was surveyed. The trained interviewers spent about two hours interviewing each farmer.

Table 1 summarizes the characteristics of both trained and nontrained farmers in treated and nontreated villages. The results show that, in general, trained and nontrained farmers are very comparable. For example, all three groups of farmers had nearly the same average farm size (0.6 ha [1.5 ac])(table 1). When looking at household demographics (e.g., household population, age of household head, share of off-farm labor before the maize season, and consumption asset value per capita), this study found that the trained farmers in treated villages were not significantly different from the nontrained farmers in treated villages and farmers in nontreated villages. The only exception is education status of household head. Trained farmers in treated villages were found to receive more education (7.5 years) than the other two groups (6.5 and 6.7 years, respectively). However, the absolute difference is only about 1 year. There was also no significant difference between trained and nontrained farmers' access to fertilizer markets.

Table 1

Characteristics of trained and nontrained farmers in 2009.

		Nontrained farmers	
Characteristic	Trained farmers	Treated villages	Nontreated villages
Samples	103.0	474.0	236.0
Cultivated land (ha)	0.6	0.6	0.6
Household population	4.1	4.0	3.8
Age of household head (y)	51.6	50.3	51.0
Education of household head (y)	7.5	6.5**	6.7*
Share of off-farm labor before the maize season (%)	29.0	26.0	25.0
Consumption asset per capita (¥1000)	22.0	19.0	20.0
Distance to nearest fertilizer shop (km)	1.0	1.1	0.9

*p < 0.05 **p < 0.01

Table 2

Average fertilizer use by trained and nontrained farmers in maize production in 2009.

		Nontrained farmers	
Fertilizer	Trained farmers	Treated villages	Nontreated villages
Inorganic fertilizers			
Number of application	1.48	1.68*	1.56
Amount used (kg ha^{-1}) †			
Nitrogen	201	252*	259*
Phosphorus	88	85	86
Potassium	45	30*	43
Organic fertilizer			
Number of applications	0	0.03	0.03
Nitrogen (kg ha^{-1}) †	0	4	2

*p < 0.01

† The figures indicate pure content of nitrogen, phosphorus, and potassium.

Results and Discussion

Fertilizer Use and Nitrogen Fertilizer Application. Table 2 reports average fertilizer use by trained and nontrained farmers in 2009, which provides several interesting observations. First, it seems that farmers were not interested in applying fertilizers twice during one maize growing reason—one of two key findings provided in the training course. For trained farmers, the average inorganic fertilizer application (1.48 times) was even statistically significantly lower than nontrained farmers (1.68 times) in the same village. Moreover, no statistically significant difference was found in the number of inorganic fertilizer applications between trained farmers and farmers from nontreated villages (table 2). There are two possible explanations for this unexpected finding. Farmers might be used to their conventional fertilizer application practices, and as such, it was difficult to change their fertilizer use behaviors in the short term. Some farmers might also be concerned about increased labor input by changing their one-time fertilizer application to a two-time application. While this paper is not able to empirically examine the reasons behind the above observation, it is an interesting issue that requires further study.

Second and most importantly, while the application time did not change with the introduction of training, trained farmers used much less N fertilizer than nontrained farmers (table 2). Nontrained farmers applied an average of 252 kg ha^{-1} (225 lb ac^{-1}) of inorganic N fertilizer in treated villages and 259 kg ha^{-1} (231 lb ac^{-1}) in nontreated villages, which is more than 50% higher than the amount recommended by scientists (150 to 180 kg ha^{-1} [134 to 161 lb ac^{-1}]). The observed N fertilizer use for nontrained farmers in this study is consistent with the findings from existing literature. For example, Cui (2005) found an average application of 249 kg ha^{-1} (222 lb ac^{-1}) N from 370 farmers in Shandong. In the findings of this study, the trained farmers applied an average of 201 kg ha^{-1} (179 lb ac^{-1}) of N fertilizer, or about 20% less N fertilizer use than nontrained farmers in the treated villages (252 kg ha^{-1} [225 lb ac^{-1}]), and 22% in the nontreated villages (259 kg ha^{-1} [231 lb ac^{-1}]).

Third, despite a statistically significant effect of training on farmers' N fertilizer use, trained farmers still used much more N fertilizer than recommended by scientists. As mentioned earlier, farmers were advised to apply 150 to 180 kg ha^{-1} (134 to 161 lb ac^{-1}) of N fertilizer in maize production. However, trained farmers still applied an average of 201 kg ha^{-1} (179 lb ac^{-1}), greater than 20% more than the recommended level of N fertilizer.

The data in table 2 reveals some additional observations. Training in the improved N

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management practice for maize production had no impacts on farmers' potassium (K) and phosphorus (P) application. As shown in table 2, the average P and (K use per hectare for trained farmers in treated villages were 88 and 45 kg ha^{-1} (78 and 40 lb ac^{-1}), while the figures were 86 and 43 kg ha^{-1} (77 and 38 lb ac^{-1}), respectively, in nontreated villages. In addition to inorganic fertilizer use, some farmers also applied organic fertilizer, but in amounts that were negligible (table 2).

There were several types of inorganic N fertilizer used in maize production in China. Urea was the primary source, but trained farmers tended to use more compound fertilizer. As shown in table 3, farmers mainly used three types of inorganic N fertilizers in maize production: urea, diammonium phosphate, and other compound fertilizers. Among these, urea accounted for more than 60% of total N fertilizer. However, compared with nontrained farmers, trained farmers used more compound fertilizer (table 3). This may explain the higher use of P and K application for trained farmers in treated villages (table 2), as the compound fertilizer contains P and K.

Fertilizer Use and Household Characteristics. Farmers' N fertilizer use might also be associated with some of their household characteristics. As shown in table 4, farmers' N fertilizer use was either positively or negatively related with cultivating land area, access to fertilizer markets, and other characteristics. For example, farmers with large farms tended to use less N fertilizer per hectare. When household cultivated land area went from less than 0.33 ha (0.81 ac) to more than 0.56 ha (1.38 ac), the N fertilizer use tended to decrease by about 5% (table 4). Meanwhile, large-area farmers tended to increase the number of applications, implying that these farmers used less N fertilizer per application. There was no clear relation between N fertilizer use and age of farmers, but there was a negative relationship between N fertilizer use and farmers' education (table 4). Female-headed households tended to use higher N fertilizer (table 4).

Access to the fertilizer market is positively related with farmers' N fertilizer use in maize production. As shown in table 4, most farmers were able to purchase fertilizer in local and neighborhood villages, as the distance to the nearest fertilizer shop was less than 1.5 km (0.9 mi) away for 75% of the sample. It is not surprising that maize farmers applied less N fertilizer when the fertilizer sellers were

Table 3

Percentage of inorganic nitrogen fertilizer use from different sources by trained and nontrained farmers in maize production in 2009.

Source	Trained farmers (%)	Nontrained farmers: Treated villages (%)	Nontrained farmers: Nontreated villages (%)
Urea	62	75*	70*
Diammonium phosphate	6	8	5
Other compound fertilizers	32	17*	25

*p < 0.01

Table 4

Nitrogen (N) fertilizer use in maize production and household characteristics in 2009.

Characteristic	Samples	Total N fertilizer use* (kg ha^{-1})	Inorganic N fertilizer use* (kg ha^{-1})	Number of inorganic fertilizer applications
All households	813	250	248	1.62
Household land area (ha)				
<0.33	223	259	256	1.47
0.33 to 0.56	264	245	245	1.61
>0.56	326	249	244	1.73
Age of household head (y)				
<46	296	249	244	1.65
46 to 56	273	242	240	1.62
>56	244	262	260	1.58
Education of household head (y)				
<6	266	265	263	1.64
6 to 9	456	247	244	1.60
>9	91	224	222	1.67
Gender of household head				
Female headed	105	277	274	1.73
Male headed	708	246	244	1.60
Share of off-farm labor before the maize season (%)				
<25	380	257	254	1.61
25 to 50	331	250	248	1.64
>50	102	225	224	1.59
Consumption asset per capita in 2009 (¥1,000)				
<10	245	267	264	1.67
10 to 20	250	239	237	1.62
>20	318	246	243	1.58
Distance to nearest fertilizer shop (km)				
<0.25	324	258	255	1.62
0.25 to 1.5	284	251	249	1.64
>1.5	205	236	233	1.60
County				
Huimin	471	276	274	1.84
Shouguang	342	215	211	1.32

* The figures indicate pure N content.

Table 5
Descriptive statistics of all variables used in the regression analysis.

Variable	Mean	Standard deviation
Total nitrogen fertilizer (kg ha^{-1})	250	119
Inorganic nitrogen fertilizer (kg ha^{-1})	248	116
Numbers of inorganic fertilizer application	1.62	0.60
Trained farmers in treated villages (Yes = 1; No = 0)	0.13	0.33
Nontrained farmers in treated villages (Yes = 1; No = 0)	0.58	0.49
Household land area (ha)	0.56	0.41
Age of household head (y)	51	11
Education of household head (y)	7	3
Female headed household (Yes = 1; No = 0)	0.13	0.34
Share of off-farm labor before the maize season (%)	26	28
Consumption asset per capita in 2009 (¥1,000)	20	19
Distance to nearest fertilizer shop (km)	1.03	1.03
County dummy (1 = Huimin; 0 = Shouguang)	0.58	0.49

distant. There were also regional differences in N fertilizer use. Farmers in HM used much more N fertilizer than those in SG.

Multivariate Analysis of the Impacts of Knowledge Training on Farmers' Nitrogen Fertilizer Use. Based on the survey data, a cross section dataset was created consisting of 813 farmers from 30 villages in two counties in the Shandong province in China. To estimate the impacts of training on maize farmers' N fertilizer use, the following empirical model is specified:

$$N_{ij} = a + b(TFarmT_i) + c(NTFarmT_i) + \varphi(X) + \varepsilon_i, \quad (1)$$

where N_{ij} is the i^{th} household's N fertilizer use per hectares, which is measured in three ways (j = 1, 2, and 3), total N fertilizer use (from both inorganic and organic fertilizer) per hectare, inorganic N fertilizer use per hectare, and the number of N inorganic fertilizer applications. The key independent variable of interest is *TFarmT*, trained farmers in treated village, which falls on the right hand side of equation 1; it is a binary variable that equals 1 if a household attended the N fertilizer application training in the treated village, otherwise it equals 0. *NTFarmT* indicates nontrained farmers in treated village; it is designed to catch the likely spill-over effect within a treated village. The bases for comparison are those households from nontreated villages.

As a set of control variables, X includes a household's demographics (for example, land area, age of household head, education of household head, female headed household, share of off-farm labor before the maize season, and consumption asset per capita in 2009), and regional characteristics (for example, access to the nearest fertilizer shop and county dummy variable). The term ε_i is the idiosyncratic error term. Marginal effects to be estimated include b, c, and φ. A summary of statistics of both dependent and independent variables is presented in table 5.

To estimate equation 1, an Ordinary Least Squares estimator (OLS) and OLS with logarithmic transformation for nondiscrete variables (including the dependent variable and six independent variables, the latter of which include household land area, age and education of household head, share of off-farm labor before the maize season, consumption asset per capita, and distance to the nearest fertilizer shop) were specified. While the former presents marginal effects directly, the logarithmic functional specification directly provides coefficients with percentage effect interpretations.

The modeling performs well, and the results are presented in table 6. The estimated coefficients of variables of interest and for control have intuitive signs. When estimating the impacts of training on farmers' overall N use and inorganic N fertilizer use, the coefficients are significantly negative, and the results are similar in either linear or logarithmic specifications (table 6). The statistical significance for all estimated coefficients is also robust and consistent in both OLS and logarithmic transformation specifications. Since inorganic fertilizer accounts for the majority of N use in maize production, the following discussion focuses on the impacts of N fertilizer application training on inorganic N fertilizer use (table 6).

Regression results show that the training led to a significant reduction (22%) of inorganic N fertilizer use by trained farmers in treated villages. As shown in table 6, the coefficient of the knowledge training is negative and statistically significant, implying that *ceteris paribus* the trained farmers in treatment villages reduced inorganic N application by 46.82 kg ha^{-1} (42 lb ac^{-1}) compared with farmers in nontreated villages. The reduction rate related to knowledge training is 22% (table 6); the training was thus effective in reducing maize farmers' N use.

Interestingly, the results also show that farmers who did not receive the direct training in the treated villages also used less N fertilizer than those in nontreated villages. As shown in table 6, coefficients of nontrained farmers in treated villages are negative and significant (–15.71; –0.08), implying that, compared to farmers in nontreated villages, farmers who did not receive the direct training in the treated villages reduced the use of N fertilizer by 15.71 kg ha^{-1} (14 lb ac^{-1}, namely an 8% reduction) when holding all else constant. This implies that there is evidence of a knowledge spillover effect.

While there are several controlling variables in different sets of regressions, only three variables are shown to have a statistically significant effect on farmers' N fertilizer use: household land area, distance to nearest fertilizer shop, and county or locations. The rising negative household land area or farm size could result in a significant reduction on N fertilizer use per hectare (table 6). Double farm size could reduce N fertilizer use by 14%. As expected, the closer a local fertilizer seller was, the more N fertilizer was applied by farmers in maize production.

Lastly, notwithstanding that trained farmers reduced overall N fertilizer use in maize production, the yield was not affected. As shown in table 7, the average yield of maize for trained farmers in treated villages did not decrease when comparing the figures for farmers in nontreated villages. Admittedly, the higher yield of trained farmers is difficult to explain. But in the literature, several studies reported maintained and even increased crop yields with the appropriate reduction of N fertilizer use (Cui et al. 2008a; Ju et al. 2009; Peng et al. 2006).

Summary and Conclusions

Inorganic fertilizer plays an important role in increasing food production in China.

Table 6
Estimated results of farmers' nitrogen (N) fertilizer use in maize production in Shandong, China, in 2009.

	Total N fertilizer use† (kg ha^{-1})		Inorganic N fertilizer use† (kg ha^{-1})		Number of inorganic fertilizer applications	
Variable	TN	Ln (TN)	CN	Ln (CN)	Freq	Ln (Freq)
Trained farmers in treated villages (Yes = 1; No = 0)	−49.29*** (3.65)	−0.23** (3.43)	−46.82** (3.59)	−0.22** (3.37)	−0.03 (0.52)	−0.01 (0.28)
Nontrained farmers in treated villages (Yes = 1; No = 0)	−13.83 (1.50)	−0.08* (1.71)	−15.71* (1.76)	−0.08* (1.91)	0.04 (0.89)	0.02 (0.67)
Household land area (ha)	−33.47*** (3.37)	−0.14 *** (4.57)	−37.25*** (3.88)	−0.14*** (4.68)	0.00 (0.09)	−0.01 (0.73)
Age of household head (y)	0.24 (0.58)	0.02 (0.16)	0.31 (0.79)	0.03 (0.27)	0.00 (0.13)	−0.002 (0.04)
Education of household head (y)	−1.47 (1.10)	−0.01 (0.92)	−1.62 (1.26)	−0.01 (0.89)	0.01** (2.06)	0.01 (1.59)
Female headed household (Yes = 1; No = 0)	14.38 (1.16)	0.05(0.79)	12.92 (1.08)	0.04 (0.66)	0.05 (0.94)	0.03 (0.76)
Share of off-farm labor before maize season (%)	−0.21 (1.43)	0.001 (0.22)	−0.18 (1.24)	0.002 (0.34)	−0.00 (0.50)	−0.00 (0.17)
Consumption asset per capita in 2009 (¥1,000)	−0.09 (0.42)	−0.005 (0.26)	−0.07 (0.35)	−0.01 (0.27)	0.00 (0.28)	0.005 (0.38)
Distance to nearest fertilizer shop (km)	−4.60 (1.14)	−0.01* (1.68)	−4.54 (1.17)	−0.01* (1.69)	0.03 (1.62)	0.01** (2.16)
County dummy (1 = Huimin; 0 = Shouguang)	59.60*** (6.79)	0.30*** (6.72)	62.42*** (7.37)	0.32*** (7.02)	0.53*** (12.80)	0.35*** (11.14)
Intercept	256.92*** (8.76)	5.11*** (12.93)	251.47*** (8.88)	5.06*** (12.92)	1.16*** (8.38)	0.17 (0.62)

Notes: Total samples used in regressions are 813. The figures in the parentheses are absolute *t*-ratios of estimates. TN = total nitrogen. CN = inorganic nitrogen. Freq = frequency.

*$p < 0.1$ **$p < 0.05$ ***$p < 0.01$

† The figures indicate pure N content.

However, farmers in China use much more fertilizer per hectare than do farmers in many other countries. This paper seeks to find appropriate measures to reduce excess fertilizer use through a training program. The results show that delivering information and knowledge on the efficiency of N fertilizer can significantly lower inorganic N fertilizer use by 22% in maize production in the NCP; knowledge training indeed matters. Farm size is negatively associated with per hectare N fertilizer use.

The findings of this study have important policy implications. Besides economic benefits for farmers reducing N fertilizer use, the environmental benefits can also be substantial, as excessive N fertilizer use in China has led to large N losses through NH_3 volatilization and N leaching into ground water, rivers, and lakes (Xing and Zhu 2000; Zhu and Chen 2002). Moreover, as 30% of agricultural GHG emissions come from N fertilizer production and utilization and agriculture has accounted for about 18% of GHG in China during recent years, reducing N fertilizer use in agriculture can significantly contribute to a reduction of China's GHG emissions and should be considered as a critical component of China's low carbon agricultural initiative in the coming years (SAIN 2010). Policies on land rental markets or land consolidation programs that aim to expand farm size can also help Chinese farmers reduce N fertilizer use in crop production.

However, training more than 200 million small farmers is not without cost, and despite significant reductions of N fertilizer use by farmers after training, farmers still use N fertilizer at higher than recommended levels. Whether China's current agricultural extension system can deliver appropriate information and knowledge on the efficiency of N fertilizer to millions of farmers is an issue that requires further study since the existing agricultural extension system also faces great challenges related to providing technology services to farmers (Hu et al. 2009).

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Table 7
Yield (kg ha^{-1}) of maize in treated and nontreated villages in 2009.

		Nontrained farmers	
Items	Trained farmers	Treated village	Nontreated village
Average yield	7,845	6,993*	7,065*
County			
Huimin	6,730	6,468	6,500
Shouguang	8,511	7,985*	7,829*

*$p < 0.01$

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