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RESEARCH ARTICLE

Farmer's Adoption of Improved Nitrogen Management Strategies in Maize Production in China: an Experimental Knowledge Training

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Abstract

Chemical fertilizer plays an important role in increasing food production in China. Nevertheless, excessive nitrogen fertilizer use in China has resulted in severe environmental problems. The goal of this paper is to examine the impacts of an improved nitrogen management (INM) training experiment on farmers' chemical nitrogen (N) use behaviors in maize production in China. Based on household data collected from 813 maize farmers in Shandong, China, this study finds that while INM training can significantly reduce farmers' N fertilizer use, an INM training is not sufficient to change farmer's practices significantly, and farmers only partially adopted the recommended INM. This study reveals that China faces challenges to transform its agriculture to a low-carbon one. The research also sheds light on China's extension system and future technologies in meeting the objectives of reducing the excessive nitrogen fertilizer use in agricultural production.

Key words: maize, nitrogen, training, farmer, China

INTRODUCTION

While fertilizer use is an important way to increase crop yields, excessive usage of chemical fertilizer in China is prevalent and getting severe. By 2000, the average fertilizer nutrient application in China was more than 200 kg ha^{-1}, which was much larger than average application in India (less than 100 kg ha^{-1}) and the industrialized countries (about 120 kg ha^{-1}) (Heisey and Norton 2007). Measured in partial factor productivity (PFP) of nitrogen (N) use, the PFP of China's N in maize production was 27 kg kg^{-1} in 1997-2000, while it was 53 kg kg^{-1} in USA and 100 kg kg^{-1} in Argentina in the same years (Zhang *et al*. 2007). By surveying 370 maize farmers in Shandong Province, China, Cui (2005) found an average application of 249 kg N ha^{-1} in maize production in 2004 and 40% of N fertilizer use can be saved by improving farming practice. A recent study shows that N fertilizer use in maize production in the same area of Cui's study further increased to 259 kg N ha^{-1}, and the rate was 57% higher than the recommendation (Huang *et al*. 2012). Such an excessive use was not only found in grain production (Cai *et al*. 2002; Chen *et al*. 2006; Cui *et al*. 2008a; Ma *et al*. 2008), but also in greenhouse vegetable farming (Chen *et al*. 2004;

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He *et al*. 2009).

The overuse of nitrogen fertilizer has resulted in serious environmental stress by increasing greenhouse gas emissions and polluting ground and surface water through nitrogen leaching (Izaurralde *et al*. 2000). Overuse of nitrogen fertilizers in China has also led to increasing environmental damage (Zhu and Chen 2002; Ju *et al*. 2009). Direct N_2O emission from agricultural fields in China in 1990 was 0.282 Tg N, and the total NH_3 volatilization from agricultural fields accounted for 11% of the applied synthetic fertilizer (Xing and Zhu 2000).

Scientists attribute the excessive use of nitrogen (N) fertilizer in China to inappropriate farming management. As such, substantial efforts have been made to identify more efficient N fertilizer use in field (Chen 2003; Cui 2005). However, Chinese farmers' N fertilizer use continues to grow, and its efficiency remains low (Zhang *et al*. 2007; Cui *et al*. 2008a), drawing attention to the importance of overuse of N fertilizer by economists. Huang *et al*. (2008) argued that farmer's lack of knowledge and information on crop response to N fertilizer are the primary reasons for its overuse. Chinese farmers had been relying on previous experience during the Green Revolution (during 1960-1980) that suggested more fertilizer use led to higher crop yield. Huang *et al*. (2008) showed that through training and scientist-guided on-farm pilot experiments, N fertilizer could be reduced by about 20-30% in rice production without compromising rice yield.

Economists view technology adoption in agriculture as a complicated process ranging from partial to full adoption that depends on heterogeneity in human capital, risk preference, and geographic considerations (Feder and Umali 1993; Sunding and Zilberman 2001). For example, Leathers and Smale (1991) found that, even as uncertainty falls with experience, farmers might choose to only some components of a technology package rather than the complete technology. Sunding and Zilberman (2001) reviewed the adoption studies on credit, tenure, and other institutional constraints and concluded that, due to these financial or institutional constraints, partial technology adoption is common in household economies in agriculture.

In developed countries, site-specific nitrogen management (SSNM) that targets input applications more precisely to match the spatial and seasonal variability in soil conditions has been studied. For example, Thrikawala *et al*. (1999) found that the environmental benefits of site-specific nitrogen management in maize production were higher than those with conventional practices. However, the authors found that SSNM involved high application costs and the net returns were higher for the conventional methods. Using evidence from four midwestern states in the US, Khanna (2001) found that farmers adopted the SSNM sequentially and partially. But those non-adopters could also achieve large gains in productivity. The authors concluded that agro-environmental policies mandating the adoption of the complete site-specific technologies are likely to be inefficient.

Given the efforts made by scientists to improve the efficiency of nitrogen fertilizer use in China and the experience in developed countries with SSNM technologies, we explore new approach that may facilitate adoption of improved nitrogen management by small-scale farmers in China. In exploring this new approach, we focus on the effectiveness of reducing overuse of nitrogen through delivering information on appropriate nitrogen use technology by offering a training course to farmers in villages. Answers to this question have important implications for agricultural technology extension and N fertilizer use in China.

The overall goal of this paper is to examine impacts of improved nitrogen management (INM) training experiment on farmers' chemical nitrogen use behaviors in maize production in China. To achieve this goal, the paper is organized as follows. Section 2 briefly introduces the research design, a training program on INM, and the survey and data collection methods. Section 3 compares the nitrogen fertilizer use behavior between trained and untrained farmers. In section 4, we investigate the impacts of training on farmers' adoption of INM. Conclusions are provided in the last section.

RESEARCH DESIGN AND DATA

Site description and INM

The experimental study was implemented in two counties in Shandong Province. As one of the major maize production provinces in China, Shandong is located in North China Plain (NCP). In the recent years, soil scientists have conducted several studies in Huimin (HM) and Shouguang (SG) on optimized fertilization strategies based on large-scale soil tests. Hence, appropriate knowledge- and experiment-based N fertilizer application techniques are available for farmers in these two counties (Cui *et al.* 2008b; Ju *et al.* 2009).

Chemical N fertilizer has been overused in NCP (Cui *et al.* 2008a). Maize in Shandong is mainly planted in the middle of June (after harvesting winter wheat) and is harvested at the end of September. As 70-80% of the annual precipitation is concentrated during maize growing season and most nitrate-N flow also occurs in this period, maize is a very important crop for capturing excessive soil nitrate-N and limiting its movement out of the root zone. Nevertheless, the average N fertilizer use in NCP was 263 kg ha^{-1} in 2005, 40% higher than the amount recommended by scientists (Cui *et al.* 2008b).

Based on regional soil characteristics and the results of N fertilizer management experiments conducted by soil scientists from China Agricultural University in the two counties, a fine-tuned and simplified nitrogen optimization management system, called INM, was provided to farmers in maize production in HM and SG. There are three major components in this INM: 1) limit total amount of N fertilizer use to between 150 and 180 kg ha^{-1}; 2) apply N fertilizer twice; and 3) limit N fertilizer use before and after the 10-leaf stage to 50-60 kg ha^{-1} and 100-120 kg ha^{-1}, respectively.

Sampling method and experiment design

In each of HM and SG counties, we randomly selected 3 townships and within each township 5 villages. In total there were 30 sampled villages in the two counties. In each township, we divided the 5 villages into 2 groups: 3 treated villages and 2 non-treated villages. In the total, there were 18 treated villages and 12 non-treated villages from HM and SG.

For each of the treated villages, a training course on INM in maize production was offered to farmers by trained extension staff in May 2009 before maize was planted. The extension staffs were selected from local township extension stations and were trained by the soil scientists from China Agricultural University. The trained staffs were asked to offer one-hour training course to 20-30 maize farmers in the treated villages. We refer to them in the treated villages as “trained farmers”.

For comparison, we construct two control groups of farmers, non-trained farmers in treated village and farmers in non-treated villages. Non-trained farmers in treated villages are those who did not participated in the training course in the treated villages. This comparison group allows us to see whether there is technology diffusion from the trained farmers to others in the same treated villages.

In November 2009, we conducted a questionnaire-based household survey immediately after the maize was harvested. In each treated village, we randomly surveyed on average 30 maize farmers. We designed to survey on 30 maize farmers in each treated village. During the survey, the sample size in treated village slightly varies (18 to 43) according to the village size. By asking whether the household participated in the training about improved nitrogen management, we can differentiate between trained farmers and non-trained farmers in treated villages. In total, 103 farmers received the training in the 18 treated villages (Table 1, column 1). The average number of trained farmers surveyed in treated villages is about 6, which accounts for 18% of the sampled households (30) in treated villages. In each of the non-treated villages, we randomly surveyed 20 maize farmers for the comparison (or control) group. The number of farmers in the non-treated villages totals 236 (Table 1, column 1).

For all surveyed farmers, in addition to the questions on participation in the experimental training course, we also asked about farmers’ maize production and inputs (e.g., fertilizer use, pesticide use, irrigation, and labor inputs) on the biggest maize plots, basic demographic characteristics, and farmers’ knowledge of fertilizer use in the field. It’s important to note that because very few farmers used manure in maize production in HM and SG, the N fertilizer use refers to only nitrogen input from chemical fertilizers in this study.

ADOPTING INM IN MAIZE PRODUCTION

N fertilizer use and INM training

The training that was tested in this study reduced farm-

Table 1 Chemical nitrogen fertilizer use by trained and non-trained farmers in maize production in 2009[1)]

	Samples (1)	N fertilizer use (kg ha^{-1})		
		Overall (2)	Before 10-leaf (3)	After 10-leaf (4)
All households	813	248	122	126
Trained farmers in treated villages	103	201	101	100
Non-trained farmers in treated villages	474	252***	122*	130**
Farmers in non-treated villages	236	259***	132**	127*
Huimin (HM)	471	274	105	169
Trained farmers in treated villages	37	238	102	136
Non-trained farmers in treated villages	314	268	104	164
Farmers in non-treated villages	120	301***	108	193**
Shouguang (SG)	342	211	146	65
Trained farmers in treated villages	66	179	99	80
Non-trained farmers in treated villages	160	221***	158***	63
Farmers in non-treated villages	116	217**	157***	60

1) The figures indicate pure N content.

*, ** and ***, statistical significance of the mean different from trained farmers in treated villages at 10, 5 and 1% level, respectively. Source: author's survey. The same as below.

ers' overall N fertilizer use. As shown in Table 1 (column 2), the overall N fertilizer use by the trained farmers in treated villages (during an entire maize season) was 201 kg ha^{-1}, an amount close to the recommended level of 150-180 kg ha^{-1}. The N fertilizer use by non-trained farmers in treated villages and farmers in non-treated villages was much higher than that of the trained farmers, with an average of 252 and 259, respectively.

The INM training, however, did not achieve the goal of balancing N fertilizer use before and after the 10-leaf stage. The INM guideline is to reduce the N fertilizer use before the 10-leaf stage to 50-60 kg ha^{-1} and maintaining N use at 100-120 kg ha^{-1} after the 10-leaf stage. From the descriptive results in Table 1, we find that the INM training led to reduced N fertilizer use both before and after the 10-leaf stage. For example, as shown in Table 1 (column 3), the trained farmers used 101 kg N fertilizer ha^{-1} before the 10-leaf stage and the farmers in non-treated villages used 132 kg N fertilizer ha^{-1}. Thus, there was still excessive use of N fertilizer. For N fertilizer use after the 10-leaf stage, we find that trained farmers used 100 kg ha^{-1}. For non-trained farmers in treated villages and farmers in non-treated villages, N fertilizer use was 130 and 127 kg ha^{-1}, respectively. Training seems to be ineffective in balancing the N fertilizer use before and after the 10-leaf stage.

Regional heterogeneity of N fertilizer use in maize production

Farmer's N fertilizer use practices in maize production differed between SG and HM. While maize farmers in HM generally used more N fertilizer after the 10-leaf stage, SG farmers used more N fertilizer before the 10-leaf stage in maize production. As shown in Table 1 (columns 3 and 4), the average N fertilizer use before the 10-leaf stage in HM and SG were 105 and 146 kg ha^{-1}, respectively. The average N fertilizer use after the 10-leaf stage in HM was 169 kg ha^{-1}, an amount almost 3 times as high as that in SG (65 kg ha^{-1}).

Most farmers in HM used N fertilizer in maize production twice or more per season but in SG the majority of farmers used N fertilizer only once per season. In Table 2, we decompose farmers in both HM and SG by the number of N fertilizer applications during maize production. In HM, 81% of trained farmers who used N fertilizer twice (70%) or three times (11%); the corresponding numbers were 76% (66+10, column 2) for non-trained farmers in treated villages and 72% (65+7, column 3) for non-trained farmers in non-treated villages. In SG, more than two-thirds of farmers used N fertilizer in maize production one time only (i.e., 80% for trained farmers and 66-69% for non trained farmers).

Not all farmers who use N fertilizer twice or more balanced the N fertilizer use before and after the 10-leaf stage. For example, in SG, nearly 8% (5+3, column 1, Table 2) of trained farmers used N fertilizer twice either before or after the 10-leaf stage. The figure was 16% for non-trained farmers in treated villages and 15% for farmers in non-treated villages. Similar results are found in HM. For example, for farmers who participated in INM training, 11% of them used N fertilizer twice before the 10-leaf stage (column 1, Table

2). For non-trained farmers in treated villages and farmers in non-treated villages, the figures were 9 and 6% (columns 2 and 3, Table 2), respectively.

The distinct farming practices in N fertilizer applications in maize production in HM and SG led to different impacts of training on farmer's adoption of INM. In HM where farmers intensively used N fertilizer after the 10-leaf stage, the effectiveness of INM training was minor in reducing N fertilizer use before the 10-leaf stage, but N fertilizer use after the 10-leaf stage fell significantly. As shown in Table 3, for farmers in HM who applied N fertilizer twice, trained farmers used N fertilizer 147 kg of N fertilizer ha^{-1}. In comparison, farmers in non-treated villages used 224 kg ha^{-1}. INM training effectively reduced farmer's N fertilizer use after the 10-leaf stage in HM. In SG where farmers mostly applied fertilizer once only before the 10-leaf stage, INM training reduced N fertilizer use by 90 kg ha^{-1} for single application and 137 kg ha^{-1} for trained farmers who applied two time applications for trained farmers. Untrained farmers applied about 140 kg ha^{-1} (136-142) for single application and more than 190 kg ha^{-1} (190-194) in double applications (Table 3).

N fertilizer use and household demographics

N fertilizer use in maize production in SG and HM is related to a farmer's demographic characteristics. The larger the farm size is, the better INM recommendation was adopted for maize production. As shown in Table 4 (column 1), when household land area increased from less than 0.33 ha to more than 0.56 ha, the overall N fertilize use decreased from 256 to 244 kg ha^{-1}. Most of this reduction occurred before the 10-leaf stage. For example, N fertilizer use before the 10-leaf stage decreased sharply from 143 to 116 kg ha^{-1} when the farm size increased from less than 0.33 ha to more than 0.56 ha. Meanwhile, large farms tended to increase N fertilizer use after the 10-leaf stage.

Education, age, and off-farm activities are also related to N fertilizer use in maize production. As shown in Table 4 (column 1), the older a household head was, the more N fertilizer was used in maize production. In addition, the more educated a household head was, the less N fertilizer was used. Interestingly, when more household labor was engaged in off-farm activities prior to the maize production in 2009, overall N fertilizer use tended to be low, with most the differential use occurring after the 10-leaf stage.

IMPACTS OF TRAINING ON ADOPTING INM: MULTIVARIATE ANALYSIS

Because many factors might be simultaneously affect-

Table 2 Sample of chemical nitrogen fertilizer use frequency by trained and non-trained farmers in maize production in 2009

	Trained farmers (%) (1)	Non-trained farmers (%)	
		In treated villages (2)	In non-treated villages (3)
HM	100	100	100
1 time application	19	24	28
Before 10-leaf	14	11	14
After 10-leaf	5	13	14
2 time application	70	66	65
One before and one after	59	53	57
Only before 10-leaf	11	9	6
Only after 10-leaf	0	4	2
3 time application	11	10	7
Both before and after	11	10	7
Only before 10-leaf	0	0	0
Only after 10-leaf	0	0	0
SG	100	100	100
1 time application	80	66	69
Before 10-leaf	50	48	51
After 10-leaf	30	18	18
2 time application	20	33	30
One before and one after	12	17	15
Only before 10-leaf	5	16	14
Only after 10-leaf	3	0	1
3 time application	0	1	1

Table 3 Chemical nitrogen fertilizer use by trained and non-trained farmers in maize production in 2009 (kg ha^{-1}) and by number of chemical nitrogen fertilizer application

	Trained farmers (1)	Non-trained farmers	
		In treated villages (2)	In non-treated villages (3)
HM			
1 time application	192	204	221
N fertilizer use before 10-leaf	135	80	102
N fertilizer use after 10-leaf	57	124	119
2 time application	240	276*	328***
N fertilizer use before 10-leaf	93	105	104
N fertilizer use after 10-leaf	147	171	224***
3 time application	309	379	375
N fertilizer use before 10-leaf	105	159	165
N fertilizer use after 10-leaf	204	220	210
SG			
1 time application	159	190**	192**
N fertilizer use before 10-leaf	90	136***	142***
N fertilizer use after 10-leaf	69	54	50
2 time application	263	276	272
N fertilizer use before 10-leaf	137	194	190
N fertilizer use after 10-leaf	126	82	82
3 time application	-	388	271

Table 4 Chemical nitrogen fertilizer use in maize production by household characteristics in 2009

	Samples	N fertilizer use (kg ha^{-1})		
		Overall (1)	Before 10-leaf (2)	After 10-leaf (3)
All households	813	248	122	126
Household land area				
<0.33 ha	223	256	143	113
0.33-0.56 ha	264	245	112	133
>0.56 ha	326	244	116	128
Age of household head				
<46	296	244	119	125
46-56	273	240	110	130
>56	244	260	139	121
Education of household head				
<6 yr	266	263	124	139
6-9 yr	456	244	123	121
>9 yr	91	222	114	108
Gender of household head				
Female headed	105	274	113	161
Male headed	708	244	124	120
Share of off-farm labor before the maize season				
<25%	380	254	129	125
25-50%	331	248	111	137
>50%	102	224	135	89
Durable consumption asset per capita in 2009				
<10000 RMB yuan	245	264	129	136
10000-20000 RMB yuan	250	237	113	124
>20000 RMB yuan	318	243	125	119
Distance to nearest fertilizer shop				
<0.25 km	324	255	114	141
0.25-1.5 km	284	249	126	123
>1.5 km	205	233	129	104

ing the observed association between farmers' N fertilizer use and the experimental knowledge and information training, multivariate analysis is needed. In this section, we specify a multivariate model that seeks to isolate the impact of training from other factors.

Model

Based on the survey data, we created a cross-section dataset consisting of 813 farmers from 2 counties, 6 townships, and 30 villages in Shandong Province in

China. To estimate the impacts of INM training on a farmer's adoption behavior in maize production, the empirical model is specified as:

$$N_{ij}=a_0+a\times TFarm_i+b\times HM_i\times TFarm_i+c\times NTFarm_i+d\times HM_i+\jmath\times X+e_i$$

Where dependent variable N_{ij} measures the overall N fertilizer use (j=1), N fertilizer use before the 10-leaf stage (j=2), and N fertilizer use after the 10-leaf stage (j=3) for the ith household.

As the key independent variable of interest on the right hand side of eq., *TFarm* refers to trained farmers in treated villages. It is a binary variable and equals to 1 if a household attended the INM training in the treated villages, otherwise it equals 0. However, not all farmers in the treated village received training. To examine likely spill-over effect within a treated village, we introduce *NTFarm*, which denotes non-trained farmers in the treated village. Both *TFarm* and *NTFarm* are compared with farmers from the non-treated villages. To examine the regional heterogeneity of adopting INM, we introduce both county dummy *HM* (which equals to 1 for farmers in HM county) and the interaction between HM county and the INM training attendance.

The control variables, *X*, include several household demographic characteristics including household land area, age of household head, education of household head, female household head, share of off-farm labor before the maize season, durable consumption assets per capita in 2009, and distance to the nearest fertilizer shop. The term e_i is the idiosyncratic error term. Marginal effects to be estimated include a_0, a, b, c, d and a vector variable $\jmath$.

To estimate the eq., we specify a Tobit model. We focus our discussions on the Tobit model due to significant proportion of household with zero N fertilizer use before and after the 10-leaf stage.

Multivariate results

The multivariate analysis of the impact of training on farmers' adoption of INM in maize production is capable of producing results that are consistent with our expectations. The signs on trained farmers in treated villages and the HM county dummy of HM county are both as expected and are consistent with descriptive statistics. The multivariate results clearly show the adaptive adoption behavior of farmers in maize production after receiving the INM training.

Regression results show the effectiveness of the training in reducing the overall N fertilizer use in both SG and HM. The coefficients for trained farmers in treated villages are significant and negative in Table 5, implying an effective reduction of overall N fertilizer use in SG after farmers received the INM training. The coefficient for the interaction between trained farmers and HM county is not statistically significant, which suggests that the impact of INM training in reducing overall use of N fertilizer in HM was not statistically different from that in SG. The coefficient for non-trained farmers in treated villages is negative (-15.39), which suggests a moderate evidence (statistically significant at 10% level) of spillover effects of INM training in the treated villages.

Interestingly, the regression results also show that INM training only led to a reduction of N fertilizer use before the 10-leaf stage in SG. In Table 5 (column 2), the coefficient for trained farmers in treated villages is significant and negative (-43.60), implying that, compared to farmers in non-treated villages, farmers in SG used 43.60 less kg ha^{-1} of N fertilizer before the 10-leaf stage. The coefficient for the interaction between trained farmers and HM county is positive (46.89) and statistically significant, implying an overall coefficient of 3.29 (46.89-43.60) for trained farmers in HM. However, the t-test shows that there is no statistically significant difference between 46.89 and 43.60 (or between 3.29 and 0), which implies that there is no obvious impact of INM training on N fertilizer use before the 10-leaf stage in maize production in HM.

While we only find evidence for a reduction of N use before the 10-leaf stage SG (and not in HM), the INM training did lead to significant reduction of N fertilizer use in HM after the 10-leaf stage. For farmers in SG who used to apply N fertilizer intensively in maize production before the 10-leaf stage prior to training, after INM training, these farmers increased N fertilizer use by 13.30 kg ha^{-1} after the 10-leaf stage (column 3, Table 5). This may be explained by farmers' concern that the reduction of N fertilizer use in the first stage might negatively affect maize growth in the later stage, and therefore, they tried to increase N fertilizer use some-

Table 5 Estimated results of farmers' nitrogen fertilizer use in maize production in 2009 based on Tobit model[1)]

	N fertilizer use (kg ha^{-1})		
	Overall (1)	Before 10-leaf (2)	After 10-leaf (3)
Trained farmers in treated villages (Yes=1; No=0)	-49.19*** (3.15)	-43.60*** (3.91)	13.30 (1.16)
Trained farmers in HM county	7.72 (0.33)	46.89** (2.82)	-32.35* (1.94)
Non-trained farmers in treated villages (Yes=1; No=0)	-15.39* (1.76)	-0.54 (0.09)	-7.42 (1.20)
HM county dummy (Yes=1; No=0)	60.52*** (6.85)	-33.88*** (5.48)	85.70*** (12.84)
Household land area (ha)	-37.18*** (3.94)	0.49 (0.08)	-26.90*** (3.43)
Age of household head (yr)	0.31 (0.79)	-0.03 (0.10)	0.17 (0.61)
Education of household head (yr)	-1.65 (1.30)	-0.35 (0.40)	-0.19 (0.21)
Female headed household (Yes=1; No=0)	12.92 (1.10)	-0.32 (0.04)	7.26 (0.89)
Share of off-farm labor before the maize season (%)	-0.17 (1.22)	0.01 (0.15)	-0.17* (1.66)
Durable consumption asset per capita in 2009 (1 000 RMB yuan)	-0.07 (0.35)	-0.17 (1.14)	0.15 (1.04)
Distance to nearest fertilizer shop (km)	-4.54 (1.19)	-1.66 (0.62)	-0.15 (0.05)

[1)] Total samples used in regressions are 813.

what after the 10-leaf stage.

Most of other control variables also have the expected sign, but only a few are statistically significant. The coefficient for HM county is positive (60.52) and statistically significant in overall N fertilizer use equation (column 1, Table 5), reflecting overall higher level use of N fertilizer use in maize production in HM than that in SG. This is consistent with descriptive analyses presented in Tables 1 and 3. Large maize farms used less N fertilizer ha^{-1}. The coefficient for household land area is negative and significant (Table 5, columns 1 and 3).

DISCUSSION

The results of the INM training experiment from both descriptive and multivariate analysis show that knowledge training can help farmers to reduce their N fertilizer use. Although the reduction of N fertilizer in maize production was much less than those recommended by scientists, about the approximately 20% reduction (49.19/248) is still meaningful, especially for a training session that was only one-hour long. Nevertheless, to have a long-term and more significant reduction of N fertilizer use, more efforts in training or other methods such as participatory approach of farming training for the entire crop season are needed.

The results also show that the proposed INM training can only partially solve the problem of overuse and unbalanced use over time of N fertilizer in maize production. The recommended INM technology requires farmers to spend additional time on fertilizer application, which is a significant challenge for a farming system dominated by small-scale farms, many with family labourers who engaged in off-farm employment in urban areas (Wang *et al.* 2011) where wages have been rising significantly since the early 2000s (Brauw and Giles 2008).

The results further show that the effectiveness of INM training differs between two counties studied. A diversified training program that addresses better the local situation and farmers' practices should be considered in similar training programs in the future.

Despite the reduction of N fertilizer, the economic benefits of adopting INM for individual farmers are minor. The reduction of 20% (or 49.19 kg) in N fertilizer use can save farmers 185 RMB yuan ha^{-1} (average price of N fertilizer paid by farmers in 2009 was 3.76 RMB yuan kg^{-1}). With the average farm size of 0.56 ha in the study area, reduced N fertilizer cost was only about 104 RMB yuan per household, which was equivalent to about earnings of 1.7 d in off-farm job (the local daily wage was 60 RMB yuan or 9.4 US$ in 2009). But good news is that a 20% reduction of N fertilizer use did not hurt yield. Indeed, Table 6 shows a higher maize yield for trained farmers than that for non-trained farmers. Admittedly, this result is difficult to explain. But in the literature, several studies also reported that increased yields were recorded for the appropriate reduction of N fertilizer use in crop production in China (Peng *et al*. 2006; Cui *et al*. 2008a; Ju *et al*. 2009).

Table 6 Yield of maize in treated and non-treated villages in 2009 (kg ha^{-1})

	Average yield	By county	
		Huimin	Shouguang
Trained farmers	7 845	6 730	8 511
Non-trained farmers			
Treated village	6 993***	6 468	7 985***
Non-treated village	7 065***	6 500	7 829***

CONCLUSION AND POLICY IMPLICATIONS

Nitrogen fertilizer has been overused in maize production in China, and providing INM training to farmers can reduce overall use of N fertilizer. However, this study also shows that it is difficult for farmers to adopt all INM recommendation in short term, and the effects of training in terms of balancing use of N fertilizer across crop stages differ among regions.

The findings of this study have several policy implications. First, through INM and other knowledge training methods in agricultural production, the environmental problems and economic losses related to the excessive nitrogen use in agriculture can be mitigated. As 70% of agricultural greenhouse gas (GHG) emissions come from N fertilizer, improving nitrogen management has the potential to contribute to low-carbon agriculture in China (SAIN 2010). Second, for balancing N fertilizer use between early and late stages of the crop growing season, one-time training might not be enough. Other alternative and more intensified methods, such as participatory approaches or farmer field schools, should be explored. Third, each farmer's practices and the local context should be considered in the recommended technologies to maize farmers. While training was found to be effective in overall reduction of N fertilizer in maize production, actual reductions varied between regions. In this study, one county was able to significantly reduce N fertilizer use before the 10-leaf stage but not after 10-leaf stage, while the other county experienced the opposite result, reducing N fertilizer use only after the 10-leaf stage. Last but not least, fertilizer technology that is less labor intensive is critical to encourage farmers to adopt INM technology and reduce N fertilizer use. With rising wages and off-farm employment opportunities (Brauw and Giles 2008; Wang *et al.* 2011), and given the predominance of small-scale farms in China, advising farmers to use higher frequency but less-intensive fertilizer technologies seems not to appeal by farmers. New technologies (for example, slow release fertilizer and nitrification inhibitors) that are less labour-demanding may fit with farmers' habits and strategies of optimizing household welfare.

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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