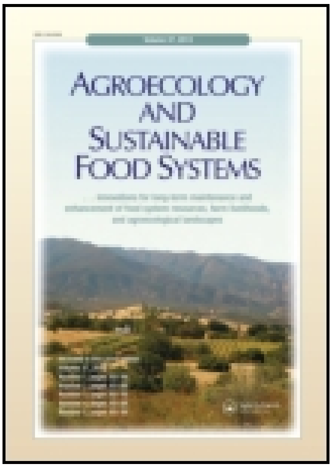

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Reducing Excessive Nitrogen Use in Chinese Wheat Production Through Knowledge Training: What Are the Implications for the Public Extension System?

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Reducing Excessive Nitrogen Use in Chinese Wheat Production Through Knowledge Training: What Are the Implications for the Public Extension System?

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Excessive use of nitrogen fertilizer in crop production in China leads to environmental problems, and farmers' lack of knowledge is the primary constraint. The public extension system, however, lacks the accountability and capability to deliver ecoagricultural extension services to farmers. Previous studies show that extension staff had little incentive to deliver extension services because they were overwhelmed by assigned non-extension activities. By applying a combined incentive scheme of cash rewards and political motivation on extension agents from 2009 to 2010, we found that knowledge training effectively reduced nitrogen use by 7% with no impact on yields in wheat production in two locations in Shandong Province, a major grain production region in north China. As such, improving nitrogen management has a great potential for a low-carbon agriculture in China and should be included into the extension program. However, the effectiveness of the training depends largely on the institutional capacity of the local extension system, which varies by region. In counties where extension employees were overwhelmed by assisting township administrations, a pure economic incentive without a long-term commitment was not effective. In the future, China faces challenges

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with delivering low carbon technologies through the existing agricultural extension system.

KEYWORDS *wheat, nitrogen, training, extension, farmer, China*

INTRODUCTION

Fertilizer has played an important role in maintaining China's grain production, but the excessive use of chemical fertilizer has resulted in severe environmental problems. Fertilizer has been intensively used in China's agricultural production since the 1960s, and its application has surpassed the average level of application in industrialized countries since 1980 (Heisey and Norton 2007). Excessive use of nitrogen fertilizer (N-fertilizer) leads to soil acidification in China, with major implications for the sustainability of grain production (Guo et al. 2010). Excessive use of N-fertilizer in China's major agricultural areas has resulted in large N losses in the form of NH_3 volatilization and nitrogen leaching into ground water and lakes (Zhu and Chen 2002). Furthermore, it has been estimated that greenhouse gas emissions associated with the manufacture and use of N fertilizer amount to about 7% of total emissions from China, so measures to decrease unnecessarily large applications can make a significant contribution to the goal of moving to a low carbon future (Zhang et al. 2013).

Scientists have developed improved nitrogen technologies (INM) to optimize fertilizer use in grain production. For example, Cui et al. (2008) proposed a nitrogen saving technology by targeting N-fertilizer use to soil nitrate content at different soil depths during various crop growth periods. Such a reduction can also achieve economic gains of over US $200 per hectare. Similarly, in wheat production Chen et al. (2006) developed new approaches to optimize fertilizer use by synchronizing N application and N demand over different crop growth periods in wheat production. These authors found that 60% of N-fertilizer could be reduced without affecting crop yield, compared with the conventional N fertilization practices in 2005. Similarly, Ju et al. (2009) showed that N fertilizer applications could be decreased by 30–60% in the maize-wheat and rice-wheat systems in the North China Plain and Yangze Basin, respectively, with no loss of crop yield.

Notwithstanding the efforts made by scientists, excessive use of chemical fertilizer is pervasive and becoming more severe in China. For example, the average application of nitrogen in maize production in the north China plain was 249 kg/ha in 2004 (Cui 2005), but increased to 259 kg/ha in the same areas in 2009 (Huang et al. 2012). In rice production, Peng et al. (2010) found that the average application of nitrogen ranged from 180 to 240 kg/ha and this figure was similar to other studies (Hu et al. 2007). A recent study in the same area shows that the figure rose to 258 kg/ha in 2010 (Huang et al. 2012).

A lack of knowledge was found to be the primary reason for farmers' excessive fertilizer use in China, and knowledge training can effectively reduce farmers' use of nitrogen fertilizer. Chinese farmers rely on their experience from the Green Revolution (1960–1980), which suggests that more fertilizer use always leads to higher crop yields (Xiang 2012). There are many examples showing that training and scientific guidance can lead to decreases in N-fertilizer applications of 20% or more in rice and maize, again with no loss of yield (Hu et al. 2007; Huang et al. 2008; Peng et al. 2010; Huang et al. 2012).

Nevertheless, most knowledge training workshops that show the positive effects of reducing fertilizer use in China were conducted by scientists rather than local extension agents. Consequently it is not clear whether the impact of training will be effective if delivered in a routine fashion by extension agents rather than as part of scientific studies.

Economists view technology adoption in agriculture as a complicated process. Existing studies found that technology adoption in agriculture depends on heterogeneity in human capital and risk preference; demographic characteristics such as the age and gender of agricultural labor affect technology adoption (Feder and Umali 1993; Sunding and Zilberman 2001). In addition, the correlation between farm size and technology adoption has been intensively investigated (Feder 1980; Feder and O'Mara 1981; Just and Zilberman 1983). Inside China, the agrarian economy is based on 200 million farms each with fewer than 0.5 ha. In recent years, land renting has emerged in large part because of the revival of non-farm activities and policy directives (Gao et al. 2012). While excessive N-fertilizer use is pervasive in China's agricultural production, large farms tend to use less (Jia et al. 2013).

Internationally, the performance of public agricultural extension systems in developing countries faces inherent problems related to budgets, incentives of extension employees, and low accountability (Anderson and Feder 2004). There is evidence that participatory and interactive knowledge transfer systems are more effective than traditional approaches (Swanson 2006). Although the need for taking into account the environmental impacts of intensive agriculture are now well known, assimilating this agroecological approach into the extension systems of developing countries is difficult because of the overriding emphasis on increasing food production.

China's agricultural extension system has experienced dramatic reforms. In 1985, to overcome budget constraints, the Chinese government decentralized its extension system from county agricultural bureaus to the township level. After this many extension staff were taken off the government payroll and reassigned to township governments (Zhi et al. 2007). This greatly undermined the incentives and accountability of delivering public ecoagricultural extension services at the local level, and led to extension staff becoming increasingly involved in commercial activities. In response to the mixed results of the early reforms, in mid 2000s China started a number of new initiatives to promote a more demand-driven public agricultural extension system (Hu et al. 2012). These pilot programs highlighted responsiveness to farmers' needs and performance-based evaluation to increase accountability, and increased the availability of extension agents and the provision of extension services.

The objective of this study is to empirically examine the effects of knowledge training on farmers' nitrogen fertilizer use in wheat production in China, with information being delivered through the public extension system at the local level and not by researchers. An innovation that we introduce is a combined incentive mechanism of political supervision and cash compensation. Specifically, we address the following two questions: First, does knowledge training delivered by extension employees have any effect on farmers' reduction of nitrogen fertilizer use? Second, compared with a pure economic incentive, will political incentives be effective?

The rest of this article is organized as follows. Section 2 introduces the study sites, research design and sampling method. Section 3 describes farmers' knowledge of nitrogen fertilizer use and presents the delivery of extension services in the study area. Section 4 examines farmers' fertilizer use under different training schemes. Section 5 investigates the impacts of training on farmers' use of N-fertilizer by using a multivariate analysis. Conclusions are drawn in the last section.

RESEARCH DESIGN AND DATA COLLECTION

Study Areas and Capacity for Ecoagricultural Extension Related to INM

The experimental study was implemented in two counties in Shandong Province, where INM was studied by soil scientists.[1] Shandong is located in the North China Plain (NCP) and is one of the major grain production provinces in China. Double-cropping of winter wheat and summer maize in the two counties is the primary cropping pattern and pervasive in NCP; maize is mainly planted in mid-June (after the harvest of winter wheat) and is harvested at the end of September. Winter wheat is planted immediately afterwards and is harvested the following June. In recent years, soil scientists have conducted several studies on optimizing fertilization use in wheat production in the research area using large-scale soil tests (Cui 2005; Cui et al. 2008). Hence, appropriate knowledge- and experiment-based N-fertilizer application techniques are available for the region.

TABLE 1 Allocation of working time of extension employees and capacity of extension institutions in the study area (China), 2009

	County A	County B
Working time allocation (%)		
Deliver public extension services	18	21
Assist in township administration	75	16
Deliver commercial services in agriculture	5	63
Others	2	0
Institutional capacity of public extension stations		
Average age of extension employees	44	43
Number of female extension employees	1	0
Number of employees having professional background in ecoagriculture or related field	2	4
Average annual income (Yuan)	15,236	36,000
Had annual budget for extension in the township station	No	No

Note. In each county, we surveyed four extension employees from four townships.

The accountability of extension agents in the two counties was both low but different. As shown in Table 1, the percentage of extension staff time actually devoted to delivering public extension services was only about 20% in both counties. In county B, the majority of extension employees' working time was dedicated to delivering commercial services related to agriculture for which they received payments (such as marketing promotion of seeds or agrochemicals). In county A, they spent 75% of their working time assisting the township government with local administration duties (such as birth control, village governance, land acquisition, dispute resolution, etc.). The institutional setting of the local extension system in the two counties is similar with that in other regions. For example, based on a national representative survey on 363 extension stations in seven provinces in 2002, Hu et al. (2009) found that the time spent by local extension employees on agricultural extension was only 30%. This figure is close to our own survey results (20%). The institutional constraints on the local extension system discovered in the studied counties are pervasive in China.

The weak incentives and political support undermined the capacity of the local extension system. Half of the extension employees in county A had no professional background in ecoagriculture or related fields (Table 1, row 7). The average annual income per extension employee in county B (36,000 Yuan, equivalent to US $5,500 in 2009) was about twice that in county A (Table 1, row 8), mainly because of payments for commercial services. None of the extension agents had a budget for extension in the townships (Table 1, last row). Such findings are similar to a ministerial report (Reseach Center for Rural Economy 2005) that shows less than 55% of extension employees had a background in ecoagriculture or related subjects. Although recent reforms were intended to control the proliferation of overstaffed extension centers, newly recruited personnel were not trained in agronomy or related fields.

INM and Research Design

An adapted and modified INM technology was first studied by a group of soil scientists prior to the experimental training. The recommended fertilizer use for wheat production was based on the local soil situation and N-fertilizer management experiments conducted in this region by soil scientists. In addition, the INM technology was calibrated based on farmers' perceptions and conventional practices. Eventually, farmers in the study area were advised to use N-fertilizer in the following ways: a) maintain a total amount of N-fertilizer use between 180 and 210 kg/ha; b) apply N-fertilizer during the wheat growing season at least twice—one application before the jointing stage and the other afterwards; c) balance nitrogen use by reducing N application before the jointing stage (60–70 kg/ha), and increasing N application after the jointing stage (120–140 kg/ha).

To estimate the impacts of knowledge training on farmers' use of nitrogen fertilizer, we delivered the INM knowledge training to a group of randomly selected farmers in some villages, and exempted farmers from training in other villages as a control.[2] In each county, we selected four townships, and within each township five villages were targeted. In each township, the INM training was delivered in three villages, and the remaining two villages were kept as a control group. In total, there were 24 villages given INM training, and 16 non-treated villages in the study area.

We introduced two types of incentives in different townships. In each county, for 2 selected townships we randomly assigned a *combined incentive* of both political supervision and *cash compensation*. Extension employees in the remaining two townships received only the *cash compensation*. In the combined incentive with political supervision treatment, the local county government included the performance of delivering INM training into the evaluation of local extension employees. The cash compensation was identical for all extension employees; each of them received about US $350 to cover the costs of travelling, printing, and a daily allowance.

Households were randomly selected in all of the villages before we delivered the experimental training. In each of the treated villages we randomly selected 40 farmers who produced wheat in the 2008–2009 season before the INM knowledge training was delivered. Twenty wheat farmers were randomly selected in each non-training village.

To obtain baseline data, in late August 2009 we conducted a questionnaire-based household survey after the wheat harvest. For all surveyed farmers, we asked about their production and inputs (e.g., fertilizer use, pesticide use, irrigation, labor inputs) on their largest plots of wheat during the 2008–2009 season. We also surveyed their basic demographic characteristics (e.g., age, education, off-farm engagement, and household assets) and farmers' knowledge of fertilizer use in wheat production. For the baseline survey, the total number of households sample was 1,226 from 40 villages.

At the time of the baseline survey, the experimental INM training was introduced to the local government and extension employees. We first explained the motivation and the design of the study to officials from the county government. After obtaining their approval and support, the county government issued a policy instruction to the selected township government to implement the assignment of the combined incentives treatment. During private conversations with the selected extension agents, we explained the INM technology and the individual assignment of incentives in detail, and asked for their agreement and confidentiality.

In late July 2009, the INM technology was presented to all the selected extension employees by the soil scientists. The INM knowledge training was then delivered by the extension employees to farmers in September 2009. Based on the baseline survey conducted in August 2009, we collected field observations on farmers' use of nitrogen fertilizer and their concerns over yield loss. We then sent the feedback to soil scientists and local extension employees, who calibrated the INM recommendation. The trained extension employees were asked to offer knowledge training to at least 30% of the wheat farmers before the crop was planted in the selected treatment villages.

In July 2010, the research team returned to the research sites and conducted a follow-up survey on the same respondents. In the *treated villages*, we first asked whether the farmers received the INM knowledge training. Once a trained farmer was identified, the household survey was repeated. When a respondent did not receive any INM training, the survey was ceased and the enumerators moved on to the next respondent. In *non-treated villages*, the household survey was repeated on all of the previously surveyed households.

Eventually, we constructed a household longitudinal dataset consisting of 773 farmers surveyed in 2009 and 2010. As shown in Table 2, for households sampled in the treated village in the baseline survey (76% of the total sample, column 1), almost 51% of them received the INM knowledge training [(19 + 20)/76, column 1]. The figure was higher than the required coverage (one third of the households in the treated village) and there was no significant difference in the two counties. Because the post-training survey was conducted only on trained farmers in treated villages, and non-trained farmers in non-treated villages, we were thus able to construct a two-period household survey dataset consisting of 773 wheat farmers [1,226 × (19% + 20% + 24%)].

TABLE 2 Household sample and treatment scheme in the study area (%)

	Total (N = 1,226) (1)	County A (N = 600) (2)	County B (N = 626) (3)
Treated village	76	75	76
Trained with combined incentive	19	17	20
Training with cash compensation	20	19	20
Non-trained*	37	39	35
Non-treated village	24	25	24

*Non-trained farmers in treated villages were not surveyed in the final survey.

FARMERS' KNOWLEDGE OF NITROGEN USE AND EXTENSION SERVICES

Farmers' knowledge of N-fertilizer use was limited in the study area. Before the training was delivered, we asked several qualitative questions about farmers' knowledge and their perceptions of fertilizer use. Almost half of the households surveyed did not know the meaning of the nutrient information on the fertilizer package (Table 3, row 1, column 1). Also, only one-third of wheat farmers were able to recognize the labeling identification of nitrogen, phosphate, or potash fertilizer. Almost 44% of farmers mistakenly believed that fertilizer use leads to high yields without any limit in wheat production (column 1). Only 39% of farmers agreed that "it is better not to use more fertilizer at the early growth stage of wheat." Overall, the results showed that farmers in the study area had been relying too much on their experience during the Green Revolution, from which they concluded it was always appropriate to apply high rates of fertilizer to achieve high yields.

There was little difference between farmers' knowledge in the two counties. Farmers in county B did seem to know the nutrient readings on the fertilizer package better than farmers in county A (Table 3, rows 1 and 2 and

TABLE 3 Farmers' knowledge of N management and the delivery of public extension services in wheat production in Shandong, China (%)

	Total (1)	County A (2)	County B (3)
1. Know the mark of 15-15-15 on fertilizer package (Yes)	56	51	61
2. Know the meaning of the symbols N, P_2O_5 and K_2O on the package (Yes)	28	21	35
3. More fertilizer use doesn't lead to higher crop yield (Agree)	56	57	56
4. It's better not to use more fertilizer at the early growth stage of wheat (Agree)	39	39	39

Note. The survey was conducted as a baseline survey before the INM training was delivered.

columns 2 and 3). Nonetheless, the false perception that more fertilizer leads to high yields without limit was equally held by farmers in the two counties. There was no difference in farmers' knowledge of variable rate N-fertilizer use during different crop seasons in the two counties (Table 3, row 4).

FARMERS' NITROGEN USE IN WHEAT PRODUCTION AND INM TRAINING

The excessive use of nitrogen fertilizer in wheat production is prevalent and severe in the study area. As shown in Table 4 (column 3), farmers in county A and county B applied 396 kg and 318 kg of nitrogen per hectare, respectively, during wheat production in the 2008–2009 season. These figures were almost 100% higher than the recommendation of the INM training. The overuse of N-fertilizer in the study area had previously been found by other researchers. For example, Cui (2005) found that farmers in Shandong used an average of 365 kg of nitrogen per hectare in 2003. Apparently, the excessive use of N-fertilizer in the study area has continued since then.

The INM training seems to have effectively reduced N-fertilizer use by trained farmers in county B. As shown in Table 4, N-fertilizer use by non-trained farmers in non-treated villages increased by 35 kg/ha from 2008 to 2010. Trained farmers also increased their N fertilizer use, but the increase was much smaller. Use increased by 9 kg/ha (Table 4, row 6, column 2) when the extension employees were assigned cash compensation. The training effects are evidenced in the scenario of the combined incentive;

TABLE 4 Overall inorganic nitrogen fertilizer use by trained and non-trained farmers in 2008–2009 and 2009–2010 wheat production

	Trained farmers		
	Combined incentive (N = 231) (1)	Cash compensation (N = 242) (2)	Non-trained farmers (N = 300) (3)
	kg N per ha		
County A			
2008–2009 (before training)	326	374	396
2009–2010 (after training)	309	382	407
Δ	−17	9	10
County B			
2008–2009 (before training)	289	330	318
2009–2010 (after training)	290	339	353
Δ	1	9	35

Note. Figures in the table indicate pure nitrogen content.

N-fertilizer use increased by only one kg/ha (Table 4, row 6, column 1) in wheat production from 2008 to 2010.

In county A, the INM knowledge training was only effective in reducing N-fertilizer use when township extension employees were motivated by political instructions (namely, the combined incentive). As shown in Table 4 (column 1), the average N-fertilizer use by the trained farmers decreased by 17% where the combined incentive was in place. The rate for the other two groups (farmers under pure economic incentive and non-trained farmers in non-training villages) increased by about 9 kg and 10 kg/ha, respectively (Table 4, columns 2 and 3). The pure economic incentive in county A seems to have been ineffective in reducing farmers' overall use of N-fertilizer.

Our data also shows that farmers in the study area used the majority of N-fertilizer before the jointing stage. As shown in Table 5, almost 89% of nitrogen (351/(45 + 351), column 3) was used before the jointing stage by non-trained farmers during the 2008–2009 wheat season in county A. The figure did not vary in the 2009–2010 wheat season. In county B, the figure was 98% for non-trained farmers in the two years. These figures reveal that the one-time application of nitrogen fertilizer has been the conventional practice for wheat farmers in north China.

TABLE 5 Chemical N-fertilizer use before and after jointing stage in 2008–2009 and 2009–2010 wheat production in Shandon

	Trained farmers		
	Combined incentive (N = 231) (1)	Cash compensation (N = 242) (2)	Non-trained farmers (N = 300) (3)
In county A			
Before jointing stage			
2008–2009 (before training)	293	304	351
2009–2010 (after training)	289	332	376
Δ	−5	28	25
Jointing stage and after			
2008–2009 (before training)	33	70	45
2009–2010 (after training)	20	50	31
Δ	−13	−20	−14
In county B			
Before Jointing stage			
2008–2009 (before training)	287	327	313
2009–2010 (after training)	279	317	337
Δ	−7	−10	24
Jointing stage and after			
2008–2009 (before training)	2	3	5
2009–2010 (after training)	10	22	16
Δ	8	19	11

Note. Figures in the table indicate pure nitrogen content.

The INM knowledge training did not change farmers' conventional practice from a one-time application to balanced N-fertilizer use in wheat production. The INM guideline was to reduce N-fertilizer use before the jointing stage to 60–70 kg/ha, and to maintain N use at 120–140 kg/ha after the jointing stage. The survey results in Table 5 show that training, with either type of incentives to the extension staff, had virtually no impact on farmers practice with respect to improving the timing of N application to better match crop uptake dynamics.

MULTIVARIATE ANALYSIS

Because many factors might simultaneously affect the observed association between farmers' N-fertilizer use and the experimental knowledge and information training, multivariate analysis is required. In this section, we specify a multivariate model that seeks to isolate the impacts of training from other factors.

The Model

Based on the survey data, we created a longitudinal dataset consisting of 773 farmers from two counties in the 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:

$$N_{ijkt} = a_0 + a \cdot Training_{it} + b \cdot Training_{it} \times Incentive2_{kt} + c \cdot Year2010 + \varphi \cdot X + \varepsilon_{it} \quad (1)$$

where dependent variable N_{ijt} measures the overall N-fertilizer use ($j = 1$), N-fertilizer use before the jointing stage ($j = 2$), and N-fertilizer use after the jointing stage ($j = 3$) for the i^{th} household in township k in year t ($t = 1$ for 2009 and $t = 2$, for 2010).

As the key independent variable of interest on the right-hand side of Equation (1), $Training_{it}$ refers to trained farmers in treated villages for wheat farmer i in time period t. This is a binary variable and equals 1 if a household attended the INM training in the treated villages, otherwise it equals 0 in year 2009 before the INM was delivered, or for the household in the non-treated villages. To differentiate between the two incentive schemes and examine the pure effects of the political instruction, we specify an interaction term for both $Training_{it}$ and $Incentive2_{kt}$. Thus, $Incentive2_{kt}$ denotes the assignment of the combined incentive scheme for household i in year t. This is a binary variable and equals 1 if the township extension employees were assigned the combined incentive of political supervision and cash compensation.

In addition to knowledge of nutrient management, farmers' N-fertilizer use in wheat production is also affected by other factors. As our longitudinal household data consists of two years (2009 and 2010), we create a dummy variable for 2010 to capture the dynamics. A dummy variable for county A is included to reflect the regional difference of N-fertilizer use in wheat production. Because of an evolving land market in rural China towards consolidated and large farms, we include the variable of cultivated land area to explore the effects of farm size. We also include individual characteristics (such as age of household head, education of household head, female household head) to reflect farmers' distinction in perception and attitude in N-fertilizer use. Lastly, we include a few other variables at the household and community level (such as durable consumption assets per capita in 2009 and distance from the village to the nearest fertilizer shop). The term ε_i is the idiosyncratic error term. Marginal effects to be estimated include a_0, a, b, c, and a vector variable φ.

To estimate Equation (1) we first specify an ordinary least square model (OLS) and the results are presented in Table 6. However, there might be some unobserved but time-constant factors that affect N_{ijt}. In addition, the OLS model has limitations in potential problems of endogeneity. To account for unobserved and non-time varying heterogeneity and to address potential problems of endogeneity, we use a household fixed effect model (the results are presented in Table 7).

Multivariate Results

The multivariate analysis of the impact of training on farmers' adoption of INM in wheat production is capable of producing results that are consistent with our expectations. The signs on the county dummy are expected, and are consistent with descriptive statistics (Tables 4 and 5).[3]

Regression results show the effectiveness of the INM training in reducing the overall N-fertilizer use in the sample area. The total value of coefficients for trained farmers and the interaction of trained farmers and combined incentive reflects the overall impacts of the INM knowledge training on farmers' use of N-fertilizer in wheat production. The values are negative and significant (–79.72kg/ha; Table 6, rows 1 and 2, column 1). When controlling for the fixed effects, the sum of coefficients are also negative and significant (Table 7, rows 1 and 2; columns 1 and 4). The results suggest that the INM training can effectively, but very modestly, reduce farmers' N-fertilizer use by 26 kg N per ha in both counties. However, the training effects were caused by different incentive mechanisms in the two counties. As shown in Table 7, the coefficient for trained farmers is not significant, but the coefficient for the interaction term is negative and significant (Table 7,

TABLE 6 Estimated results of farmer's inorganic N-fertilizer use in 2008–2009 and 2009–2010 wheat production based on OLS model

	N fertilizer use (kg/ha)		
	Total[a] (1)	Before jointing (2)	Jointing stage and after (3)
1. Trained farmers	−18.76**	−32.24***	13.49**
(yes = 1; no = 0)	(2.07)[b]	(3.40)	(2.55)
2. Trained farmers × combined Incentive	−60.96***	−40.41***	−20.55***
(yes = 1; no = 0)	(6.29)	(3.98)	(3.62)
3. Year dummy of 2010	39.52***	42.18***	−2.66
(yes = 1; no = 0)	(5.55)	(5.66)	(0.64)
4. County A dummy	48.66***	14.25**	34.40***
(yes = 1; no = 0)	(8.67)	(2.43)	(10.48)
5. Cultivated land area (ha)	−17.67**	−9.18	−8.49*
	(2.36)	(1.17)	(1.94)
6. Consumption asset per capita in 2009	0.13	0.19	−0.05
(1000 Yuan)	(0.74)	(0.99)	(0.50)
7. Age of household head (year)	−0.01	−0.23	0.22
	(0.05)	(0.81)	(1.37)
8. Education of household head (year)	−1.93**	−3.19***	1.26**
	(2.16)	(3.41)	(2.42)
9. Female headed household	−7.72	−3.27	−4.45
(yes = 1; no = 0)	(0.71)	(0.29)	(0.70)
10. Distance to nearest fertilizer shop	−0.81	−3.09	2.28
(km)	(0.31)	(1.13)	(1.50)
11. Intercept	338.40***	346.16***	−7.76
	(17.62)	(17.22)	(0.69)
Observation	1546	1546	1546
R^2	0.105	0.052	0.079
F test (P value):	0.000	0.000	0.190
H_0: coef1 + coef2 = 0			

[a]Figures indicate pure nitrogen content.
[b]Figures in parentheses are absolute t ratios of estimates. *, **, and *** represent statistical significance at the 10%, 5% and 1% levels, respectively.

row 2, column 1); this implies that the pure cash compensation on extension employees had no effects in county A, and that motivation mainly came from political supervision. In county B, the coefficient for trained farmers is negative and significant (Table 7, row 1, column 4) but the coefficient for the interaction term is not significant. This means that in county B, besides economic compensation, political supervision had no additional effects that encouraged extension employees to deliver the INM training and to reduce N-fertilizer use by farmers in wheat production.

The regression results also show that in both incentive schemes, INM training only led to (small) decreases in N-fertilizer use before the joint stage, but had no effects on N-fertilizer use after the joint stage. Although the coefficients for trained farmers and the interaction term are both statistically significant in the OLS results, the result of the F test implies that the

TABLE 7 Estimated results of farmer's inorganic N-fertilizer use in 2008–2009 and 2009–2010 wheat production by using fixed-effect OLS models

	N-fertilizer use (kg/ha) in county A			N-fertilizer use (kg/ha) in county B		
	Total[a] (1)	Before jointing (2)	Jointing stage and after (3)	Total[a] (4)	Before jointing (5)	Jointing stage and after (6)
1. Trained farmers (yes = 1; no = 0)	−1.79 (0.13)[b]	3.55 (0.23)	−5.34 (0.44)	−26.46** (2.02)	−34.18** (2.30)	7.72 (1.16)
2. Trained farmers × combined incentive (yes = 1; no = 0)	−25.70* (1.75)	−32.78* (1.92)	7.08 (0.53)	−8.48 (0.62)	2.74 (0.18)	−11.22 (1.63)
3. Year dummy of 2010 (yes = 1; no = 0)	10.40 (1.17)	24.72** (2.40)	−14.32* (1.79)	35.49*** (4.00)	24.05** (2.39)	11.44** (2.55)
4. Intercept	369.39*** (92.36)	320.03*** (69.03)	49.36*** (13.66)	312.72*** (81.88)	309.35*** (71.46)	3.38* (1.75)
Observation	738	738	738	808	808	808
R^2	0.013	0.031	0.025	0.040	0.017	0.058
F test (P value): H_0: coef1 + coef2 = 0	0.0481	0.0698	0.8897	0.0079	0.0347	0.5980

[a]Figures indicate pure N content.
[b]Figures in parentheses are absolute t ratios of estimates. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

training did not change farmers' N-fertilizer use after the joint stage (Table 6, column 3). The results hold the same in the fixed-effects model, as none of the coefficients are significant (Table 7, rows 1 and 2, columns 3 and 6). It is hard to change farmers' behavior to optimize N-fertilizer use according to the cropping seasons.

One of the major trends across China's agricultural landscape is the movement of young labor from rural farms to urbanized areas. Given the small farm plots and cropping systems dedicated to commodity grains, there is little economic opportunity in farming. The majority of these migrant workers engaged in off-farm work in nearby cities but still keep their primary residence and land on the farms. Applying fertilizer efficiently takes time and planning, especially for split applications. Thus, the economics of labor are the primary driving force of excessive nitrogen use in China's smallholder agriculture. As the analysis shows, the negative coefficient for "cultivated land area" implies that when the size of cultivated land was expanded, farmers would decrease overall N-fertilizer use (Table 6, row 5). Farm size indeed matters.

Discussion

The results of the experimental training under different incentive schemes from both descriptive and multivariate analyses show that knowledge training can reduce farmers' N-fertilizer use, but the magnitude of training effects is small (an average of only 7%). The reduction of N-fertilizer in wheat production was much less than that recommended by scientists (about 162 kg/ha), or approximately a 45% reduction (162 × 2/(396 + 318)). However, even such a small reduction is meaningful, especially for a training session that was only 2 h long and had no site-specific guidance or demonstrations.

Importantly, the results show that the effects of training are highly dependent on the institutional capacity of the local extension systems. For example, the extension employees in county B spent most of their time providing commercial services in agriculture and very little time engaged in local administrative activities (Table 1). The experimental INM training did not change their priority of working time much, and the pure economic incentive worked. In comparison, the extension employees in county A were overwhelmed by assisting the township administration (75% of their working time) and barely had time to deliver any extension service. In such a situation, a pure economic incentive without a long-term commitment was not effective. Instead, political instruction combined with an incentive did work.

Besides incentives, the new cadre of extension staff need to be empowered from a broad experience of knowledge covering both environmental aspects as well as agriculture. Within the current extension system, extension technicians are specialized in different disciplines such as seeds, fertilizers, pest management, mechanics, and so on. But for an integrated ecoagricultural system, extension agents should master a broader knowledge of food system sustainability, including the ability to experiment, observe, monitor, evaluate, and communicate. In developed countries, extension agents and agricultural communities are becoming accustomed to integrating the pressures from competitive markets, new regulatory demands, and the public's awareness of global issues such as environmental degradation and climate change as well as the need to maximize farmers' profits (Lightfoot and Noble 2001; Wall 2001). There is an increasing recognition that the role for ecoagricultural extension should move beyond conventional training. The goals should address broader issues of resource management, sustainability and lifestyle preferences and quality (Robotham and McArthur 2001).

Last, despite the fact that trained farmers reduced overall N-fertilizer use in wheat production, there is no evidence that this affected wheat yields. In fact yields in all cases were lower in 2009 and 2010 compared to 2008 and 2009 by 10–17%. This was presumably due to weather differences between the two seasons, but the decreases were similar for both the untrained and trained farmers as shown in Table 8. Yet, N fertilizer application rates had increased in the case of the untrained farmers (by 10 or 35 kg N per hectare in counties A and B, respectively) but had either decreased or increased less with the trained farmers. The yield results are consistent with existing literature. For example, several studies reported that China's grain production

TABLE 8 Yield (kg/ha) of wheat in training and non-training villages (China) in 2009 and 2010

	Trained farmers		
	Combined incentive (N = 231) (1)	Cash compensation (N = 242) (2)	Non-trained farmers (3)
2008–2009	6,779	6,477	6,687
2009–2010	6,103	5,556	5,899
Δ(%)	−10	−14	−12
In county A			
2008–2009	6,201	5,716	6,143
2009–2010	5,565	5,145	5,522
Δ(%)	−10	−10	−10
In county B			
2008–2009	7,252	7,167	7,231
2009–2010	6,542	5,929	6,276
Δ(%)	−10	−17	−13

is maintained by the excessive use of fertilizer, and the yield would not be affected (and even increase) with the appropriate reduction of N-fertilizer use (Peng et al. 2006; Cui et al. 2008; Ju et al. 2009).

CONCLUSIONS

The excessive use of nitrogen fertilizer in wheat production is severe in China, and this study shows that providing even a limited amount of INM knowledge training to farmers can reduce overall N-fertilizer use to a modest extent. However, China's public extension system lacks such capabilities due to insufficient incentives. To promote the efficient use of natural resources and to address the environmental stress related to the excessive use of fertilizer in grain production, China faces great challenges to deliver such knowledge to smallholder farmers in an effective way that is relevant to the economic and social conditions of farmers. A key issue is to recognize that many farmers are part-time, deriving a large proportion of their household income from off-farm activities, thus presenting issues of labor shortage and lack of incentive to improve fertilizer management.

The findings of this study have several policy implications. First, INM training should be included into public extension programs and be reassigned a high priority. Since 70% of agricultural greenhouse gas emissions come from N-fertilizer, improving nitrogen management has a great potential to contribute to low-carbon agriculture in China (SAIN 2010; Zhang et al. 2013). Even though the possible reduction on each plot of farmland may be small, the aggregated effects would be immense on a national level.

Second, the institution of the local extension system should be restructured. Currently, the majority of local extension employees' working hours is occupied by nonextension activities. Without an independent extension institution, little can be achieved in terms of delivering information to farmers that will alter fertilizer management practices with the resulting economic and environmental benefits. Third, innovative extension approaches should be revised to strengthen training effects. The traditional training approach of delivering courses is found to have limited effectiveness, even for creating short-term effects (Huang et al. 2012). Chinese farmers are accustomed to using excessive fertilizer because of their experience during the Green Revolution (1960–1980), when they were encouraged to use fertilizer; it takes time to change such behavior. For effective training with persistent effects, an on-site demonstration and a participatory training approach is required. In recent years, farmer field schools have been introduced in soil and pest management in many developing countries (Simpson and Owens 2002; Feder et al. 2004; Bunyatta et al. 2006). It is expected that such innovations applied to fertilizer management would be far more effective than traditional training approaches.

To develop a low carbon-emitting agricultural sector by reducing farmers' excessive nitrogen fertilizer use, China needs to redesign the institutional extension system approach. In the short run, it is important to keep qualified extension employees and provide them with adequate support. In the long run, given the unsatisfactory performance of the public system regarding its accountability, efficiency, and effectiveness, the roles of the public sector should be revisited. As summarized in a World Bank workshop on agricultural extension, the central role of the public sector is to develop a framework for various stakeholders in a pluralistic extension system and to strengthen its institutional capacity and human capital (Alex et al. 2004). Although agricultural extension and innovation has been emphasized as China's number one target of development for several years, it is still an open question as to the extent to which it has been integrated into the national development strategy and the approaches for doing this effectively such that agricultural extension has real impacts on farmers' management practices.

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NOTES

1. This study stands as a case study on N-fertilizer use of wheat production in two counties of rural China. Given the small samples of the study and possible heterogeneity of different regions in China, we necessarily must limit the scope and generalizability of the study.
2. Due to ethical concerns, after this experimental study, the research team collaborated with local governments and phased in the INM knowledge training in all control villages.
3. It is possible that the explanatory variables correlate. To test this, we implemented "collinearity diagnostics" and found that the variance inflation factor (VIF) for all the variables is less than 5. A common rule of thumb is that VIFs of 10 or higher (or equivalently, tolerances of 0.10 or less) may be reason for concern of collinearity. In addition, the condition number is only 2.84, suggesting an overall performance of the model without problems of multicollinearity.

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