REPORT

Practices, perceptions, and implications of fertilizer use in East-Central China

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Abstract Face-to-face interviews ($n = 553$) were conducted in five counties in East-Central China to study farmers' fertilizer application behaviors, decision-making processes, attitudes towards adopting better fertilizer application technologies, and environmental consciousness. The survey results revealed widespread fertilizer misapplication and highly variable application behaviors in the study regions. The lack of scientific knowledge on fertilizers and the absence of guidance from agricultural extension services have forced the farmers to rely on personal judgment and advice from fertilizer dealers and friends to make decisions in fertilizer application. Overall, farmers have been idiosyncratic in fertilizer application with limited adoption of better fertilizer application technologies. There are great potentials for reducing pollutant load from agricultural runoff through promoting scientific fertilizer application in the regions. However, farmers' diverse preferences over agricultural extension programs necessitate an integrated approach emphasizing farmer involvement throughout the development of such programs for promoting better fertilizer application practices.

Keywords Fertilizer use · Farmer behavior · Perception · Survey · Environmental consciousness

INTRODUCTION

China is faced with the severe challenge of widespread water pollution. Many studies have indicated that non-point source pollution has become one major cause of the country's water quality deterioration (Ongley et al. 2010; Wu and Chen 2013). Like many developed countries (Turner and Rabalais 2003; Yang and Jin 2010), agricultural runoff has become a primary source of water pollution in China due to its sharp increase in chemical fertilizer use

in the pursuit of high crop yield so as to feed its vast population with limited arable land (Sun et al. 2012; Huang et al. 2013; Ma et al. 2013; Wu and Chen 2013).

China is now the largest producer and consumer of chemical fertilizers in the world. There have been many reports of excessive nitrogen fertilizer application in the country (Xiong et al. 2008; Zhang et al. 2011; Yang et al. 2012; Yan et al. 2013). Nitrogen fertilizer that is not absorbed by crops migrates to water bodies, leading to nutrient enrichment and causing negative impacts on environmental quality, ecosystem services, and biodiversity (Glibert et al. 2006; Howarth 2008).

Much research has been conducted on technologies to improve fertilizer application practices and mitigate adverse impacts on water ecosystems (Hite et al. 2002; Ladha et al. 2005; Cui et al. 2010). There has been much less research, however, to study farmers' fertilizer application behaviors, their decision-making processes and attitudes towards the adoption of better technologies (Adrian et al. 2005; Han and Zhao 2009; Tey and Brindal 2012). To fill in the gap, surveys were conducted in five counties of East-Central China to gain insights into the local farmers' decision-making in fertilizer application, their perceptions of the environmental impacts of chemical fertilizers, and attitudes towards better fertilizer application technologies, which may ultimately help develop effective programs to promote the implementation of better fertilizer application practices.

MATERIALS AND METHODS

Farmers were randomly interviewed with a pre-constructed questionnaire in five counties in East-Central China, each located within one of the country's major food production

provinces: Anhui, Henan, Jiangsu, Shandong, and Shanxi (Fig. 1). The questionnaire consists of 36 questions in six categories: socio-economic and farm characteristics, crop production costs, current fertilizer application behaviors, decision-making in fertilizer application, attitudes towards adopting better fertilizer application technologies, and environmental consciousness.

Due to their limited education, the interviewed farmers were mostly incapable of finishing the questionnaires themselves. Hence, the interviews were conducted in the form of “oral inquiry and answer”. Overall, a total of 553 face-to-face interviews were conducted, including 100 in Anhui, 95 in Henan, 150 in Jiangsu, 108 in Shandong, and 100 in Shanxi. In the following discussion, each sample is referred by the name of the province where it was drawn.

RESULTS

Characteristics of the interviewed farmers

The interviewed farmers exhibit many similar characteristics among the five regions. First, they are mostly middle to old-aged with limited education. Their average age is around 50, and their highest level of education is mostly limited to primary or junior high school. Secondly, they generally practice the traditional intensive small-scale

farming. The average farm size is 1.2 ha in Anhui and around 0.5 ha in the other four regions. Finally, they mostly have a low to middle-level monthly household income, with the highest proportion in the range of 326–653 USD.

Nitrogen fertilizer use

There is some variation in the crop rotation regime among the five regions. For example, rice and wheat are planted in Anhui, while wheat, corn, and soybeans are grown in Shanxi. Since wheat grows in all five regions, its fertilizer use provides a common ground for making regional comparisons.

Farmers' N fertilizer application behaviors vary considerably in the study regions. The mean N fertilizer application rates for growing wheat in an increasing order are: 139 kg N ha⁻¹ in Henan, 158 kg N ha⁻¹ in Anhui, 234 kg N ha⁻¹ in Jiangsu, 262 kg N ha⁻¹ in Shandong, and 274 kg N ha⁻¹ in Shanxi. The variability in the N application is smaller in Anhui, Henan, and Jiangsu with a standard deviation around 40 kg N ha⁻¹, compared to 73 kg N ha⁻¹ in Shanxi and 97 kg N ha⁻¹ in Shandong.

How do the surveyed N fertilizer application rates compare to recommendations by experts? Zhu and Chen (2002) suggested that cereal crops were able to achieve high yields at an N application rate of 150–180 kg N ha⁻¹ per crop. Ju et al. (2004) suggested the threshold for

Fig. 1 Study regions

environmentally-safe N-application rate to be 200 kg N ha⁻¹ per crop to minimize N losses through nitrate leaching. Comparisons between expert recommendations and survey results suggest that the majority of the farmers in Jiangsu, Shandong, and Shanxi are fertilizing their crops excessively.

Changes in fertilizer application behaviors

Besides current practices, farmers were inquired about their fertilizer application practices in the past and their plans for the future. Eighty-three percent of the interviewed farmers in Shanxi are applying more chemical fertilizers than they did in the 1990s, whereas the percentage is above 92 % in the other four regions. The main reasons given for the increase include the decline in soil fertility, the desire to increase crop yield, the increase in crop density, and the doubt of the quality of fertilizers. Furthermore, despite the region's highest average N application rate, 74 % of the farmers in Shanxi state that they plan to increase their fertilizer application rates if economically allowed, compared to 47 % in Henan, 30 % in Shandong, 26 % in Jiangsu, and 6 % in Anhui.

In contrast to the general increase in chemical fertilizer application is the sharp decrease in the use of organic fertilizers such as animal manure and plant materials. About 25 % the farmers are applying some organic fertilizers in Henan, Shandong, and Shanxi, and the percentage drops to 3 % in Jiangsu and 6 % in Anhui.

Implementation of better fertilizer application practices

Our survey includes the inquiry about the knowledge and implementation of two better fertilizer application practices: soil testing and applying controlled-release fertilizers. More than 70 % of the farmers in Shanxi have heard about soil testing and controlled-release fertilizers, compared to less than 50 % in Anhui and Shandong, and around 20 % in Henan and Jiangsu. Regardless of the disparity in knowledge, there is a universal lack of implementation. Controlled-release fertilizers are applied by less than 5 % in Jiangsu and less than 20 % in the rest regions. Meanwhile, soil testing is practiced only by 3 % in Jiangsu, 11 % in Shandong, and none in the other regions.

What causes the low rates of adopting better fertilizer application practices? In Shanxi, the reasons given for not practicing soil testing include the lack of organizing soil testing by authorities (61 %), technical difficulty (31 %), doubt of its effects (19 %), and high cost (12 %). The reasons for not applying controlled-release fertilizers include high cost (93 %), inability to increase crop yield

(28 %), consumption of time (26 %), and doubt of their effects (21 %).

Environmental attitudes and perceptions

During this survey, farmers were asked to give their subjective estimates of the crop N-recovery efficiency. Farmers in Henan gave the lowest estimates, with 29 % falling between 20 and 40 % and 62 % between 40 and 60 %. Farmers in Shandong gave the highest estimates, with 45 % falling between 60 and 80 % and 31 % between 80 and 100 %. Sixty-five percent of the farmers in Shanxi and over 80 % in Anhui and Jiangsu give their estimates to be between 40 and 60 %.

How do the farmers' subjective estimates of crop N-recovery efficiency compare to scientific findings? Zhu and Chen (2002) estimated that mean crop N-recovery efficiency was in the range of 28–41 % based on 782 data points collected from literature. Peng et al. (2006) found that N-recovery efficiency was 20–30 % in four provinces in China. Hence, the majority of the surveyed farmers seem to be over-estimating the proportion of N absorbed by the crops.

Besides the crop N-recovery efficiency, farmers were also interviewed about their attitudes towards water pollution. More than 90 % of the farmers feel concerned over water pollution in all five regions except a lower 68 % in Henan. There is much difference in their assessment of agriculture's impacts on water environment. Sixty-nine percent of the farmers in Shanxi agree that agriculture is one major cause of water pollution, while 82 % in Jiangsu and 69 % in Shandong oppose. In Anhui and Henan, around 53 % of the farmers are unsure while the rest hold opposite opinions. Despite the disagreement over agriculture's impacts on water pollution, over 70 % feel obligated to control fertilizer use in all five regions, except a lower 36 % in Shanxi.

Decision-making in fertilizer application

During the survey, farmers were asked to list their sources of acquiring knowledge on fertilizers and their bases for making decisions on fertilizer application. The potential sources of knowledge on fertilizers include agricultural extension services, fertilizer dealers, neighbours/friends, TV/radio, and agricultural magazines. In spite of the variability, the important role played by fertilizer dealers and the minor role by agricultural extension services in disseminating knowledge on fertilizers are consistent across the five regions. Nearly all farmers consider fertilizer dealers as one of their sources of knowledge on fertilizers in Jiangsu, while 70–80 % of the farmers concur in the other four regions. In sharp contrast, only 21 % of farmers

list the agricultural extension service as one of their knowledge sources in Shandong, and the percentages drop even further to less than 10 % in the other four regions. In addition, neighbours/friends play major roles in providing information on fertilizers in Jiangsu and Henan (>60 %), and moderate roles in the other regions (20–40 %). TV/radio play major roles in Jiangsu, Henan, and Shandong (>55 %), a moderate role in Shanxi (36 %), and a minor role in Anhui (15 %). Agricultural magazines play a major role in Jiangsu (>90 %), moderate roles in Shandong and Shanxi (30–40%), and minor roles in Anhui and Henan (<10 %).

The potential bases for the farmers' decision-making in fertilizer application include advice from agricultural extension services, crop conditions, weather conditions, soil fertility, price of fertilizers, expected price of crops, traditional habits, and neighbours/friends. Individual judgement of crop growth conditions is consistently a dominant factor influencing fertilizer application followed by judgement of soil fertility. Crop growth condition is considered as one factor for decision-making in fertilizer application by more than 80 % of the farmers in all five regions, while soil fertility is considered by more than 65 % in all five regions except 47 % in Anhui. Consistent with the survey results in the knowledge sources of fertilizers, less than 5 % of the farmers rely on the advice from agricultural extension services in making decisions in all five regions except 26 % in Shandong. Unexpectedly, less than 10 % of farmers consider either the cost of fertilizers or the expected market price of crops as an influencing factor in making decisions on fertilizer application in all five regions except around 30 % in Shanxi. While playing an important role in Jiangsu, weather conditions, traditions, and neighbours/friends are all less important factors in the other regions.

DISCUSSION

Our survey results have indicated that excessive nitrogen fertilizer use remains a serious issue in the study regions, accompanied by a lack of applying organic fertilizers and the implementation of better fertilizer application practices. There is an urgent need to find effective ways to guide the farmers towards rational fertilizer application practices to reduce the enormous nutrient loss from agricultural fields and mitigate the consequent adverse environmental impacts.

Despite the variability in fertilizer application behaviors, our survey results reveal much similarity in farmers' characteristics, attitudes, and perceptions in the study regions, which should be incorporated in the development of agricultural programs. First, with fast economic development

and urbanization, growing crops is no longer a major source of income for many rural households. Young and educated members of the farming families often leave their hometowns to seek higher incomes in cities, leaving the old and less-educated to take care of the farms (Qin 2010). This demographic shift in the farming force and the less importance of farming income pose great obstacles to the adoption of better fertilizer application technologies, especially those requiring relatively complex models and tools.

Secondly, previous studies usually assume that farmers make decisions to maximize their economic returns under market and weather uncertainties. Factors such as age, education, and perceptions of net benefits play important roles affecting the adoption of better agricultural practices (Adrian et al. 2005; Zbinden and Lee 2005). However, these factors could barely explain the observed highly variable fertilizer application rates in the study regions. This suggests that local farmers apply fertilizers mainly based on their habitual practices modified by their individual judgment of crop, weather, and soil conditions. The cost of fertilizers and the expected market price of crops are seldom taken into account. Therefore, the farmers' decision-making in fertilizer application could be mostly characterized as idiosyncratic, which is not based on systematic optimization, whether of yields, profits, or social benefits.

Thirdly, most farmers have ceased the traditional practice of applying organic fertilizers. While realizing the consequences of declining soil fertility, many farmers resort to applying more chemical fertilizers to compensate the decline. If crops are not growing as well as expected, they often blame the poor quality of the chemical fertilizers and translate that into the need of more fertilizers. For example, 74 % of the farmers in Shandong and 47 % in Shanxi have attributed their increase in chemical fertilizer use to the decreasing use of organic fertilizers and the need to compensate for the declining soil fertility. Inadvertently, they have been trapped into the vicious cycle of deteriorating soil quality, decreasing crop yield, and more chemical fertilizer use. How to bring organic fertilizers back to farming and break the gridlock between soil quality deterioration and excessive chemical fertilizer use is a serious challenge.

Fourthly, agricultural extension service (AES) has failed to play a crucial role in disseminating knowledge and providing technical support of fertilizer application. Our survey results show that few farmers have received training on fertilizer application from AES. In addition, farmers seldom consider AES as their main source of knowledge on fertilizers, nor do they turn to the agency for advice on the amount and timing of fertilizer application. In sharp contrast, many farmers consider fertilizer dealers who sell chemical fertilizers for profits as their major source of

knowledge on fertilizers. AES needs to play a more effective role in improving farmers' fertilizer application practices.

Much research in China and elsewhere has been conducted on measures to improve nutrient management in intensive agricultural systems (Xie et al. 2012). However, the current lack of adopting better fertilizer application technologies is in sharp contrast to the tremendous investment devoted to relevant research. The key challenges are how to ensure these better fertilizer application technologies are cost-effective and user-friendly, and therefore attractive to the farmers of the targeted demographic groups (Dobermann and Cassman 2005; Ladha et al. 2005).

During the survey, farmers were inquired about their preferences over different types of agricultural programs for promoting better fertilizer application practices. Their attitudes towards the programs are quite different, with those in Jiangsu the most receptive and Anhui the least. As a low-cost and easy-to-implement program option, distributing brochures and recommendations on fertilizer application is the single program with an acceptance ratio of above 30 % in all five regions. Free fertilizer training is another relatively popular program with an acceptance ratio of above 45 % in all five regions except a lower 6 % in Anhui. On-site personal guidance and field demonstration are moderately acceptable with an acceptance ratio of less than 40 % in all regions except Jiangsu. The program of offering economic incentives is surprisingly only popular in Henan, while none of the regions favor direct regulations over fertilizer use. In addition, there are some farmers who insist on relying on their own experiences and judgment instead of following external advice. They are mostly in Shanxi and Anhui, accounting for 24 and 15 % of the total, respectively.

With numerous small farms, it is particularly important to develop effective programs to induce farmers' willingness to improve fertilizer application practices in their own interests, given the absence and unpopularity of environmental regulations over fertilizer use. The revealed high variability in farmers' attitudes towards agricultural programs warns against the reliance upon general assumptions in the development of such programs. Effective incorporation of farmers' needs and preferences throughout the development is prerequisite to the success of the programs.

CONCLUSIONS

Like many countries around the world, agricultural runoff has become a major cause of water quality deterioration in China. Because of its diffusive nature, it is expensive and sometimes impossible to rely on the "end-of-pipe" pollution treatment technologies to control agricultural runoff effectively. Promoting better fertilizer application practices

and reducing nutrient loss from agricultural fields is a more cost-effective approach.

Despite the progress made in fertilizer application technologies, our survey results indicate that they are rarely adopted across the study regions. Without guidance from agricultural extension services, farmers have resorted to subjective guesses and advice from fertilizer dealers and friends in making decisions related to fertilizer application. This has led to the observed widespread excessive N fertilizer use and large variability in fertilizer application behaviors. By and large, the declining use of organic fertilizers and the fear of crop failure have led the farmers into this vicious cycle of deteriorating soil quality, decreasing crop yield, and more chemical fertilizer use, which may potentially evolve into an agricultural crisis in the future.

Although this study is limited to five counties in China, the revealed issues of inappropriate fertilizer application, absence of active roles by agricultural extension services, and farmers' subjectivity in determining fertilizer use are likely to prevail in other parts of China, and possibly in many other developing countries. Given the variability in farmers' preferences over agricultural extension programs and some extent of resistance to behavioral change in fertilizer application, an integrated approach incorporating farmers' preferences and emphasizing active stakeholder involvement is required to ensure agricultural programs to work better with farmers.

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