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Reducing China's fertilizer use by increasing farm size

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ABSTRACT

The excessive use of fertilizer has resulted in serious environmental degradation and a high health cost in China. Much research has focused on the technological innovation to improve fertilizer use efficiency in crop production, but the socioeconomic constraints are at present poorly understood. Here, we find that fertilizer use on a per-area basis sharply decreased with the increase of farm size; surprisingly, the crop yield is higher in large-scale farms compared to that in smallholder farms in China. High labor cost suggests a low machinery level in smallholder farms, which inhibit the application of precise fertilization technologies and management based on scientific knowledge. Meanwhile, the dependence of income from cropland is lower for smallholder farmers who have part-time jobs in urban areas compared to the professional farmers in large-scale farms. Therefore, compared to smallholder farms, large-scale farms are generally more sensitive to the increase of fertilizer price and would reduce their fertilizer use if withdrawing fertilizer subsidies that used to be considered as the key driver of fertilizer overuse. Considering the dominance of smallholder farms in China, increasing farm size should be integrated into the actions such as improving technological innovation and providing better information transfer to achieve the goal of no increase in Chinese fertilizer use.

1. Introduction

To meet the food, fiber and feed demands of an increasing and gradually wealthier population, a series of policies were implemented to encourage synthetic fertilizer (SF, fertilizer produced in factories) production and use in China during the last three decades (Li et al., 2013). However, synthetic fertilizers are substantially overused and misused in Chinese cropland (Ju et al., 2009; Chen et al., 2014). In 2010, over 55 million tonnes of SF, accounting for over 30% of global fertilizer use, was applied to Chinese cropland, which only accounts for 7% of the global cropland area (FAO, 2016). Nevertheless, this overuse of SF still cannot meet the grain demand in China, leaving a gap that is filled by importing corn and soybeans, mainly for animal feed (Gu et al., 2015). More seriously, overusing SF in China has heavily polluted the environment including not only water bodies (Chen et al., 2014), but also the atmosphere (Gu et al., 2014). Unfortunately, SF use is still increasing with an average annual increase rate of 3% over the last decade (2003–2013) (NBSC, 2015). Given that SF overuse is already causing many negative impacts (Gu et al., 2012, 2014), the production of sufficient food with less fertilizer and less pollution in the near future is imperative and urgent for China. The challenge is also quite relevant to countries around the world far beyond China that struggle to address agricultural productivity while also mitigating environmental impacts related to fertilizer use.

Therefore, to address this issue, the central government of China officially launched the 'Action Plan for the Zero Increase of Fertilizer Use' (APZIFU) in 2015 (See Supporting information (*SI*) *text* for details of this plan). The goal of this plan is to stop the increase of SF use by 2020 without reducing food production. However, it focuses largely on fertilization technologies but only minimally on the social and economic aspects, and how to realize the goals in the face of social-economic barriers remains unclear. In this paper, we explore how proper fertilization technologies can be utilized by farmers, via policy improvements, to overcome social and economic barriers and realize the goal of zero percent increase in SF use, with a focus on N fertilizer.

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2. Methodology

2.1. Scenario analysis

We used the Urban Rural Complex N Cycling (URCNC) model to predict N fertilizer use in China (Gu et al., 2015). Human population and the per capita gross domestic product (PGDP) are two important parameters that affect future N fertilizer use (Table S1). Human population and per capita consumption level determine the total demands for food in the future, and PGDP is generally related to the per capita consumption level and N fertilizer management ability (Tilman et al., 2011).

We adopted a middle-of-the-road scenario for business as usual (BAU), that assumes a Chinese population of 1.38 billion people (Xiang and Zhong, 2013) with an urbanization level of 55% in 2020 and a PGDP US$17,500 at 2005 prices and adjusted for purchasing power parity (PPP) (Table S1). The PGDP in China will increase substantially as a consequence of economic development, leading to an overall increase in food demand in the BAU scenario. Human food consumption would increase based on the PGDP growth. Per capita food demand would increase to 6.2 kg N yr^{-1} with 51% of the N being in animal products in 2020 (Gu et al., 2015). The NUEs and nutrient recycling rates of different subsystems (e.g., cropland, livestock, grassland, etc.) remain constant and no policy measures are implemented to reduce N fertilizer use under BAU. Under this context, we ran two suits of scenarios, one with grain imports remaining at the 2010 level, and one with no grain imports. Although China is unlikely to have trade limitations for grain imports in 2020, the second suit of scenarios with no grain imports represents the upper limit of grain import pressure. The intervals between these two suits of scenarios should cover the majority situations of future N fertilizer use in China. Under each suit of scenarios, we have another five sub-scenarios: diet change, NUE improvement, nutrient recycling improvement, all the above three combined, and half increase of NUE and nutrient recycling rates.

Scenario S1 described a change in diet. We assumed that the per capita total food consumption would not change because 6.2 kg N yr^{-1} (including food waste) is a common value in most of the developed countries – even in Hong Kong and Taiwan which share a similar dietary habit with mainland China (FAO, 2016); however, the animal food share would decrease from 51 to 40% following 'Chinese Dietary Guidelines' (CNS, 2012). Scenario S2 suggested an improved NUE. We assumed the NUEs in agricultural subsystems would reach the current best level worldwide (Table S1). In fact, these NUEs have already reached levels of 60% for cropland and 20% for livestock systems in some provinces of China owing to the larger farm size and better management (Ma et al., 2013). Scenario S3 suggested a higher nutrient recycling rate. We assumed waste-recycling rates in agricultural subsystems reached the current best level worldwide (Table S1). Currently, the nutrient recycling rates are about half those in developed countries. These differences are largely due to the air-dry process to produce manure for application in China compared to the closed system to produce liquid manure in developed countries (Oenema, 2006). Therefore, with an increase of livestock farm size, the applications of new waste treatment systems can significantly increase waste recycling in China. Scenario S4 is a combination of S1, S2 and S3, representing the best N management in China in 2020. This assumption seems unrealistic but it does represent the maximum likelihood. Therefore, we also ran another scenario (S5) with NUE and nutrient recycling only increasing to 50% of the best levels in developed countries (Table S1); we believed this to be more realistic.

2.2. Data on farm size, subsidy and cost-benefit analysis

The data on average farm size and the fertilizer use for smallholders and collectives are from China's second agricultural census (data year, 2006) (CSAC, 2009). The census includes all the smallholders (over 200 million households) and collectives (over 395,000 collectives). The underreporting rate is lower than 0.2%, and the error rate of original data was 0.14% (CSAC, 2009). The total area of smallholder farm accounted to 98% of the total farm area in China.

Data sources for fertilizer price and subsidy are from governmental departments, including Ministry of Agriculture, Ministry of Finance, National Development and Reform Commission, etc. These data include the changes of price formation in China's fertilizer market, and the establishment and withdraw of fertilizer subsidies from 1978 to 2015.

The data on cost-benefit agricultural production has two parts. The first part is about the overall cost-benefit of agricultural production calculated based on the average situation of rice, wheat and corn in Chinese croplands (PNRC, 2014). The input costs of agricultural production include several items such as labor, land, fertilizer, pesticides, seeds, machinery, etc. The second part is about the comparison of smallholder and large-scale farms for wheat and rice (RCS, 2013; Liu et al., 2014). One case was in Henan province, where has a cropland area around 7.9 million hectares (mainly wheat). Wheat production in Henan province accounted to 25% of national production, which could be the typical case to analyze the cost-benefit. In 2013, the wheat-cultivated farmlands in Henan were surveyed to analyze how farm size affects the cost-benefit of wheat cultivation (Liu et al., 2014). 150 large-scale farms were investigated, while for the smallholder farms, the average data for the whole Henan province were used, over 15 million rural households. The survey included several groupings, based on farm sizes. To make the comparison simple, we combined these groups into two groups: one group represents large-scale farms with an average farm size at 36.6 ha and the other group represents smallholder farms with an average farms size at 0.3 ha. The other case was in Jiangsu province with a cropland area at 4.7 million hectares and rice production accounting to 10% of overall national production (RCS, 2013). The survey was conducted in Suining County, where has cropland around 100,000 ha, about half of which is large-scale farms because of migration of rural labors to urban areas during the urbanization process.

3. Results and discussion

3.1. Biophysical potentials to reduce fertilizer use

The N fertilizer use is projected to increase from 29 Tg N yr^{-1} in 2010 to 42 Tg N yr^{-1} by 2020 with imported grain remaining at the 2010 level, and to 53 Tg N yr^{-1} in 2020 with no grains imported in 2020 under the BAU (Fig. 1). The diet change scenario (S1) reduces N fertilizer use from 42 Tg yr^{-1} (BAU) to 34 Tg yr^{-1} in 2020 with grain imports at the 2010 level. If no grains were imported in 2020, N fertilizer use would be 46 Tg yr^{-1} in 2020. The NUE scenario (S2) reduces N fertilizer use to 18 Tg yr^{-1} in 2020 with grain imports at the 2010 level and to 25 Tg yr^{-1} in 2020 with no grains imported in 2020. The nutrient recycling scenario (S3) reduces the N fertilizer use to 33 Tg yr^{-1} in 2020 with grain import at the 2010 level and to 42 Tg yr^{-1} in 2020 with no grains imported in 2020. Therefore, NUE improvement seems essential to substantially reduce the N fertilizer use in 2020 to be equal or below 2010 level. N fertilizer use in 2020 projected by the other two scenarios (i.e., S1 and S3), is approximately 15% higher than the 2010 level. Combining these three scenarios (S4) would further reduce the N fertilizer use to 10 Tg yr^{-1} in 2020 with grain imports at the 2010 level and to 13 Tg yr^{-1} in 2020 with no grains imported.