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Exploring nutrient management options to increase nitrogen and phosphorus use efficiencies in food production of China

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ABSTRACT

Low nitrogen (NUE) and phosphorus (PUE) use efficiencies in food production in China result in large losses of nitrogen (N) and phosphorus (P) to the environment. The Chinese government formulated policies to increase the NUEs and PUEs. Recent policies aim for zero growth in synthetic fertilizer use after 2020 while ensuring food security. In this study we analyzed how current and improved nutrient management in China can affect future nutrient use efficiencies and nutrient losses from food production. The NUEs and PUEs of food production were quantified using the *NUFER* (NUtrient flows in Food chains, Environment and Resources use) model for 31 provinces and China in 2013, 2020 and 2050. Results show that national NUE (20%) and PUE (24%) in 2013 are low but vary largely among provinces (12–33% for NUE, 10–53% for PUE). The N and P losses to the air (14 Tg year^{-1} of N) and waters (12 Tg year^{-1} of N, 2 Tg year^{-1} of P) are consequently high in 2013. Three scenarios were analyzed for 2020 and 2050 to explore future trends in NUEs and PUEs, assuming *Business As Usual* (*BAU*) trends, *Zero Fertilizer* (*ZF*) *growth from 2020*, and *Improved Nutrient Management* (*INM*). In the *BAU* scenario, the NUEs and PUEs roughly remain at their low 2013 levels, while nutrient inputs to agriculture are increasing. The losses to the air therefore increase by 37% for N and to waters by 40% for N and 48% for P between 2013 and 2050. In the *ZF* scenario, the NUEs and PUEs are a few percent higher than in *BAU*. The associated N and P losses to waters are 8–16% lower than in *BAU* because of increased recycling of manure to cropland, but still higher than in 2013. Improved nutrient management, as assumed in our *INM* scenario, may increase NUEs and PUEs to 33% and 59% in 2050. Meanwhile, N and P losses to waters in 2050 are 47% and 83% lower than in 2013, and losses of N to the air 20% lower. We conclude that the policy aimed at zero growth in fertilizer use is a good start, but not very effective in reducing nutrient pollution in China. To substantially reduce N and P losses to the environment it is needed to improve nutrient management by not only reducing fertilization without yield losses, but also by improved manure management and animal production with lower nutrient excretion.

1. Introduction

Nitrogen (N) and phosphorus (P) are essential elements for food production (Galloway et al., 2004). The use of N and P in agriculture has been increasing very fast in China since the 1980s to feed the large population. According to FAO (2015b), the synthetic fertilizer use in China is the highest worldwide, and almost twice that in the United States (US). Meanwhile China is becoming a large livestock producer. More than 50% of the global pork production, and 40% of eggs took place in China in 2005 (FAO, 2015a; Scanes, 2007). However, nutrients are not used very efficiently in Chinese agriculture: the N and P use efficiencies (NUE and PUE) are very low because of poor nutrient management (Bai et al., 2014; Bai et al., 2013; Liu et al., 2008; Ma et al., 2012). Ma et al. (2010) concluded that the NUEs and PUEs of Chinese food production in 2005 was much lower than in European countries (EU) and the US.

As a result of this, the losses of N and P to the environment are large, causing air and water pollution. Agricultural greenhouse gas emissions (e.g., N_2O) contributed 17% to the national emissions from China (Chai et al., 2013; IEA, 2007; Nayak et al., 2013). Discharge of N and P to rivers results in eutrophication in many Chinese rivers (e.g., Yangtze, Yellow and Pearl rivers) and seas such as the Bohai Gulf, Yellow sea and South China sea (Liu et al., 2009; Müller et al., 2008; Qu and Kroeze,

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2010; Strokal et al., 2014a; Strokal et al., 2014b; Sumei et al., 2008; Xie et al., 2014). This pollution will likely continue to increase in the future, as a result of the food demand by a growing population in China (Alexandratos and Bruinsma, 2012).

Since the early 2000s, the Chinese government has been recognizing these environmental challenges in food production (Zheng, 2013). There are several policies and regulations for sustainable agricultural production. For example, a "Discharge Standard of Pollutants for Livestock and Poultry Breeding" has been introduced in water polluted areas since 2003 to reduce pollution from livestock production (MEP, 2001). Another example is the so-called "Double High Agriculture" project, aiming for high yield of crops, and high nutrient use efficiency. This project is being implemented by government, scientists, and farmers in Chinese agriculture (Chen et al., 2011; Fan et al., 2008; Fan et al., 2009; Zhang et al., 2011). Recently, the "Zero Growth in Synthetic Fertilizer Use from 2020" policy was introduced by the ministry of agriculture in China to increase nutrient use efficiencies, and to reduce pollution from agriculture (MOA, 2015b). It includes specific reduction targets for synthetic fertilizer use, manure recycling and nutrient management for the period 2015–2020 (MOA, 2015a). Clearly, the Chinese government demonstrates willingness to move to a more sustainable food production.

The effectiveness of nutrient management strategies for Chinese agriculture is not well studied. Existing studies typically assess selective nutrient management practices, but not the effects of more integrated policies (Chai et al., 2013; Ermolieva et al., 2009; Huang et al., 2015; Ju et al., 2009; Ma et al., 2013a; Ma et al., 2013b; Nayak et al., 2013; Qu and Kroeze, 2012; Sims et al., 2013; Zhang et al., 2015). There are no integrated assessments of current policies as done for some other countries (Oenema et al., 2009; Velthof et al., 2014). Thus, a study that evaluates the effectiveness of current policies in China in improving N and P use efficiencies, and reducing nutrient pollution is needed. This would show us whether the current Chinese policies are effective. And if current policies are not effective, what would be needed for sustainable food production in the future.

In this study we aim to analyze how current and improved nutrient management in China can affect future nutrient use efficiencies and nutrient losses from food production in all 31 provinces. To this end, we analyzed three scenarios for 2020 and 2050. These scenarios are assuming *Business As Usual* (*BAU*) trends, *Zero Fertilizer* (*ZF*) *growth from 2020* representing current nutrient management, and *Improved Nutrient Management* (*INM*) in China. We updated the *NUFER* model to the year 2013 in order to quantify the current situation of NUEs and PUEs, and N and P losses from agriculture, and to implement the scenarios. This way, we can evaluate the effectiveness of current policies, and help to formulate nutrient management strategies to ensure food security with low environmental pollution in China.

2. Method

2.1. Study area

We analyzed the N and P use efficiencies of food production including crop and animal production for all 31 Chinese provinces and China (Fig. 1). The 31 provinces are located in eight regions: North China, Northeast China, East China, Central China, South China, Southwest China, Plateau and Northwest China (Fig. 1). Most crop production is in the eastern regions (North China, Northeast China, East China, Central China, South China, Southwest China), where more than 15% of total land area is cultivated (Table 1). Animal production is more intensive in North China, Northeast China, East China, Central China, Southwest China, and Northwest China (Table 1). For example, the total number of animals in North China in 2013 (more than 30 million livestock unit) was twice that in South China (less than 16 million).

2.2. NUFER

We used the *NUFER* (NUtrient flows in Food chains, Environment and Resources use) model to quantify the N and P use efficiencies of food production for 2013, 2020 and 2050 (Ma et al., 2010; Ma et al., 2012). *NUFER* was developed to quantify nutrient flows in the food chain of China from 1980 to 2005, and in 2030. This model also quantifies nutrient flows in the food chain of all 31 provinces in China in 1980 and 2005. *NUFER* has been widely applied to quantify nutrient flows in the food chain (Bai et al., 2014; Bai et al., 2013; Hou et al., 2013; Ma et al., 2013b; Qin et al., 2012) and as a basis for policies aimed at improved nutrient management in China (MOA, 2015b). The food chain in *NUFER* includes crop production, animal production, food processing and food consumption. The nutrient import to, output from and cycling within the food chain are quantified by this model.

For this study, we updated *NUFER* to the year 2013 for 31 provinces in China. The model inputs of *NUFER* are divided into three categories: 1) human activities in food production and consumption; 2) transformation and portioning coefficients; 3) N and P content and loss factors (Table 2). These input data for 2013 were collected from statistic yearbooks, survey reports and other studies (Ma et al., 2010; MOA, 2014; NBSC, 2014; Xu et al., 2015).

NUFER quantifies N and P use efficiencies of food production (including crop and animal production) based on the nutrient flows in the food chain. Here the N and P use efficiencies are calculated as the N and P content in crop and animal products (e.g., yield of crops, animal meat) divided by total N and P inputs to crop and animal production (e.g., synthetic fertilizer, N deposition, animal feeds). Detailed information on the calculation method for N and P use efficiencies can be found in the equations in Box 1.

We also used *NUFER* to quantify the N and P losses to the air and aquatic systems from food production (including crop and animal production) based on the nutrient flows in the food chain (Ma et al., 2010; Wang et al., submitted for publication). The N losses to the air are the emissions of ammonia (NH_3) and nitrous oxide (N_2O) from agriculture. The denitrification product dinitrogen (N_2) is also calculated in *NUFER*, but not considered here because it is not a pollutant. The N and P losses to aquatic systems (surface and ground waters) include surface runoff, leaching and erosion of N and P from cropland, and direct discharge of animal manure to rivers.

2.3. Scenarios

We analyzed three scenario using *NUFER* to assess the effects of nutrient management on N and P use efficiencies and N and P losses. One scenario is a *Business As Usual* (*BAU*) scenario. The other two scenarios are alternatives to this *BAU* scenario, assuming *Zero Fertilizer* (*ZF*) *growth from 2020*, and *Improved Nutrient Management* (*INM*) (Table 3). The *BAU* and *ZF* scenarios were implemented for 2020 and 2050, while *INM* is only implemented for 2050. We choose the year 2020 because this is the current target year for the Chinese government to reach no growth in synthetic fertilizer use. And 2050 is chosen in line with the Millennium Ecosystem Assessment scenarios (Alcamo et al., 2005); for 2050 input data are readily available, for instance from FAO outlooks on food production (Alexandratos and Bruinsma, 2012).

2.3.1. Business As Usual (BAU)

In the *BAU* scenario, crop and animal production in China is assumed to increase in order to meet the growing demand for food in the future. The expected larger population is assumed to have dietary preference for animal products. The FAO projections for crop and animal production in Asian countries are used as a baseline for agricultural production in this scenario (Alexandratos and Bruinsma, 2012). The crop yields are assumed to increase by 8% between 2013 and 2020, and by 28% between 2013 and 2050. Synthetic fertilizer application is assumed to

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