Improving nitrogen use efficiency in the Chinese food chain to reduce air and water pollution

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Abstract
Nitrogen (N) use efficiency is low in Chinese agriculture. This results in large N losses to air and water. We aim to explore effective nutrient management options to increase N use efficiencies in the food chain, and thus to reduce N losses to the environment for 2020 and 2050 in China by scenario analysis. Three scenarios were developed and implemented assuming Business As Usual (BAU) trends, Zero Fertilizer (ZF) growth from 2020, and Improved Nutrient Management (INM). N use efficiencies in agriculture, and N losses were quantified using the *NUFER* (NUtrient flows in Food chains, Environment and Resources use) model. Results show that N use efficiency in 2013 is low at about 20%. Thus the losses to air (14 Tg of N) and water (12 Tg of N) are high in 2013. The N use efficiencies will likely remain at their low 2013 levels in 2020 and 2050 under BAU, resulting in large increase in N losses to air and water between 2013 and 2050. INM is projected to increase N use efficiency to 33% in 2050. N losses to water in 2050 are almost half of that in 2013, and to air are 20% lower. Scenario ZF incorporates recent Chinese policies aiming at a zero growth in synthetic fertilizer use from the year 2020 onwards. ZF is projected to be much less effective than INM. We conclude that nutrient management that simultaneously reduces fertilization, improves manure management, and reduces nutrient excretion in animal manure, is needed for Chinese agriculture.

Key Words
nitrogen use efficiency, nitrogen losses, current policy, improved nutrient management, Chinese agriculture

Introduction

Nitrogen (N) use efficiency of agricultural production is reported to be very low in China due to poor nutrient management (Bai, Ma, Oenema, Chen, & Zhang, 2013; Jin et al., 2014; L Ma et al., 2010). This has resulted in large N losses to the environment, causing air and water pollution (Chai et al., 2013; Liu, Hong, Zhang, Ye, & Jiang, 2009; L Ma et al., 2012; Müller et al., 2008; Nayak et al., 2013). For example, eutrophication in many Chinese seas are caused by the discharge of N and P from agricultural activities (Qu & Kroeze, 2010; Strokal et al., 2016; Strokal et al., 2014).

In order to deal with these problems, the Chines government has introduced several policies and regulations to improve nutrient use efficiencies and to reduce nutrient losses to the environment. A policy named "Zero Growth in Synthetic Fertilizer Use from 2020" was recently introduced by the ministry of agriculture in China (MOA, 2015a, 2015b). "Zero growth" means that the use of synthetic fertilizer in China will stop increasing from 2020 onwards. The aim of this policy is to increase nutrient use efficiency, and to reduce environmental pollution by agriculture. However it is not clear whether these policies are likely to be effective at reducing nutrient losses, and what are the most effective nutrient management options are for China. Thus, a study that evaluates current policies and other possible nutrient management options is needed for developing sustainable food production in China.

Our aim is to explore nutrient management options that increase N use efficiencies in the food chain, and thus to reduce N losses to the environment for 2050 in China. To this end, we developed three scenarios for 2020 and 2050 assuming Business As Usual (BAU) trends, Zero Fertilizer (ZF) growth from 2020, and Improved Nutrient Management (INM). We used the *NUFER* (NUtrient flows in Food chains, Environment and Resources use) model for scenario analysis. The model and scenarios are discussed in section 2. Results are discussed in section 3 and conclusions are drawn in section 4.

The *NUFER* model and scenarios

The *NUFER* model was developed for China and is described in L Ma et al. (2010).This model quantifies nitrogen (N) and phosphorus (P) flows in food production, based on which N and P use efficiencies and N and P losses to the environment are derived. *NUFER* quantifies N and P flows on county, provincial and national levels for many past (1980 as earliest) and future (2050 as latest) years. In this study, we updated the *NUFER* model to 2013 using the information from Chinese statistical year books, survey reports and other studies (L Ma et al., 2010; MOA, 2014; NBSC, 2014; Xu et al., 2015). Next we used *NUFER* to calculate the N use efficiency of Chinese agriculture (including crop and animal production) and N losses to air and water in 2013, 2020 and 2050.

We developed three scenarios assuming Business As Usual (BAU) trends, Zero Fertilizer (ZF) growth from 2020, and Improved Nutrient Management (INM) for 2050. The BAU scenario is developed based on the projections of agricultural activities from FAO (Alexandratos & Bruinsma, 2012). Under BAU, the synthetic fertilizer use will increase by 6% between 2013 and 2020, and by 22% between 2013 and 2050. The total animal number will increase by 13% between 2013 and 2020, and by 59% between 2013 and 2050. Next, ZF was developed using BAU as the basis. The ZF scenario assumes that the growth in synthetic fertilizer use will be zero from 2020 by implementing current policies. In addition to this, manure recycling to land will be improved to 60% based on current policies. Last, the INM scenario was developed for 2050 using ZF as the basis. INM integrates further nutrient management options for fertilization, manure management, and nutrient excretion in animal production. Under INM, the N input to agriculture from synthetic fertilizer use is reduced by 55% without losses of crop yield using the balanced fertilization method (Lin Ma et al., 2013). In addition, 90% of the available manure (after losses of N during manure storage) is recycled on cropland. The NH_3 emission during manure storage will be reduced by 50%. The N excretion from animals is assumed to reduce by 20% by improving feeding in animal production.

Results of scenario analyses

Our results show that the N use efficiency of Chinese agricultural is low at around 20% in 2013 (Figure 1). The N losses to air (14 Tg of N) and water (12 Tg of N) are therefore high in this year (Figure 2). The N use efficiency is projected to stay at its low level of 2013 in 2020 (20%) and 2050 (21%) under the BAU scenario (Figure 1). This, together with more intensive agricultural activities in the future, will result in much higher N losses to water and air in 2020 and 2050 (Figure 2). N losses to air in 2020 under BAU are 9% higher than in 2013, and in 2050 37% higher than in 2013. N losses to water in 2020 under BAU are 8% higher than in 2013, and in 2050 36% higher than in 2013. The dominant source of N losses to air is ammonia (NH_3) emission from crop production in 2013, and under BAU in 2020 and 2050. Synthetic fertilizer and direct discharge of animal manure (point manure in Figure 2) are the main contributors of N losses to water in 2013, and under BAUs in 2020 and 2050.

INM is projected to be the most effective scenario for improving N use efficiencies of agricultural production in China, and reducing N losses to the environment. Under this scenario, the N use efficiency of Chinese agriculture is improved to 33% in 2050 (Figure1). This is considerably higher than in the BAU scenario (21%) for the year 2050. As a result, the N losses to the environment are also reduced largely under INM by 2050. The N losses to air under INM in 2050 are around one fifth of that in 2013, while N losses to waters are almost half of that in 2013 (Figure 2). The share of N losses to water from synthetic fertilizer and direct discharge of animal manure (point manure in Figure 2) is the lowest in INM than in other scenarios. This is because of the high manure recycling and high reduction of synthetic fertilizer use under INM. The NH_3 emission from crop production (contributes 70% of the total N losses to air) is still the dominant source of N losses to the air. This indicates that nutrient management for reducing NH_3 emission from crop production is needed to reduce N losses to the air.

Our results for the ZF scenario show that current policies are not very effective in reducing N losses to the environment, and in improving N use efficiencies. The N use efficiencies in 2020 (20%) and 2050 (22%) are still very low under ZF (Figure 1). This shows that the N use efficiency in the future will not be improved by only implementing current policies. The N losses to air under ZF are comparable to that under BAU in 2020 and 2050 (Figure 2). The dominant source of losses to air is still NH_3 emission from crop production. ZF, however, is able to reduce N losses to water. The N losses to water under ZF is 5% lower than under BAU in 2020, and is 15% lower in 2050 (Figure 2). This is because the N losses to water from direct discharge of animal manure is reduced by the higher manure recycling in current policies. However, the losses to waters under ZF are still higher than that in 2013. Direct discharge of animal manure, as well as synthetic fertilizer, are still the dominant source of N losses to water.

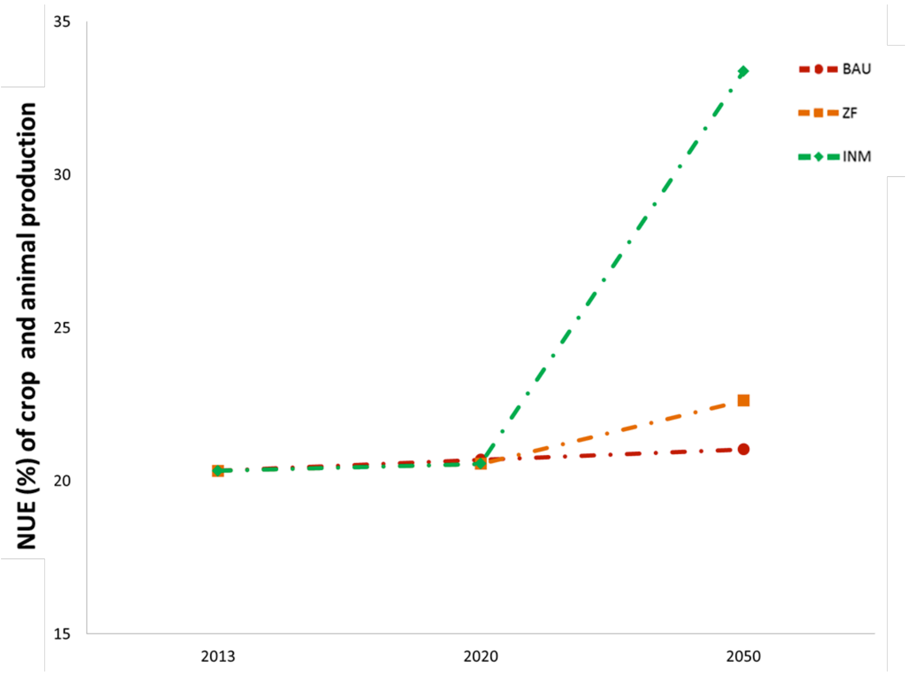

Figure 1. Nitrogen use efficiency (NUE, %) of crop and animal production for China in 2013, 2020 and 2050. Scenarios for 2020 and 2050 are Business As Usual (BAU) trends, Zero Fertilizer growth (ZF) and Improved Nutrient Management (INM).

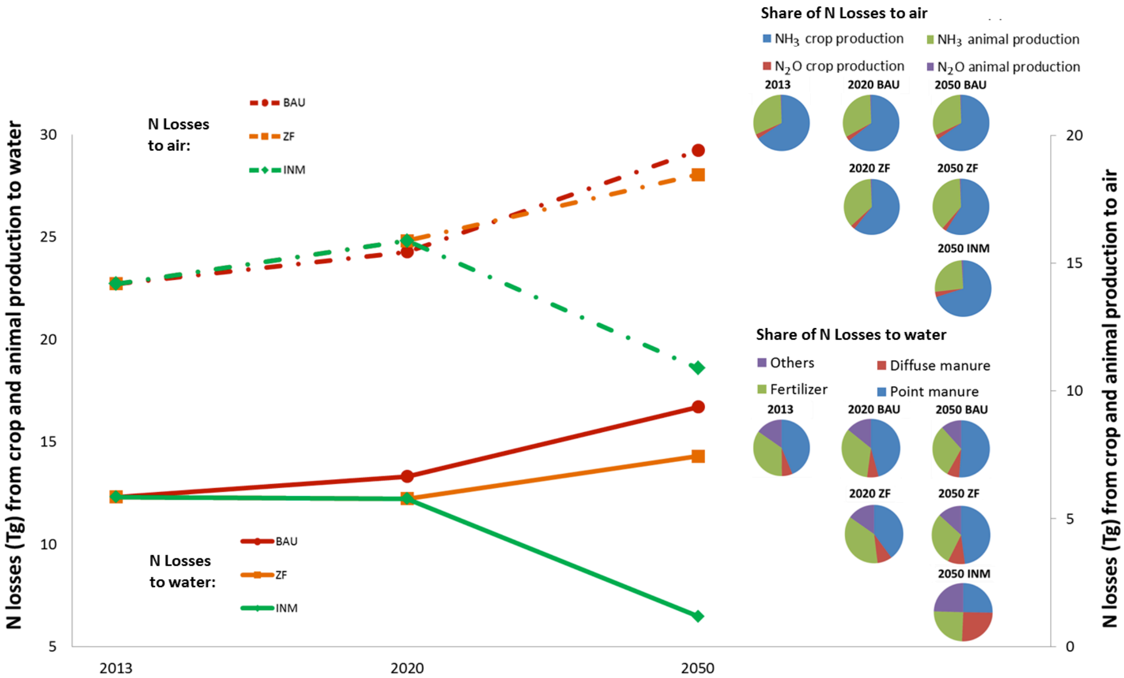

Figure 2. Total nitrogen (N) losses to air and water, and the share of sources (%) in total losses for China in 2013, 2020 and 2050. *Diffuse manure* represents N losses to water from manure that is applied to cropland. Point manure represents N losses to water from direct discharge of animal manure. Others include N losses from cropland (e.g., biological N fixation, atmospheric N deposition) except for synthetic fertilizer and diffuse manure. Scenarios for 2020 and 2050 are Business As Usual (BAU) trends, Zero Fertilizer growth (ZF) and Improved Nutrient Management (INM).

Conclusion

The N use efficiency is currently very low in Chinese agriculture. This results in large losses of N to air and water. Current policies have been introduced with the aim of increasing nutrient use efficiency and reducing off-site environmental impacts. One of the recent policies aims for zero growth in synthetic fertilizer use after 2020. However, it is not clear whether these policies are effective and what are the most effective options for nutrient management. We, therefore, explored options to improve N use efficiency of agriculture and to reduce N losses to the environment for China by 2050. Our results show that N use efficiency is as low as 20% in China in 2013, and will likely stay at this low level in 2020 and 2050. The N losses to air and water are, therefore, relatively high in 2020 and 2050. Current policies are not very effective in improving N use efficiency and in reducing N losses to the environment. Integrating reduction in fertilization, improvement in manure management, and reduction in nutrient excretion in animal production appear to be the most effective option for improving N use efficiency in the Chinese food chain and in reducing N losses to the environment.

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