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Changes in nitrogen budget and potential risk to the environment over 20 years (1990–2010) in the agroecosystems of the Haihe Basin, China

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ABSTRACT

The nitrogen balance can serve as an indicator of the risk to the environment of nitrogen loss from agricultural land. To investigate the temporal and spatial changes in agricultural nitrogen application and its potential threat to the environment of the Haihe Basin in China, we used a database of county-level agricultural statistics to calculate agricultural nitrogen input, output, surplus intensity, and use efficiency. Chemical fertilizer nitrogen input increased by 51.7% from 1990 to 2000 and by 37.2% from 2000 to 2010, concomitant with increasing crop yields. Simultaneously, the nitrogen surplus intensity increased by 53.5% from 1990 to 2000 and by 16.5% from 2000 to 2010, presenting a continuously increased environmental risk. Nitrogen use efficiency decreased from 0.46 in 1990 to 0.42 in 2000 and remained constant at 0.42 in 2010, partly due to fertilizer composition and type improvement. This level indicates that more than half of nitrogen inputs are lost in agroecosystems. Our results suggest that although the improvement in fertilizer composition and types has partially offset the decrease in nitrogen use efficiency, the environmental risk has still increased gradually over the past 20 years, along with the increase in crop yields and nitrogen application. It is important to achieve a better nitrogen balance through more effective management to significantly reduce the environmental risk, decrease nitrogen surplus intensity, and increase nitrogen use efficiency without sacrificing crop yields.

Introduction

Nitrogen (N) plays an important role in crop production. Total consumption of world fertilizer N has increased from 76.8 Tg (1 Tg = 10^{12} g) in 1990 to 104.3 Tg in 2010, with China, India, and the United States occupying the top three slots (Heffer, 2013). China consumed 19.2 Tg N of chemical fertilizer in 1990, a fourth of the world's total amount, and 32.6 Tg in 2010, about one-third of the world's total (Guo et al., 2012). Nitrogen inputs into agroecosystems have helped to improve world crop productivity and can enhance economic development (Vitousek et al., 2009), but surplus N has also led to a host of environmental problems, ranging from eutrophication in terrestrial and aquatic systems to global acidification (Nicolas and Galloway, 2008; Ping et al., 2014).

The nitrogen balance for agricultural land is defined as the difference between the total quantity of N inputs, including

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inorganic fertilizers, livestock manure, biological nitrogen fixation, and atmospheric deposition and the quantity of outputs, including uptake by harvested food and fodder crops and pasture (OECD, 2008). This balance is one of the key indicators for agricultural N management. Nitrogen balance analysis is useful not only for predicting N accumulation in an ecosystem but also for improving nitrogen use efficiency and reducing the environmental risk of N loss. It has been widely adopted in the transition toward more sustainable agriculture practices (Öborn et al., 2003; Oenema et al., 2003).

To understand nitrogen use efficiency and assess the environmental risk of fertilizer N application, N budgets have been estimated in many countries (Breemen et al., 2002; Liu et al., 2008; Atsushi et al., 2009) at various scales, including by country, watershed, region, and worldwide (Sun et al., 2008; Junko, 2012). These estimates have contributed to agricultural N management to minimize environmental degradation while maintaining high crop yields (Liu and Chen, 2007). Many case studies have focused on particular ecosystems, such as greenhouses, the fields of smallholder farms, and different types of vegetable fields (Wang et al., 2008; Hou et al., 2012). However, spatial differences in N balance and N budget changes over time have rarely been addressed at a regional scale, particularly in China (Liu et al., 2008).

The Haihe Basin is one of the important grain production bases in China. Due to agricultural development and the overuse of N fertilizer, water shortages and water pollution have become very serious problems in the Haihe Basin, which has been one of the most polluted regions in China (Chen et al., 2005; Liu et al., 2010; Wu et al., 2011). A survey of groundwater nitrate-N concentrations in the Haihe Basin showed that approximately 45% of 600 groundwater samples exceeded 11.3 mg NO_3-N/L (50 mg NO_3N/L), the World Health Organization's and Europe's limit for nitrate in drinking water. The highest nitrate-N concentration reached 113 mg/L (Zhang et al., 2004).

We examined the N balance in this region to determine the characteristics of N balance, nitrogen use efficiency, and nitrogen surplus intensity, as well as their change trends in the Haihe Basin. We also examined the potential environmental risks of current crop N management practices and their change trends. We approached these questions by calculating agricultural N input, output surplus intensity, and use efficiency by using a database of county-level agricultural statistics. The data in the database were collected every 10 years, and we used data from 1990, 2000, and 2010.

1. Materials and methods

1.1. Study area

The Haihe Basin, which is located in northern China (112–120°E, 35–43°N), encompasses all of Beijing and Tianjin, the vast majority of Hebei Province, the eastern part of Shanxi Province, and the northern parts of Henan and Shandong provinces, as well as a small part of the Inner Mongolia Autonomous Region and Liaoning Province. There are 312 counties in the Haihe Basin and the total area is 3.18×10^5 km^2 (Fig. 1). In 2010, the total population was 1.40×10^8 and the cultivated land accounted for 1.29×10^7 ha in the Haihe Basin. The predominant climate is the Asian monsoon climate, with average annual precipitation of 539 mm and average annual temperatures of 1.5°C–14.0°C.

The Haihe Basin is one of the top three grain production bases in China. Its grain yield accounts for more than 10% of the country's total grain yield. In addition, the Haihe Basin is a "vegetable basket" production base for mega cities (Beijing, Tianjing, *etc.*). To yield sufficient food to feed the increasing

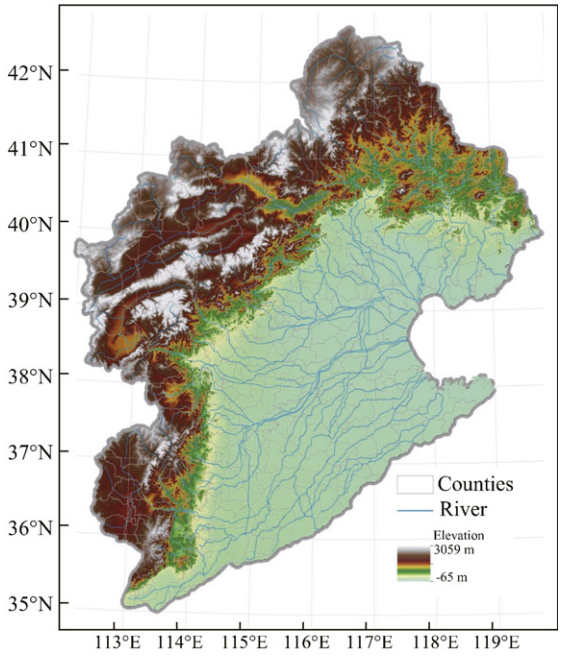

Fig. 1 – The location of the Haihe Basin in China.

population, chemicals, dominated by N fertilizer, are widely used in the Haihe Basin to boost agricultural productivity (Zhang et al., 2012). Their use makes the Haihe Basin one of the most polluted regions in China. A survey of the NO_3-N concentrations of shallow groundwater in the North China Plain indicated that approximately 21.5% of the total surface area of the plain had NO_3-N levels above 10 mg/L (Li et al., 2001). Groundwater NO_3-N increased significantly as the N fertilization rate increased (Zhao et al., 2007), and the overuse of N fertilizer was the principal factor affecting groundwater nitrate pollution (Chen et al., 2005).

1.2. County-level database

We created a county-level database by using the ArcGIS software developed by ESRI. First, we collected county-level agricultural data recorded in 1990, 2000 and 2010 from the Chinese Academy of Agricultural Sciences, including fertilizer type and amount, crop type (wheat, maize, rice, *etc.*) and yields, cultivated land area, paddy land area, upland area, irrigation acreage, livestock type (pigs, sheep, cattle, *etc.*) and amount, *etc.* Second, we used GIS software to generate the spatial data. For example, average annual precipitation data recorded between 1990 and 2010 at 104 monitoring stations of China Meteorological Administration located in the Haihe Basin were utilized in atmospheric wet deposition calculations to produce county-level data with the kriging method. Finally, the N input and output were calculated at the county level. A total of 312 county units were used to aggregate various budgets in 1990, 2000 and 2010 in the Haihe Basin based on the above data.

1.3. Nitrogen balance calculation

The annual N balance followed the definition used by the Organisation for Economic Cooperation and Development (2008)