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Nitrogen application rates need to be reduced for half of the rice paddy fields in China

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ABSTRACT

Increasing nitrogen (N) application to croplands in order to support growing food demand is a major cause of environmental degradation. However, evaluations of suitable N application rates based on environmental benefit have rarely been carried out for paddy-rice at a national scale in China. To address this challenge, we investigated the current status of N management in 1531 counties, covering the primary agro-ecological regions of Chinese rice production in 2008, and conducted 12 field experiments with six N level practices for 3 years (2011–2013). Results showed that the highest yields for rice were 5.8–8.6 Mg ha^{-1} with N rates of 209.4–289.8 kg N ha^{-1}. Compared with the N rate for the highest yield (YHN), the environmentally optimal N rate (EnON) was lower by 20–39% and the corresponding N loss was reduced by 21–45%, while ensuring 95–99% of the highest crop yield. In China, the N inputs to paddy fields exceeded the YHN and EnON rates by 10% and 45%, respectively. After adjusting the N rate to paddy fields to the EnON rate, the N amount used in China and the corresponding N lost would be reduced by 0.9 and 0.5 Tg N yr^{-1}, respectively, which enable highly efficient production of food with the lowest N loss possible. Thus, we suggest that N use rates for 45% of rice paddy fields in China, for which N application rates exceed the EnON rate, need to be reduced to mitigate environmental damage, and this can be done while still meeting China's food demand.

1. Introduction

To meet the food and fiber demands of an increasing and gradually wealthier population, a series of policies were implemented to encourage synthetic fertilizer production and use in China during the last three decades (Li et al., 2013). However, nitrogen (N) fertilizer is substantially overused and misused in Chinese cropland, which is causing a series of environmental problems (Ju et al., 2009; Lu et al., 2015), such as greenhouse gas (GHG) emissions (Gu et al., 2012), eutrophication (Zhang et al., 2013), soil acidification (Guo et al., 2010), and a loss of biodiversity (Humbert et al., 2016; Zeng et al., 2016).

With the aggravation of environmental pollution, maintaining food production while reducing the detrimental effects of anthropogenic N application is an urgent priority for global food security and environmental sustainability (Erisman et al., 2011; Qiao et al., 2015). Ultimately, there is a need to balance the benefits derived from N applications with the associated environmental costs. The environmental cost assessment could provide guidance for emerging policy priorities in mitigating certain Greenhouse Gas (GHG) or reactive N (Nr) species, after quantifying their both release amounts and damage costs to ecosystems (Chen et al., 2011; Gu et al., 2012). However, previous studies have mostly focused on the optimal N rate to improve N use efficiency (NUE) and increase yield to its maximum potential (Xu et al., 2014), such as by testing the soil NO_3^--N content in the root zone (Cui et al., 2010), developing fertilizer recommendations based on soil testing, yield targets and crop responses (He et al., 2009) and fertilizer effect function equations (Sonar and Babhulkar, 2002), etc. Few studies have attempted to evaluate N input management and the associated

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environmental costs from rice production (Xia et al., 2016).

Rice is an important staple crop in China, playing a crucial role in food security. The global warming potential of GHG emissions and N loss from rice systems have been found to be several times higher than from either wheat or maize (Linquist et al., 2012). Thus, quantification of current N fertilization and improved N management practices and policies in Chinese rice production regions is of national and global interest (Wu et al., 2015). The rice planting area in China is extensive, with different crop rotations, such as a single rice crop per year in Northeast China, rice-upland rotation in the Yangtze River region, and double rice in South China. Furthermore, most Chinese farms are very small, with large variation in N rates, which makes it hard to determine the optimum N application rates for paddy-rice at a national scale in China (Zhang et al., 2013).

In this study, three questions we attempted to answer were: (i) What N rates achieve the highest rice yield and the optimal economic/environmental benefit for the single rice, rice-upland, double rice systems? (ii) What is the current level of N fertilizer application for paddy rice across China based on the above N rates? and (iii) What is the potential for reducing N application and N loss intensity using a reasonable management approach?

2. Materials and methods

2.1. Study areas

The distribution of the 12 in-situ field sites is shown in Fig. 1. According to the natural climatic conditions, cropping system used and cultivation history, the 12 sites covered three types of rice cultivation: (i) single rice, mainly distributed in Northeast China, which is dominated by a temperate monsoon climate with an average annual temperature of 2.9–8.7 °C and an annual precipitation of 350–700 mm; (ii) rice-upland (wheat/rape/vegetable) rotation, mainly distributed in the Yangtze River Basin, which is dominated by a subtropical monsoon climate with an average annual temperature of 14.8–17.3 °C and an annual precipitation of 950–1500 mm; (iii) double rice, mainly distributed in Southeast China, which is dominated by a subtropical monsoon climate with an average annual temperature of 17–21 °C and an annual precipitation of 1200–2000 mm. Double rice cultivation consists of early and late rice with growing seasons from April to July and from July to November, respectively.

The number of study sites in each cropping system was mainly determined by the total rice planting areas and the heterogeneity of environmental factors and management practices. Accordingly, 1, 8 and 3 field sites were set up for the single rice, rice-upland rotation and double rice systems, respectively. The planting areas of the above three systems in China were 4.6, 11.1 and 10.9 million ha, respectively (NBS, 2014). Compared with the latter two systems, the single rice system is commonly concentrated over relatively small areas with little variation in climatic conditions and soil type. Therefore, only one representative field site was chosen for the single rice system in this study. In view of the large variations in climatic conditions in the rice-upland crop growing regions and different crops (wheat/rape/vegetable) used for rotation with rice, 8 field sites were chosen for the study.

2.2. Field measurements

The experiments were conducted over a three-crop cycle during 2011–2013 (two-crop cycle for Anhui, Jiangsu01, Jiangsu02 and Zhejiang02 sites), with a total of 211 site-year observations across China. The experiments included a total of six fertilization treatments: zero N-fertilizer (CK), local farmers' practice (FT), and another four treatments with 50, 67, 83, and 133% of FT (there were no 133% of FT treatments at the Jilin, Anhui and Jiangsu02 sites). Although each site had 5 or 6 treatments, the local farmers' practice treatment (FT) included a range of fertilization rates due to variations in the local practice among various regions. Consequently, the rates for the treatments with 50, 67, 83, and 133% of the local FT rates also varied. Prior to rice transplantation, soil was irrigated and ploughed for better separation and homogeneity, followed by basal fertilization. Based on local farmers' practices, some sites also applied tillering topdressing and anthesis topdressing fertilization. Basic information about climate, soil properties, and fertilization for each site is shown in Tables S1–2. At each experimental site, the plots (20–40 m^2 in area) were arranged following a randomized complete block experimental design with three replicates. At maturity, grain yield and above-ground biomass were sampled and measured for each plot, with five replicate plants being randomly taken and mixed together for each plot. Their N concentrations were determined using the Kjeldahl procedure (Peng et al., 2011).

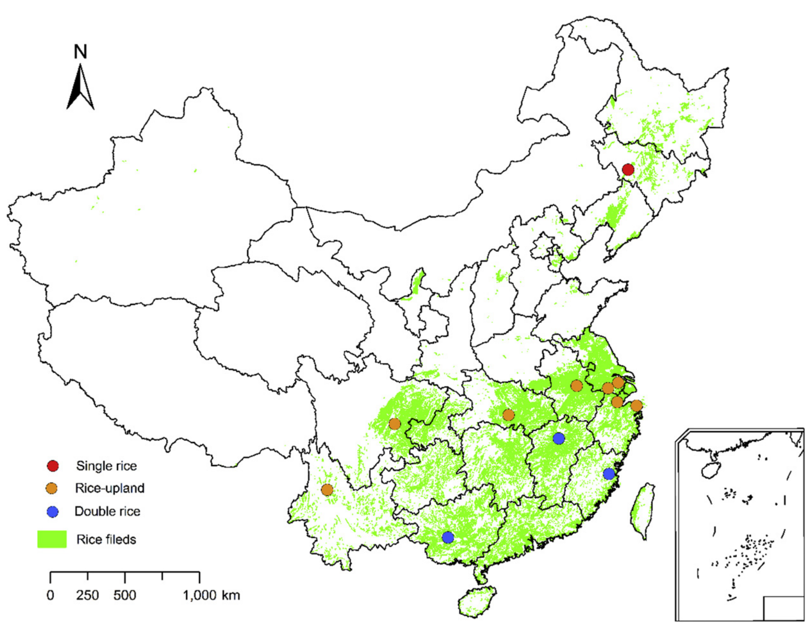

Fig. 1. Geographical distribution of the 12 monitoring sites in China. Double rice was subdivided into early and late rice.