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Optimizing rates and sources of nutrient input to mitigate nitrogen, phosphorus, and carbon losses from rice paddies

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ABSTRACT

Decreasing nutrient losses from excessive synthetic fertilizer inputs is the direct and valid way to address low nutrient use efficiency and the related environmental consequences. Here, we established a comprehensive database of nitrogen (N), phosphorus (P), and carbon (C) losses from rice paddy fields in China, which we used to evaluate fertilization-induced losses and the impact of environmental factors, and to mitigate losses by adopting alternative fertilization options and setting input thresholds. Our results showed that most N-loss pathways had exponential increases with additional N input. In average, 23.8% of the N applied was lost via NH_3 (16.1%), N_2O (0.3%), leaching (4.8%), and runoff (2.6%). Total P loss was approximately 2.7% of the input, composed of leaching (1.3%) and runoff (1.4%). C lost as CH_4 accounted for 4.9% of the organic C input. A relative importance analysis indicated that climate or soil variation rather than fertilizer rate was the dominant factor driving N and P leaching, and CH_4 emissions. Based on the sensitivity of multiple N-loss pathways to N fertilization, we propose upper thresholds for N inputs of 142−191 kg N ha^{-1} across four rice types, which would avoid dramatic increases in N losses. Compared to conventional chemical fertilization, alternative fertilization options had diverse performances: enhanced-efficiency N fertilizer reduced N loss rate by 7.8 percent points and the global warming potential (GWP, considering N_2O and CH_4 emissions) by 28.8%; combined manure and chemical N fertilizer reduced N loss rate by 9.0 percent points but increased the GWP by 56.9%; straw return had no effect on total N loss but almost doubled the GWP. Using nutrient sources most appropriate to site-specific conditions is demonstrated as a robust way to decrease nutrient losses. Setting nutrient input thresholds would also contribute to the mitigation of environmental pollution, especially in regions with poor fertilization recommendation systems.

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important staple crops worldwide, with a grain yield production of 7.7 × 10^8 tons and harvested area of 1.7 × 10^8 ha, in which China contributed approximately 27.3% of yield production (FAOSTAT, 2017). In order to produce high yields, the use of synthetic fertilizers has been increasing steadily during recent decades; in China alone, application has grown from 12.7 million tons (total N, P_2O_5 and K_2O) in 1980 to 58.6 million tons in 2017 (National Bureau of Statistics of China, 2018). There are complicated rice paddy ecosystems extending from the cold to the tropical zones of China, and the large variations of natural conditions and agronomic practices make fertilizer recommendation a challenge. Given that N and P recovery efficiency for most farmers' fertilization practices in China are less than 30% and 20%, respectively (Xu et al., 2016), there is no doubt that there are excessive amounts of chemical N and P fertilizers being applied in paddy fields to guarantee this high productivity (Cui et al., 2018). For example, the application rate of seasonal N fertilizer (averaged 209 kg N ha^{-1}) used in Chinese rice production was found to be 90% greater than the global average

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