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The potential of fertilizer management for reducing nitrous oxide emissions in the cleaner production of bamboo in China

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ABSTRACT

Quantifying the rapidly increasing nitrous oxide emission from excessive nitrogen fertilizer input is a pressing demand for reducing greenhouse gas in cleaner agricultural production. The purpose of this work is to assess the nitrous oxide emission from the intensively fertilized bamboo plantations to better understand the mitigation potential of fertilizer management, and to develop an approach for advancing the site-specific emission factors considering influences of climate and soil conditions. Based on the commonly adopted fertilization practices, the biogeochemical model DeNitrification–DeComposition was adjusted and validated to estimate and analyze nitrous oxide emission under four typical fertilizer management scenarios, namely fertilizer input reduction, split fertilization, deeper placement, and slow-release fertilizers. The simulation results show that the tested fertilizer management practices present great potential for reducing nitrous oxide emissions whereas mitigation effect of each adaptation depends on the site-specific conditions. In the cases of China, fertilizer reduction and adaptation with slow-release fertilizers application are shown to be the most cost-beneficial fertilization options for nitrous oxide mitigation in humid and arid regions, respectively. The highest mitigation achievable ranged from 60.3% (humid coast) to 92.9% (arid inland) compared to the current practice with excessive fertilization. If these adapted fertilization practices are implemented at the national scale, approximately 8.02–11.38 million tonnes carbon dioxide equivalents per year of nitrous oxide emission could be reduced in 2030, which is 4.0%–5.7% of the total nitrous oxide emission from China's upland cropping system. The results indicate the critical importance of site-specific fertilizer management on reducing nitrous oxide emission in bamboo production. By considering the site-specific conditions, the overall biogeochemical modelling approach could serve as a more effective tool than the commonly used emission factors to quantify emission and screen fertilizer management options in cleaner agricultural production.

1. Introduction

The worldwide concern over greenhouse gas (GHG) emission has attracted a great deal of researches on how cleaner production in agricultural sectors will help mitigate global warming and meet the challenge of climate change (Ruviaro et al., 2012; Schäfer and Blanke, 2012; Yang et al., 2014). Agricultural production activities constitute about 10–12% of global anthropogenic GHG emissions, among which nitrous oxide (N_2O) with a warming effect 298 times higher than carbon dioxide (CO_2) will likely become the largest emission source in agricultural planting systems in less than 10 years through increasing synthetic fertilizer applications (IPCC, 2014). As the world's largest nitrogen fertilizer consumer, China alone accounts for 36% of global fertilizer usage (Hvistendahl, 2010), and 20% of global agricultural nitrous oxide emissions (World Bank, 2014b). A recent study indicated that an approximate 50% reduction of fertilizer-induced nitrous oxide emission could be achieved in China's cropland without impacting crop yield by managing currently overused fertilizers (Tian et al., 2012). While a sustainable fertilizer management approach is expected to reduce GHG emissions (Luo et al., 2014), it requires effective tools for further implementation of cleaner production audit toward nitrous oxide reduction. It is therefore of particular importance to estimate

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and reduce nitrous oxide emission from excessive nitrogen fertilizers in agro-ecosystems.

A generic methodology for the estimation of nitrous oxide emission from managed soils was provided by the Intergovernmental Panel on Climate Change (IPCC). It uses default emission factors (EFs) in Tier 1 approach, EFs specific to site conditions such as nitrogen source, crop type, climate, and management practice in Tier 2 approach, or a validated models in Tier 3 approach to assess nitrous oxide emission under various fertilization practices (IPCC, 2006). However, most existing studies concerning condition-specific (particularly management-specific) emission factors are confined to the grain crops (Decock, 2014; Shcherbak et al., 2014). For planting systems with rarely verified emission factors, the biogeochemical process-based models such as DeNitrification–DeComposition (DNDC) are more suitable for nitrous oxide emission estimation because they can reflect influences of local climate, soil conditions and vegetation types by inputting corresponding parameters (Li et al., 1992). The DNDC model in particular has been well developed and validated for nitrous oxide emission estimation in various types of crops ranging from the conventional wheat, maize, rice to the special economic plants such as sugarcane and tea (Giltrap et al., 2010). Hence, it holds promise to evaluate nitrous oxide mitigation practices such as the reduced fertilizer input rates, optimized timing, deep placement and use of new fertilizer formulations (e.g., slow-release fertilizer) as were recently proposed (Decock, 2014).

There were a growing number of recent studies focusing on the nitrous oxide mitigation practices, most of which conducted flux observations or modeling simulations in conventional annual crops (e.g., corn, rice or wheat) (Cui et al., 2014; Laville et al., 2011; Zhang et al., 2014). Nitrous oxide emissions associated with bamboo production, however, are poorly addressed. As a fast-growing perennial plant with increasing global production, bamboo has been intensively managed in recent years to satisfy the growing demand of bamboo timber as a wood substitute and bamboo shoots as a popular vegetable (Lobovikov et al., 2007). For instance, China has intensified its fertilizer application in bamboo plantations since the 1990s, and the current fertilization practices have been largely empirical by farmers without a sound scientific basis. The nitrogen fertilizer application rates of 450 kg ha^{-1} are commonly reported in the most widely distributed bamboo species – *Phyllostachy pubescen* plantations (Li et al., 2013; Liu et al., 2011b), compared to only 58–326 kg ha^{-1} in China's cropland (Chai et al., 2013). Field observations showed that the N_2O emission from bamboo plantations under intense fertilization reached 10.05 kgN ha^{-1} yr^{-1} (Liu et al., 2011a), markedly higher than the highest N_2O emission level of 5 kgN ha^{-1} yr^{-1} in China's agricultural soils (Lu et al., 2006). Hence, it is necessary to consider plant-specific nitrous oxide emission and its mitigation measures by examining the existing fertilizer management practices in bamboo production.

The main objectives of this work were to devise a feasible quantitative tool for an accurate emission inventory of nitrous oxide in bamboo production, and screen the best fertilization schemes toward minimal nitrous oxide emission. This paper presents an overall approach including the application of the biogeochemical model DNDC modified for bamboo plantations, simulating nitrous oxide emissions with a suite of input parameters, and conducting a cost-benefit evaluation for four fertilizer management scenarios in the Chinese bamboo production. The method presented will be beneficial to understand the mechanism of the control measures toward the cleaner production of bamboo as well as other economically important but less studied crops such as cotton, sugar cane, and vegetables.

2. Methods

This study used case studies in China to test the potential of biogeochemical modelling approach for estimating the performances of different fertilizer management options on mitigating nitrous oxide emissions. Detailed procedures are described as below.

2.1. Scope and sites selected for the simulation of bamboo plantations

The nitrous oxide emissions estimated in this study refer to the portion induced directly by synthetic chemical fertilizers in the on-farm stage of bamboo production, which was defined as the emissions from soil nitrification and denitrification processes (IPCC, 2006). Compared with the indirect emissions including ammonia (NH_3) or nitrogen oxides (NO_X) volatilization and leaching or runoff of water soluble nitrogen, the direct emissions account for more than 75% of total fertilizer-induced nitrous oxide (N_2O) emission according to the IPCC (2006). The direct fertilizer-induced nitrous oxide emission was thus employed as a measure to indicate the effects of various fertilizer management practices. In addition, bamboo plants typically need six years from shoots growth to timber harvest. The new growth cycle typically begins in July as underground parts (roots and rhizome) grow until the following February, then bamboo shoots emerge in March and April, grow to the regular height in June, and increase in diameter at the breast height for the remaining years. Therefore, the nitrous oxide emissions were estimated for a time span from 2007 to 2012.

The bamboo plantations selected for this study are from the major bamboo producing areas in China (Fig. S1). Zhejiang, Guangxi, Sichuan and Fujian were selected for case studies, as Zhejiang, Guangxi and Sichuan provinces are listed among the top three provinces with the fastest growth in bamboo production and Fujian is the province with the highest bamboo production. These four provinces located in distinct climate zones, i.e., Zhejiang, Fujian, Guangxi in warm and humid coastal area, and Sichuan in a relatively arid inland area. The effects of various fertilization practices on nitrous oxide emissions were simulated under these different climate conditions (Zhejiang, Fujian, Guangxi, Sichuan) unless otherwise mentioned. The major characteristics of these simulated site conditions are presented in Table S1.

2.2. Description of model modified for estimating nitrous oxide during bamboo production

The fertilizer-induced nitrous oxide emissions were estimated by the biogeochemical model DNDC (Version 9.5) developed by the University of New Hampshire (Durham, USA, downloaded from http://www.dndc.sr.unh.edu/) with a parameter-adjusted crop module containing basic physiological information of bamboo plants. DNDC simulates nitrous oxide produced in nitrification (aerobic oxidation of ammonium to nitrate) and denitrification (anaerobic reduction of nitrate to nitrogen) processes with validated equations (Li et al., 1992). For the purpose of this study, the Crop-Creator tool in the DNDC was used to create a new crop type bamboo with required parameters listed in Table S2. The maximum bamboo biomass was calculated by the average diameter at the breast height and bamboo density according to the empirical growth equations (Lou et al., 2010). Detailed parameter inputs, data sources and model evaluation methods are described in the Supplementary Information.