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Estimating nitrous oxide emission flux from arable lands in China using improved background emission and fertilizer–induced emission factors

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ABSTRACT

A nitrous oxide (N_2O) emission database was compiled for arable land (284 measurements from 62 studies) to establish predictive models for building a greenhouse gas emission inventory in China. Arable lands were grouped into dry land and rice paddy based on the IPCC 2006 guidelines. The results of the meta analysis show that the annual mean N_2O fluxes from dry land and rice paddy were 4.69±4.62 (SD) and 5.89±3.23 kg N_2O–N ha^{-1} yr^{-1}. Fertilizer–induced N_2O emission factors were 0.68±0.41% for dry land, and 0.49±0.43% for rice paddy. The relationship between N_2O flux from arable lands and various environmental variables were analyzed, and the magnitude of N_2O emissions from zero mineral N addition control plots (background emission) was determined based on precipitation. Based on the above background emissions and correlation coefficients, two new predictive models were established to estimate N_2O emissions from arable lands in China. Comparison showed that the precipitation–rectified background emissions could largely improve the model predictions, and the two new models had better performance than the 1996 IPCC guideline method. Therefore, it is strongly recommended that the important local environmental variables be included in the estimates when compiling a national N_2O emission inventory.

Keywords: *Dry land, rice paddy, factors, predictive models, greenhouse gas*

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1. Introduction

Following carbon dioxide and methane, nitrous oxide (N_2O) is the third most effective greenhouse gas. It is a long–lasting gas in the atmosphere and has relatively high global warming potential due to its strong capacity for absorbing infrared radiation. Generally, N_2O is produced in both terrestrial and aquatic systems through two microbial processes, nitrification under aerobic conditions and denitrification under anaerobic conditions (Davidson et al., 1991). Agricultural activities affect the global nitrogen (N) cycle and produce a great amount of N_2O. Synthetic N fertilizer application and organic N from crop residues and manure (Cao et al., 2003; Cao et al., 2006) have contributed approximately 80% of the N_2O emissions induced by human activity since the industrial revolution (IPCC, 2006a) and about 50% of the total N_2O emissions (Xu et al., 2008).

Many agricultural practices and environmental variables, such as soil and fertilizer types used, together with climate and water regimes can significantly impact N_2O emissions from agricultural soils (Zheng et al., 1997a). Consequently, research to quantify the N_2O fluxes (the positive values indicating emissions) from croplands has attracted great attention but still remains a major challenge.

The revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories and Good Practice Guidance (IPCC, 1996), and Uncertainty Management in National Greenhouse Gas Inventories (Penman, 2000) did not take volatilized and leached N into consideration separately. Instead, 1.25% for N fertilizer induced emission factor (EF) and a background emission (emissions from zero mineral N addition control plots) rate of 1 kg N ha^{-1} yr^{-1} were adopted to predict direct emissions from arable lands in these guidelines. The following formula is used by the Intergovernmental Panel on Climate Change (IPCC, 2006b) to calculate direct N_2O emission induced by synthetic N fertilizer:

$$N_2O = (FSN + FON + FCR) \times EF_1 + (FSN + FON + FCR) \times EF_{1FR} \quad (1)$$

where, N_2O is N_2O emissions (kg N_2O–N ha^{-1} yr^{-1}); FSN denotes added synthetic fertilizer N (kg N ha^{-1} yr^{-1}); FON denotes organic N input (kg N ha^{-1} yr^{-1}); FCR denotes organic soil N (kg N ha^{-1} yr^{-1}); EF_1 denotes the N fertilizer induced N_2O emission factor and equals the ratio of fertilizer induced emission (FIE) of N_2O to added fertilizer N (defined by IPCC) from dry lands; and EF_{1FR} denotes the emission factor for flooded rice. The default EF values are 0.3% for rice paddy and 1% for dry land (IPCC, 2006b).

Including the IPCC guideline method, four methods are currently recommended to predict N_2O emissions from agricultural lands. The other three methods are extrapolation, empirical equations, and physical models. The IPCC method focuses on anthropogenic N–fertilizer use and N–FIEs of N_2O. The 2006 IPCC Guidelines recommend that local governments use the method and the EF values from the study of Akiyama et al. (2005), in which EFs of 0.22% for continuously flooded paddy and 0.37% for midseason drained paddy are proposed.

The extrapolation method combines field measured N_2O emissions with local specified environmental conditions and crop management to extrapolate N_2O emissions from similar croplands (Eichner, 1990; Mosier et al., 1991; Xing, 1998).The empirical method (Bouwman et al., 1993; Sozanska et al., 2002; Freibauer, 2003) calculates N_2O emissions through a linear regression between N_2O emissions and the related environmental variables (those assumed to influence the N_2O flux). The accuracy of the regression depends on the availability of sufficient and credible field measurements. Physical models (Brown et al., 2002) calculate N_2O emissions based on simulations of nitrification and denitrification processes. Many physical parameters, including soil, climate and crop, together with water management are needed to formulate high accuracy physical models (Li et al., 2001; Li et al., 2004; Li et al., 2005; Zou et al., 2007).

Despite the efforts to define N_2O production from various anthropogenic and native ecosystems in recent years by the IPCC and other researchers (Lu et al., 2006; Gao et al., 2011), relationships between N–fertilization and N_2O emissions on regional or national scales continuously are needed to be further explored owing to the unbalanced budget of the N sources and the sinks for arable lands (Li et al., 2001). Furthermore, few systematic analyses have been conducted in separating background N_2O emissions and N–FIEs from both rice paddies (rice–dominated ecosystems) and dry lands (arable lands excluding rice paddies).

The objectives of this study were (i) to summarize the available published data of N_2O emissions from rice paddies and dry lands in China; (ii) to estimate the magnitude of background N_2O emissions and EFs; and finally (iii) to examine the relationships between N_2O flux and various environmental variables for arable lands.

2. Materials and Methods

2.1. Data sources

All N_2O emissions and corresponding environmental and management information at the sampling sites were collected from publications between 1982 and 2012 in China (Figure 1). In total, 284 records for field measurement were extracted from 62 studies (57 geographical sites) and built into a database (Table 1, also see the Supporting Material, SM, Table S1). The land uses for these field measurements were grouped into rice paddy and dry land as defined by the 2006 IPCC guidelines (IPCC, 2006b).

The initial database comprised 106 field N_2O emission measurements for rice paddy (cropping or fallow seasons) from 33 geographical sites, and 178 records for 44 dry land sites. Three records were excluded from further analysis owing to their significant divergence (triple standard deviation) from the mean. Rice–based rotations were further divided by growing seasons, so that the difference of N_2O emission rates between growing season and non–growing season could be further explored. Environmental information together with experimental methods at these geographical sites was also compiled into the database for the analyses.

The dry land crops were further grouped into maize, wheat, rape, soybean, cotton and vegetable. To analyze the background emissions for dry land, 178 field measurements from dry land were divided into with–fertilizer and without–fertilizer subgroups. Twenty–seven records for N_2O emissions from without–fertilizer land together with other influencing factors were selected to analyze the background emissions and the relationship between background emissions and influencing factors. Agricultural management comprises net N input (N_{input}), fertilizer types, crops, water regimes, and other management. Soil properties comprise soil types, water–filled pore space, soil pH, soil organic carbon (SOC), soil total N (STN) content, and C/N (SOC/STN) molar ratio. The mean temperature and annual precipitation were also included in the databases.

The N_2O flux for the crop growing season (seasonal flux, $\mu g\ N_2O–N\ m^{-2}\ h^{-1}$), annual total N_2O emission rate (annual flux, $\mu g\ N_2O–N\ m^{-2}\ h^{-1}$), seasonal cumulative emissions for the crop growing season (seasonal cumulative emissions, $kg\ N_2O–N\ ha^{-1}$ per season), annual cumulative emissions (ACEs) of N_2O ($kg\ N_2O–N\ ha^{-1}\ yr^{-1}$), annual FIE of N_2O (equal to the annual total cumulative emission minus the annual cumulative background emission, $kg\ N_2O–N\ ha^{-1}\ yr^{-1}$), and the total emission factor (TEFs, equal to the ACEs N_2O–N/annual added N) and the fertilizer induced emission factor (EF) were calculated to reveal the characteristics of N_2O emissions.

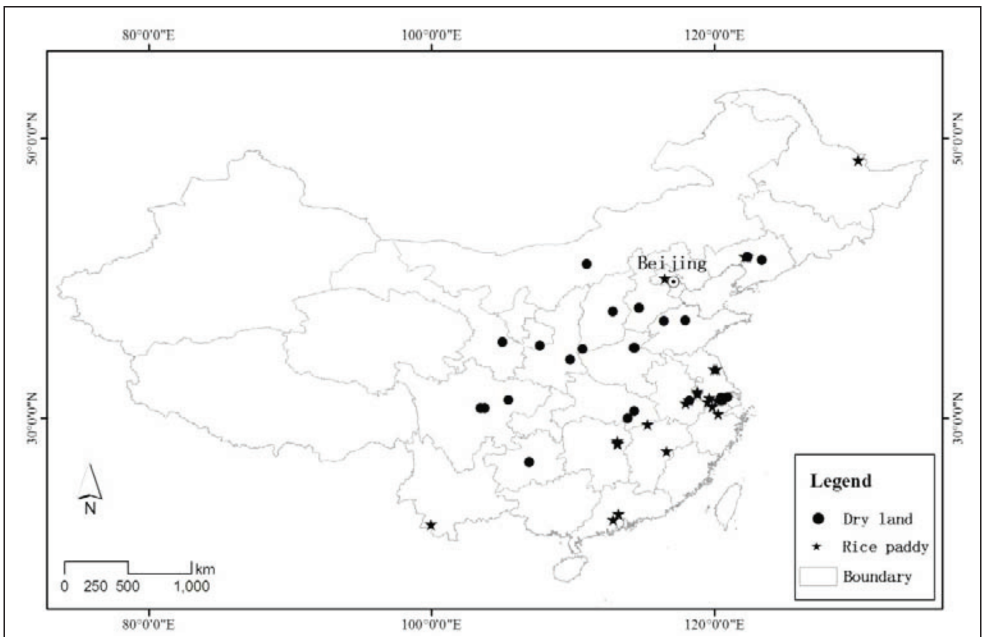

Figure 1. *Data collection points in China.*