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A meta-analysis of soil background N_2O emissions from croplands in China shows variation among climatic zones

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A R T I C L E I N F O

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A B S T R A C T

Nitrous oxide (N_2O) is one of the most important and persistent greenhouse gases, however, there is a lack of accurate data on soil background N_2O emissions (BNE) from agricultural land. Calculations of N_2O emission factors from land uses are currently based on a single, universal BNE value advocated by the International Panel on Climate Change, but BNE are thought to vary with climate and soil types. We ran a meta-analysis of 58 peer-reviewed, published data source on soil BNE from cropland fields across China, representing a range of climate and soil types. Mean soil BNE rate in croplands was estimated at 0.93 kg N ha^{-1} yr^{-1} and varied among the climatic zones, where the highest rate was in the north subtropical zone (1.66 kg N ha^{-1} yr^{-1}) and the lowest in the cold temperate zone (0.53 kg N ha^{-1} yr^{-1}). We estimated total national BNE for China based on the BNE rates for the different climatic zones and found it to be 129 Gg N yr^{-1}; this estimate was higher than the estimate of 114 Gg N yr^{-1} derived from using only a single national average BNE rate. Stepwise multiple regression modelling of soil BNE rate (kg N ha^{-1} yr^{-1}) with soil properties and climatic parameters, including soil bulk density, mean annual precipitation, soil total nitrogen, and soil pH showed that soil bulk density had the greatest influence on the BNE rate. Our study highlights that soil BNE should be included in regional N_2O inventories to inform sustainable agricultural development and management strategies in the context of mitigating impacts of soil N_2O emissions on climate change.

1. Introduction

Nitrous oxide (N_2O) is one of the most important and persistent greenhouse gases (IPCC, 2007) and one molecule of N_2O has a global warming potential (GWP) 265 times greater than a molecule of carbon dioxide (CO_2) on a 100 year horizon (IPCC, 2013). Activities associated with agricultural development and management practices, such as clearance of semi-natural habitat and nitrogen (N) additions, are major sources of N_2O emissions from farmland (Akiyama et al., 2005; Stehfest and Bouwman, 2006; Smith et al., 2008; Zaman and Nguyen, 2012; Zaman et al., 2013). Global N_2O emissions from agricultural activities have been estimated to be 3.8–6.8 Tg N yr^{-1}, accounting for 25–39% of the total global emissions of N_2O (UNEP, 2013) and, in an effort to achieve food security for the growing global human population, intensification of agriculture is likely to result in further increases in N_2O emissions (Smith et al., 2001; Zhou et al., 2017). Indeed, it has been projected that greater amounts of synthetic N fertilizers will be required to meet the increasing food demands of a global population of 9 billion people by 2050 (Mueller et al., 2012), which, together with an increase in livestock production, may result in increases in N_2O emissions of 35–60% by 2030 (FAO, 2003).

Factors that control N_2O emissions have been reviewed (e.g. Stehfest and Bouwman, 2006; Chen et al., 2008; Jiang et al., 2010; Chen et al., 2014; Zhang et al., 2015), however, data on quantification of background N_2O emissions (BNE) from soils remain incomplete, causing controversies in the application of IPCC guidelines for the

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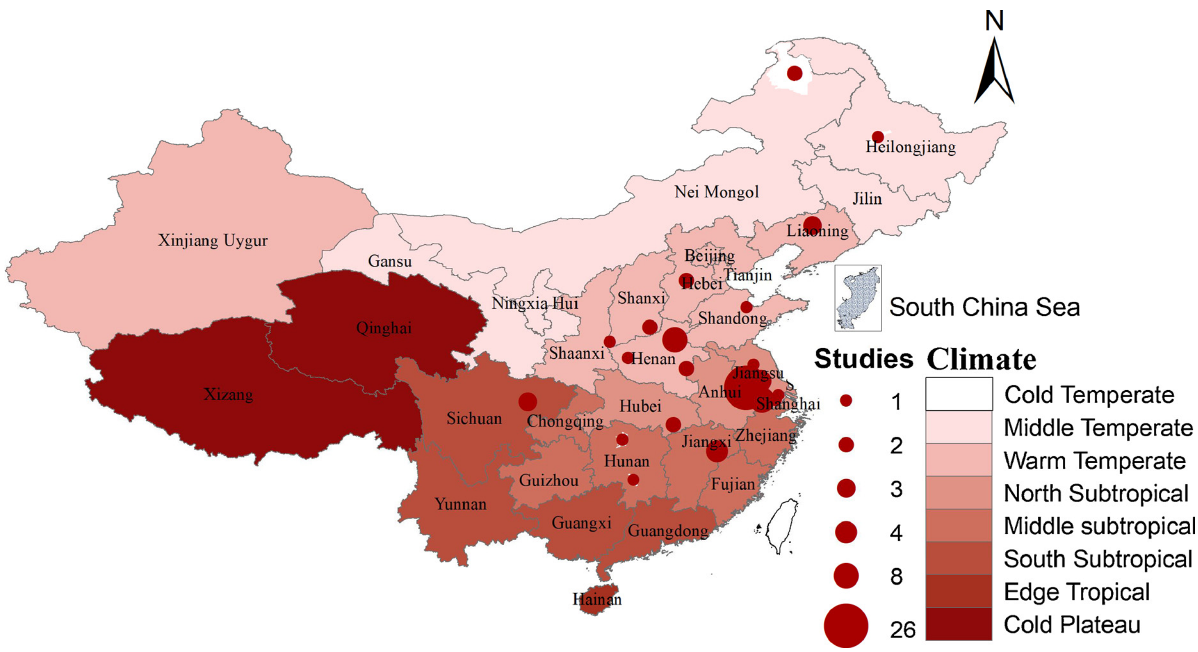

Fig. 1. Location and number of field measurements in China.

calculation of N_2O emission factors (EFs) (de Klein et al., 2010). The IPCC guidelines for the calculation of fertilizer induced total N_2O EFs are based on a single default value for BNE rate (IPCC, 2006), but this constant value for BNE rate may not account for its variability among soil types, climate conditions, agricultural management approaches, and measuring techniques, leading to discrepancies in estimated and predicted N_2O emissions at regional and global scales (Lesschen et al., 2011). These concerns are supported by recent studies that reported that the IPCC default values are unrealistic for China (Zheng et al., 2004; Zou et al., 2005; Tang et al., 2006; Song et al., 2009; Tian et al., 2012; Zhu et al., 2013), and Europe and the United States (Corazza et al., 2011; Griffis et al., 2013).

The IPCC default value for BNE rate, 1.0 kg N_2O-N ha^{-1} yr^{-1}, was based on estimates from five unfertilized field sites (Bouwman, 1996) and has been used in the estimation of regional BNE rates from cultivated cropland (Li et al., 2001). Factors that influence BNE rates in agricultural land and natural and semi-natural habitats vary among climatic zones and interactions among the factors tend to be complex and multidirectional (Kim et al., 2013), where climate change may lead to variable increases in BNE rate (Kim et al., 2012). Unlike in non-agricultural land, BNE rates from agricultural fields may reflect levels of residual N from fertilizers added in preceding years (Gu et al., 2009). Since BNE is one of the most critical contributors to N_2O emissions from agricultural land (Yan et al., 2003; Akiyama et al., 2005), it is likely that an increased number of estimates of BNE rates, representing a range of soil types, climates, and management approaches, will improve the accuracy of calculations of N_2O EFs derived from applied N (Shepherd et al., 2015).

As a national priority in China, achieving food security has driven rapid growth in fertilizer use over the past three decades, where it accounts for 30% of global use (54.3 million t) and within this, 70% of N fertilizer is applied as urea (IFADATA, 2014), partly due to fruit and vegetable production demands (Patrick, 2016). N_2O emissions associated with N fertilizer use in China are likely to be significant, but calculations of N_2O EFs may not be accurate due to variations in BNE compared with the default IPCC value (IPCC, 2006). Although BNE from agricultural soils in China has also been estimated in the previous studies, most of these estimates from croplands were calculated using the single IPCC default value for BNE (Bouwman, 1996; Gu et al., 2007; Gao et al., 2011). To date, the number of BNE measurements in China has increased four times from 15 in 2006 to 58 in 2017, which provides more insight into the estimation and prediction of N_2O emissions (Helgason et al., 2005). Here, we reviewed and evaluated the influences of climate and local farm management practice on BNE in China from peer-reviewed, published research. The objectives of this study were to develop regional, climatic zone rates of BNE from cropland in China and to assess the influence of environmental factors and management practices on BNE rates from cropland.

2. Materials and methods

2.1. N_2O emissions data

Data for field N_2O emissions from cropland in China were derived from peer-reviewed, published papers listed in the Web of Science, where N_2O measurements were field collected data, treatments were replicated at least three times, and accompanying soil background N_2O fluxes were reported; this process resulted in the extraction of data from 58 studies (see Supplementary material Table S1). Where they existed, proxies for missed soil properties values in the final dataset were obtained from the Harmonized World Soil Database (FAO, 2012) using the geographic location of the study (Zhou et al., 2017) (Table S2). All values for cumulative N_2O emissions were converted to kg N_2O-N $ha^{-1}yr^{-1}$. For agricultural fields where the climate was classified according to Zheng et al. (2010) and Wang et al. (2017), soil background N_2O emissions were grouped according to the main climatic zones in China into cool temperate ($n = 2$), middle temperate ($n = 7$), warm temperate ($n = 12$), north subtropical ($n = 27$), middle subtropical ($n = 7$), and south subtropical zone ($n = 3$) (Fig. 1). Thus, the dataset was not represented by equal numbers of field observations in different climatic zones. Other climatic zones, such as cold plateau and edge tropical zones, were not included due to lack of field data. Field crop data for each province were obtained from Zhang et al. (2014).

2.2. Data analysis

Emissions data (Table S2) were assessed for normality using the Shapiro-Wilk and D'Agostino kurtosis tests. A test for heterogeneity among the data from different regions was conducted and all datasets were squared-root transformed prior to analysis and modeling. Key