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Review

Fertiliser-induced nitrous oxide emissions from vegetable production in the world and the regulating factors: A review

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HIGHLIGHTS

- Factors regulating N_2O emissions and emission factors in vegetable fields are summarised.
- Vegetable fields do not have higher N_2O emission factors than other cropping systems.
- Global seasonal emission factor of vegetable fields is 0.94% of applied N fertiliser.
- Vegetable fields emit 9.0% of global direct N_2O emissions from synthetic fertilisers.
- Air temperature, soil moisture and pH control emission factor at high N application.

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ABSTRACT

The emission of nitrous oxide (N_2O) from vegetable fields contributes to the global greenhouse gases budget. However, reliable estimation of N_2O emissions from vegetable production in the word has been lack. Vegetable cropping systems are characterised with high N application rates, irrigation, intensive production and multiple planting-harvest cycles during the year. Improved understanding of the key factors controlling N_2O production is critical for developing effective mitigation strategies for vegetable cropping systems under different climate, soil type and management practices. Based on a comprehensive literature review and data analysis, we estimated the global N_2O emission from vegetable production using seasonal fertiliser-induced emission factors (EFs) and examined the relationship of the seasonal emissions and EFs to possible controlling factors. The global average seasonal EF for vegetable fields is around 0.94% of applied N fertiliser, which is very similar to the Intergovernmental Panel on Climate Change (IPCC) annual emission factor of 1.0% for all cropping systems. The total N_2O emission from global vegetable production is estimated to be 9.5×10^7 kg N_2O–N yr^{-1}, accounting for 9.0% of the total N_2O emissions from synthetic fertilisers. Stepwise multiple regression analysis on the relationships of soil properties, climatic factors and N application rates to seasonal N_2O emissions and N_2O EFs showed that N fertiliser application rate is the main regulator of seasonal N_2O emission from vegetable fields but the seasonal EFs are negatively related to soil organic carbon (SOC) content. In fields receiving $\geq$250 kg ha^{-1} N fertiliser, 67% ($n = 23$, $P \leq 0.01$) of the variation in seasonal emissions can be explained by the combined effects of N application rate, mean water-filled pore space (WFPS) and air temperature, while 59% ($n = 23$, $P \leq 0.01$) of the variation in seasonal EFs relates to temperature, mean WFPS and soil pH. The result also shows that in vegetable fields with mean seasonal air temperature higher than 14 °C, increases in SOC decrease the seasonal EF and total N_2O emissions from fertiliser N.

1. Introduction

Agricultural activities have greatly altered the N cycle in the environment. In order to increase agricultural production to meet the needs of a rapidly growing human population, increasing amounts of N fertilisers are being applied to cropping lands and this

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leads to emissions of nitrogenous gases including N_2O (Bouwman et al., 2002a). The atmospheric concentration of N_2O has increased from about 273 ppb in 1750 to 324 ppb in 2011 (IPCC, 2013). Nitrous oxide is a potent greenhouse gas with a long lifetime (150 yr) and has 298 times the global warming potential of CO_2 over a time horizon of 100 years (IPCC, 2007). The major processes responsible for N_2O production in agricultural soils are nitrification (the oxidation of NH_4^+ to NO_3^-) and denitrification (the reduction of NO_2^- and/or NO_3^- to nitrogen gases including NO, N_2O and N_2).

The global budget of N_2O emissions has been estimated at 17.7 Tg N yr^{-1} and about one third of that comes from anthropogenic sources (IPCC, 2007). The terrestrial sources of N_2O from natural and agricultural ecosystems contribute 9.8 to 11.1 Tg N yr^{-1} (IPCC, 2013). Soil is a significant emission source and global N_2O emissions from agricultural soils are estimated at 3.9 Tg N yr^{-1} (FAOSTAT, 2014). The major agricultural sources of N_2O are derived from manure application and management, synthetic fertilisers, crop residue application and burning, and cultivated organic soils (FAOSTAT, 2014). Some studies have shown that soil is not only the major source, but also a modest sink for N_2O (Meijide et al., 2009; Vilain et al., 2010). The balance of concurrent production and consumption mechanisms in soil determines the net N_2O flux between soil and the atmosphere.

Synthetic N fertilisers are the main source of N_2O emissions in agricultural soils (Bouwman et al., 2002b). Direct N_2O emission from agricultural fields increased 2.6 times from 1960 to 1994, mainly due to increased application of synthetic fertilisers (Mosier et al., 1999). The Food and Agriculture Organisation of the United Nations (FAO) reported that application of N fertilisers increased annually at a rate of 1.4% during the 2000s and may continue at the same rate due to growing food demand (FAO, 2008). Global application of N fertilisers is expected to increase to 130-150 Tg yr^{-1} by 2050 (Yan et al., 2003).

Nitrous oxide emissions in a specific cropland are composed of direct and background emissions. Direct emissions come from fertiliser application; whereas background emissions derive from indigenous soil inorganic N other than applied fertilisers. The current IPCC methodology for estimating the amount of direct fertiliser N_2O emissions from agricultural soils in the world is to multiply the total N inputs by a specific EF (He et al., 2009). The N_2O emission factor of fertiliser N, calculated as the percentage of fertiliser N lost as N_2O–N, is about 1.0% on average in the world (IPCC, 2007). It has been widely used to elucidate the effects of fertilisers on N_2O emissions (Bouwman et al., 2002b; Mei et al., 2009). Previous studies have shown that EF is a variable parameter ranging from 0.01 to 10% or more (Stehfest and Bouwman, 2006). The EF values can be affected by multiple factors including N inputs and management, soil water and N uptake by crops, moisture regimes, root quantity/type/exudates and soil properties such as biologically available carbon, pH, and redox potential.

Globally, vegetable fields account for approximately 7% of the total croplands, and the percentages are usually higher in developed countries (Li and Wang, 2007). Due to various optimum moisture and temperature requirements for each type and variety of vegetable, they are widely cultivated in different seasons and climatic conditions. The main features of vegetable fields are high N application rates (global average of 220 kg N ha^{-1} in each cultivation season), intensive production and management practices such as frequent irrigation and tillage and multiple planting-harvest cycles during the year. For instance, the N application rate in each cultivation season is usually 300–700 kg N ha^{-1} for vegetables in China (Li and Wang, 2007), but only 150–300 kg N ha^{-1} for non-vegetable crops (Ju et al., 2004; Zheng et al., 2004). As a result, large amounts of N_2O emissions may be produced from these fields (Diao et al., 2013; Xiong et al., 2006). It is estimated that vegetable croplands have the highest N_2O emission fluxes at the rate of 6.5–8.4 kg N_2O–N ha^{-1} $year^{-1}$ under different soil managements in the United States (Mummey et al., 1998). The N fertiliser application in vegetable cropping systems is mainly in inorganic forms. However, manure and crop residue are widely used as the supplementary forms of N application.

Better understanding of the characteristics and magnitude of N_2O emissions from vegetable production systems in various areas will help to improve the global inventory of N_2O emissions and establish mitigation options. However, accurate estimations of fertiliser-induced N_2O emissions from vegetable production in the world have been hindered by the scarcity of EFs suitable for vegetable farming systems. As soil management, irrigation and N inputs are usually more intensive in vegetable production in comparison to other crops, there is a perception that fertiliser-induced N_2O emission factors for vegetable cropping systems may be higher due to favourable conditions for N_2O production (Dobbie et al., 1999; Lin et al., 2010; Min et al., 2012). In addition, the IPCC average EF (1.0%) was calculated from annual emissions and a vegetable crop usually lasts for less than several months, thus it is questionable whether the IPCC EF is valid for vegetable cropping systems. The aims of this review are therefore to (i) collate and calculate seasonal N_2O EFs from published studies on vegetable farming; (ii) provide an inventory of fertiliser-induced N_2O emissions from vegetable production in the world using a global average seasonal EF; and (iii) identify the main controlling factors of N_2O emissions and EFs in vegetable fields.

2. Methods

All acquired field and greenhouse investigations which contain zero N application in their treatments were included. Nitrous oxide emissions from soil columns, pot experiments or incubation experiments were not considered in this study. The results derived from available data sets are summarised in Table 1. The daily mean air temperatures reported in greenhouse experiments relate to their inside air temperature. To minimise the inconsistency of the excerpted data, all reported seasonal cumulative N_2O emissions were converted into kg N_2O–N ha^{-1}. Other reported data were standardised to the consistent units as follows:

$$\text{Soil organic carbon}\left(\text{SOC, g kg}^{-1}\right) = \text{Soil organic matter}\left(\text{SOM, g kg}^{-1}\right)/1.724 \tag{1}$$

$$\text{Daily mean air temperature} = \text{daily mean soil temperature(in situations where air temperature was not reported).} \tag{2}$$

$$\text{WFPS\%} = [\text{Volumetric soil water content}/(1-(\text{Soil bulk density}/2.65))] \times 100\% \tag{3}$$

$$\text{Volumetric soil water content} = \text{Gravimetric soil water content} \times \text{Soil bulk density} \tag{4}$$

$$\text{Soil bulk density}\left(\text{g cm}^{-3}\right) = 1.398-0.0047(\%\ \text{Clay})-0.042(\%\ \text{SOC})\text{in situations where soil bulk density was not reported (Bernoux et al., 1998)} \tag{5}$$