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RESEARCH ARTICLE

Assessing soil nitrous oxide emission as affected by phosphorus and nitrogen addition under two moisture levels

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Abstract

Agricultural soils are deficient of phosphorus (P) worldwide. Phosphatic fertilizers are therefore applied to agricultural soils to improve the fertility and to increase the crop yield. However, the effect of phosphorus application on soil N_2O emissions has rarely been studied. Therefore, we conducted a laboratory study to investigate the effects P addition on soil N_2O emissions from P deficient alluvial soil under two levels of nitrogen (N) fertilizer and soil moisture. Treatments were arranged as follows: P (0 and 20 mg P kg^{-1}) was applied to soil under two moisture levels of 60 and 90% water filled pore space (WFPS). Each P and moisture treatment was further treated with two levels of N fertilizer (0 and 200 mg N kg^{-1} as urea). Soil variables including mineral nitrogen (NH_4^+-N and NO_3^--N), available P, dissolved organic carbon (DOC), and soil N_2O emissions were measured throughout the study period of 50 days. Results showed that addition of P increased N_2O emissions either under 60% WFPS or 90% WFPS conditions. Higher N_2O emissions were observed under 90% WFPS when compared to 60% WFPS. Application of N fertilizer also enhanced N_2O emissions and the highest emissions were 141 μg N_2O kg^{-1} h^{-1} in P+N treatment under 90% WFPS. The results of the present study suggest that P application markedly increases soil N_2O emissions under both low and high soil moisture levels, and either with or without N fertilizer application.

Keywords: phosphorus, N_2O emission, water filled pore space, nitrogen, greenhouse gas

1. Introduction

Nitrous oxide (N_2O) is a potent greenhouse gas that has the ability to destroy ozone (O_3) layer in the stratosphere. The concentration of N_2O in the atmosphere has been increasing and reached up to 120% from 270 to 324 ppb during 1750 to 2011 (Bouwman *et al.* 2013). Agricultural soil is the main source of N_2O emission contributing about 60% global N_2O emission (Yamulki and Jarvis 2002). Several factors affecting N_2O emissions mainly include soil type (Davidson *et al.* 2000), aeration (Law *et al.* 2015), moisture (Dalal *et al.* 2003), pH (Shaaban *et al.* 2015b), organic matter (Shaaban *et al.* 2015a), and fertilizer (Hou *et al.* 2000).

N_2O is mainly produced by microbial nitrification and denitrification processes. Nitrification and denitrification in the soils are limited by various factors, such as soil moisture and nutrients particularly N and P (Liu and Song 2009). Contradictory reports revealing P application effects on N_2O emissions have been documented in Sundareshwar *et al*. (2003) and Mori *et al*. (2010a). Soil N_2O emissions were increased with an increase in availability of P to nitrifiers and denitrifiers (Mori *et al.* 2010, 2013a). Sundareshwar *et al.* (2003) documented that P addition caused a reduction in soil N_2O emissions through stimulating N immobilization.

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Phosphorus application reduced N_2O emissions during a 2-year field experiment under *Acacia mangium* plantation primarily due to the enhancement of root uptake of soil N and water (Mori *et al.* 2013b). A study conducted on grassland demonstrated that P addition had no significant changes in nitrification rates and N_2O emissions (Zhang and Han 2008). In another field study, Mori *et al.* (2014) recently demonstrated P addition effects on N_2O emissions by separating the response of microbial and plant root activities, and documented that P addition did not have significant effects on N_2O emissions in root-excluded plots in remote tropical forest sites. Similarly, P application did not stimulate N_2O emissions from *Eucalyptus urophylla* plantation, while P applications with N together significantly decreased N_2O emission (Zhang *et al.* 2014). Contradictory reports regarding P addition effects on N_2O emissions could be attributed to different soil properties and environmental factors (Zhang and Han 2008; Mori *et al.* 2013b).

Soil moisture is a critical factor controlling N_2O emissions (Butterbach-Bahl *et al.* 2013). Moisture represents the presence of oxygen (O_2) in the soil that controls nitrification and denitrification (Simojoki and Jaakkola 2000). Nitrification is an oxic process while denitrification occurs under anoxic conditions (Bateman and Baggs 2005). Increase in soil moisture creates anoxic conditions providing feasible conditions for denitrification occurrence and N_2O emissions (Ruser *et al.* 2006). Furthermore, application of N fertilizer also inevitably enhances soil N_2O emissions (Shaaban *et al.* 2015a, b). This is mainly due to increased substrates for nitrifying and denitrifying bacteria producing N_2O (Parkin and Kaspar 2006).

The effects of phosphorus application on N_2O emission in P-deficient soils have not been well understood so far. We hypothesized that P addition to soil will influence the microbes activity and ultimately N_2O emissions. Therefore, we designed a laboratory study which aimed to investigate P addition effects on soil N_2O emissions. In addition, effects of N fertilizer and moisture levels in combination with P fertilizer were also investigated. Laboratory investigation of P addition effects on N_2O emissions will be worth enough since nutrient uptake by plant can affect N_2O emissions. Therefore, laboratory studies of P addition effects on N_2O emissions can provide fundamental scientific knowledge.

2. Materials and methods

2.1. Soil characteristic and analysis

Soil used in the present study was collected from cultivated field of maize (*Zea mays* L.) from Wuhan, China (30°34´59´´ N and 114°16´00´´E; altitude 20 m above sea level). The soil was collected from a depth of 0–20 cm, and is classified as alluvial soil (Entisol) (Guan *et al.* 2011). Soil samples were taken randomly from different places of the selected field. After removing visible plant roots and stones, a composite sample was obtained and stored in the plastic bags, and shifted to laboratory. Soil was air-dried and passed through a sieve (2 mm) before analysis. The characteristics of the soil used in this study are presented in Table 1.

The soil texture was analyzed using pipette method, and soil bulk density was measured by taking known volume through steel core method (Shaaban *et al.* 2013b). Water filled pore space (WFPS) of the soil was determined as the method presented by Lin *et al.* (2013). Dissolved organic carbon (DOC) was determined using deionized water (1:5 ratio of soil:water). Soil with deionized water was shaken for 1 h on the mechanical shaker at 250 r min^{-1}. After that, soil mixture was centrifuged at 8 000 r min^{-1} for 5 min, and the supernatant was filtered through a 0.45-μm filter membrane. The DOC contents were analyzed using a C/N elemental analyzer (Vario Max, Germany) as described by Lin *et al.* (2013). Soil ammonium (NH_4^+-N) and nitrate (NO_3^--N) concentrations were extracted from soil using KCl (1:5 of soil:1 mol L^{-1} KCl solution) by shaking soil mixture over 1 h on mechanical shaker at 250 r min^{-1} as described by Shaaban *et al.* (2015b). The soil mixture was filtered through Whatman No. 40 filter paper and the extract was analyzed using an ultraviolet spectrophotometer. Soil pH was measured using a pH meter (pH electrode PB-10; Sartorius AG, Germany) (Shaaban *et al.* 2013a). Available P concentration was extracted from soil by adding 40 mL of 0.5 N $NaHCO_3$ and shaking for 1 h on mechanical shaker at 250 r min^{-1}. The soil mixture was filtered through Whatman No. 40 filter paper, and the extract was analyzed using an ultraviolet spectrophotometer as described by Oilsen *et al.* (1954).

2.2. Experimental design, gas sampling and analysis

Soil was pre-incubated for 7 days with 40% WFPS to initiate the microbial activity. After pre-incubation, P was uniformly applied to soil at the rate of 0 and 20 mg P kg^{-1} as triple super phosphate (TSP). Each treatment of P was treated with 0 and 200 mg N kg^{-1} as urea. Fertilizers of TSP and urea were dissolved in distilled water and applied uniformly to soil. After fertilizer application, soil moisture was raised to 60 and 90% WFPS using distilled water.

Two separate sets of same treatments, each with three replicates, as described above were prepared in the 1-L glass flasks using 200 g soil (oven dry basis) for soil and gas analysis. A polythene film was placed over the tops of flasks and about 70 pin holes pierced for gaseous exchange, but to prevent moisture loss. Treatment flasks were incubated in a