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Long-term manure application increased greenhouse gas emissions but had no effect on ammonia volatilization in a Northern China upland field

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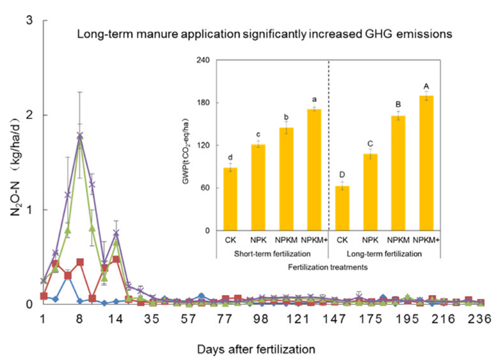
HIGHLIGHTS

- Impacts of manure application to wheat crops on soil NH_3 and GHG emissions were evaluated.
- Swine manure application reduced NH_3 emission factor both in long- and short-term fertilization.
- Long-term excessive swine manure application decreased crop yield and increased GHG emissions.
- Appropriate fertilization management practices need to be developed considering both crop yield and GHG emissions.

GRAPHICAL ABSTRACT



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ABSTRACT

The impacts of manure application on soil ammonia (NH_3) volatilization and greenhouse gas (GHG) emissions are of interest for both agronomic and environmental reasons. However, how the swine manure addition affects greenhouse gas and N emissions in North China Plain wheat fields is still unknown. A long-term fertilization experiment was carried out on a maize-wheat rotation system in Northern China (*Zea mays L-Triticum aestivum* L.) from 1990 to 2017. The experiment included four treatments: (1) No fertilizer (CK), (2) single application of chemical fertilizers (NPK), (3) NPK plus 22.5 t/ha swine manure (NPKM), (4) NPK plus 33.7 t/ha swine manure (NPKM+). A short-term fertilization experiment was conducted from 2016 to 2017 using the same treatments in a field that had been abandoned for decades. The emissions of NH_3 and GHGs were measured during the wheat season from 2016 to 2017. Results showed that after long-term fertilization the wheat yields for NPKM treatment were 7105 kg/ha, which were higher than NPK (3880 kg/ha) and NPKM+ treatments (5518 kg/ha). The wheat yields were similar after short-term fertilization (6098–6887 kg/ha). The NH_3-N emission factors (EF_{amm}) for NPKM and NPKM+ treatments (1.1 and 1.1–1.4%, respectively) were lower than NPK treatment (2.2%) in both the long and short-term fertilization treatments. In the long- and short-term experiments the nitrous oxide (N_2O) emission factors (EF_{nit}) for NPKM+ treatment were 4.2% and 3.7%, respectively, which were higher than for the NPK treatment (3.5% and 2.5%, respectively) and the NPKM treatment (3.6% and 2.2%, respectively). In addition, under long and short-term fertilization, the greenhouse gas intensities for the NPKM+ treatment were 33.7 and 27.0 kg CO_2-eq/kg yield, respectively, which were higher than for the NPKM treatment (22.8 and

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21.1 kg CO_2-eq/kg yield, respectively). These results imply that excessive swine manure application does not increase yield but increases GHG emissions.

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1. Introduction

Food security and climate change mitigation are both major challenges for agriculture in developing countries, as the increasing global population (Ouyang et al., 2013a; Gao et al., 2017). Agriculture accounts for about 50% of all ammonia (NH_3) emissions worldwide (Sommer et al., 2004a; Liang et al., 2017; Liu et al., 2017). While NH_3 is not a direct greenhouse gas (GHG), its emission into the atmosphere constitutes a loss of nutrients and affects air quality due to the fact it is a precursor of $PM_{2.5}$ (Tian et al., 2015). Carbon dioxide (CO_2) and nitrous oxide (N_2O) are important GHGs due to their global warming potential (GWP) (Lewczuk et al., 2017). Agriculture produces 20% of the CO_2, and 90% of the N_2O emitted globally (Ouyang et al., 2013b; Luo et al., 2017). CO_2 is cycled through agricultural cropping systems due to photosynthesis and plant residue decomposition (Pendyala et al., 2017). Though the volume of N_2O is much lower than CO_2, the global warming potential of N_2O is 298 times more potent than CO_2 over a 100 year period (IPCC, 2007). Soil emissions of NH_3 and GHGs are influenced by various factors, including crop type, soil properties, climatic conditions, irrigation, fertilization, etc. (Sutton et al., 2008; Dattamudi et al., 2016; Ouyang et al., 2017). It is generally believed that field fertilization is a major source of atmospheric NH_3 and GHGs (Lin et al., 2007; Zhao et al., 2009; Wang et al., 2017).

In order to satisfy the rapidly growing demand for food and other agricultural commodities in the world's most populous country, during the past 40 years Chinese farmers have tended to apply, on average, 30–50% more mineral N fertilizer than required by the crops (Ju et al., 2009a). Accordingly, 19.4–24.7% of the applied N is lost through volatilization and 0.1–3.3% is lost through denitrification from wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) rotational cropping systems (Ju et al., 2009b). This is causing severe environmental problems at global scales (Mueller et al., 2013; Zhang et al., 2017b).

Previous studies have indicated that >40% of the applied N can be lost as NH_3 under certain environmental and edaphic conditions (Singh et al., 2013; Huang et al., 2014); an average of 10–14% of applied N is lost via volatilization from synthetic fertilizers. Globally, the demand for N fertilizers was approximately 112 million tons of N in 2014 (Pan et al., 2016). Using the average value (10–14%) for volatilization from applied N, 11.2–15.7 million tons of fertilizer-N are lost as NH_3-N globally (Bouwman et al., 2002; Zheng et al., 2014). This N loss represents a substantial financial cost to farmers.

Long-term fertilization could continuously affect soil physical and chemical properties that play a significant role in controlling overall N_2O emissions (Ouyang et al., 2014a, 2014b; Cui et al., 2016). N_2O emissions are projected to grow exponentially as N inputs exceed the ability of crops to capture or use the N at any point in time, resulting in an accumulation of labile-N in agricultural soils under long-term fertilization (Jantalia et al., 2012; Shcherbak et al., 2014).

To mitigate these problems, the application of manure has been widely adopted with promising benefits to increase soil fertility and alleviate environmental deterioration (Zhang et al., 2015a; Li et al., 2016). There have been many studies focusing on the effects of manure application on soil NH_3 volatilization and GHG emissions (Banerjee et al., 2002; Xue et al., 2014; Dhadli and Brar, 2016; Xia et al., 2017). For example, it has been reported that incorporation of broadcast-applied slurry could effectively reduce NH_3 volatilization in arable lands (Skjoth et al., 2011). It is also reported that drying with superheated steam is an alternative manure management method, which results in 95% lower eutrophication and 70% lower global warming potential in comparison to direct field application (Hanifzadeh et al., 2017). Duncan et al. (2017) reported that manure application could increase the content of organic acid in soil and reduce the pH, significantly inhibiting the loss of NH_3 under long-term fertilization. However, it has also been reported that NH_3 volatilization was higher with organic manure application than with inorganic N fertilizer, which is probably caused by high soil urease activity due to the presence of organic matter (Matsushima et al., 2009). Li et al. (2013) showed that the long-term application of manure stimulated N_2O emissions by providing more N and C substrates to microbial organisms that play roles in nitrification and denitrification processes. Zhu et al. (2015) reported that manure application significantly increased N_2O emissions compared to the application of synthetic N fertilizer alone. It was also reported that both organic fertilizer and chemical fertilizer can increase the emission of N_2O, but under equal N rates, total N_2O emissions from chemical fertilizer treatments were significantly higher than from organic fertilizer (Li and Zhao, 2016). These conflicting results are probably due to differences in soil texture, climate conditions, fertilization history, etc. Aquic-cinnamon soil is a typical soil type found on the North China plain. However, crop yields are not as high as expected due to low soil fertility that is largely associated with poor physicochemical properties (Song et al., 2010). Therefore, application of fertilizer and manure may a good way to improve soil fertility and crop productivity. However, it is unclear whether application of fertilizer, especially manure addition, would promote or suppress soil NH_3 volatilization and GHG emission over time.

We hypothesized that application of swine manure would affect greenhouse gas and N emissions in North China Plain wheat fields. Consequently, long- and short-term experiments with the same regional and climatic conditions were carried out on the North China Plain. The main objective of the experiments was to quantify the loss of soil NH_3 by volatilization and emissions of GHGs (N_2O, CO_2) under long-term and short-term manure application, and indicate the impact of long-term manure application on NH_3 volatilization and GHG emissions. The related mechanisms were explored through the comparative analysis of nutrient utilization efficiencies and soil physicochemical and biological properties in the two different experiments.

2. Materials and methods

2.1. Study site

The study site (40°13′N, 116°14′E) is located in Changping County, Beijing (Fig. 1), on the North China Plain, China. As monitored at the station, the average annual precipitation has been 625 mm and the annual average temperature has been 11.5 °C over the past 15 years. The experimental field has an Aquic-cinnamon soil with light loam texture, the particle size distributions are 20.2% clay, 56.4% silt, 20% sand. This type of soil is widely distributed on the North China Plain. The long-term fertilizer experiment was established in 1990, and the baseline soil physical and chemical properties at the start of the experiment were: bulk density = 1.2 g cm^{-3}, pH = 8.2, SOC = 6.6 g kg^{-1}, TN = 0.7 g kg^{-1}, TK = 17.0 g kg^{-1}, and TP = 1.6 g kg^{-1}.The short-term experiment was established in the abandoned field from 2016 to 2017, the initial soil physical and chemical properties were: bulk density = 1.2 g cm^{-3}, pH = 8.7, SOC = 7.9 g kg^{-1}, TN = 0.8 g kg^{-1}, TK = 16.8 g kg^{-1}, and TP = 2.6 g kg^{-1}.

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