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Responses of greenhouse gas fluxes to experimental warming in wheat season under conventional tillage and no-tillage fields

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ABSTRACT

Understanding the effects of warming on greenhouse gas (GHG, such as N_2O, CH_4 and CO_2) feedbacks to climate change represents the major environmental issue. However, little information is available on how warming effects on GHG fluxes in farmland of North China Plain (NCP). An infrared warming simulation experiment was used to assess the responses of N_2O, CH_4 and CO_2 to warming in wheat season of 2012–2014 from conventional tillage (CT) and no-tillage (NT) systems. The results showed that warming increased cumulative N_2O emission by 7.7% in CT but decreased it by 9.7% in NT fields ($p < 0.05$). Cumulative CH_4 uptake and CO_2 emission were increased by 28.7%–51.7% and 6.3%–15.9% in both two tillage systems, respectively ($p < 0.05$). The stepwise regressions relationship between GHG fluxes and soil temperature and soil moisture indicated that the supply soil moisture due to irrigation and precipitation would enhance the positive warming effects on GHG fluxes in two wheat seasons. However, in 2013, the long-term drought stress due to infrared warming and less precipitation decreased N_2O and CO_2 emission in warmed treatments. In contrast, warming during this time increased CH_4 emission from deep soil depth. Across two years wheat seasons, warming significantly decreased by 30.3% and 63.9% sustained-flux global warming potential (SGWP) of N_2O and CH_4 expressed as CO_2 equivalent in CT and NT fields, respectively. However, increase in soil CO_2 emission indicated that future warming projection might provide positive feedback between soil C release and global warming in NCP.

Introduction

Global warming caused by the rising atmospheric concentrations of greenhouse gases (GHGs) has been the important environmental issue. Carbon (C) and nitrogen (N) cycles of the terrestrial ecosystem will be affected by global warming (Dou et al., 2010; Li et al., 2011; Xue et al., 2015). The main GHGs from agricultural soil are nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2), which contribute approximately 20% to global anthropogenic GHG emissions (Cole et al., 1997; IPCC, 2013). CO_2 accounts for the largest magnitude of GHGs of agricultural soil (Cole et al., 1997). Although the N_2O and CH_4 exchange rates are lower than that of CO_2, the radiative forcing of N_2O and CH_4 are higher than those of CO_2

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over a 100-year time period because they are more efficient at warming the atmosphere (Dijkstra et al., 2012; Neubauer and Megonigal, 2015). The GHG fluxes of agricultural soil may be sensitive to changes in soil microclimate caused by global warming, but there is still much uncertainty about how GHG fluxes in farmland are affected by global warming (Kirschbaum, 1995).

Previous studies in field manipulative experiments showed that warming effects on N_2O, CH_4 and CO_2 fluxes varied widely in different agricultural soils. Warming increased N_2O emission in soybean field (Z.H. Hu et al., 2013), decreased or had no effect on N_2O in wheat field (Kamp et al., 1998; Liu et al., 2015). In agricultural soil, N_2O is generated mainly through two microbial processes: nitrification, the aerobic oxidation of NH_4^+ to NO_2^- and NO_3^-, and denitrification, the anaerobic reduction of NO_3^- to NO_2^-, NO, N_2O and N_2 (Hénault et al., 2001; X.K. Hu et al., 2013; Tellez-Rio et al., 2015). N fertilizer application in farmland plays an important role in N_2O production by nitrification and denitrification processes. Elevated temperature increased N_2O emission in fertilized N farmland (Z.H. Hu et al., 2013), but had no effect in accordance with less inorganic N content (Dijkstra et al., 2013; Peterjohn et al., 1994). However, for semiarid agro-ecosystem, warming-induced soil drying may determine the decreasing N_2O due to the limitation of soil moisture on nitrification and denitrification processes (Liu et al., 2016). A few studies of C trace gases showed that warming decreased CH_4 uptake (Liu et al., 2015) and did not significantly affect CO_2 emission (Hou et al., 2014) in tillage fields of semiarid ecosystems. These were also associated with the influence of decreased soil moisture on microorganism activity and organic matter decomposition (Dijkstra et al., 2012, 2013; Hou et al., 2014). Therefore, identifying the driving factors of temperature and moisture in determining GHG fluxes response to warming in agricultural soil is important to predict accurately the amount of GHGs emission in the future.

No-tillage (NT) field that incorporates crop residual cover increases soil moisture and C sequestration and often decreases CO_2 emission compared with conventional tillage (CT) field. This approach has been implemented throughout the world, including the North China Plain (NCP) (He et al., 2011; Tian et al., 2013; Du et al., 2015). However, there is less available information on the effects of warming on N_2O, CH_4, and CO_2 fluxes in NT field for the purpose of warming projection (Hou et al., 2014; Rafique et al., 2014). Previous studies of NT effect on N_2O emission had mixed results and showed increasing (Rochette, 2008; Marquina et al., 2014), decreasing (Ussiri et al., 2009; Tian et al., 2013), and no effect (Van et al., 2013; Tellez-Rio et al., 2015) on N_2O emission, which depended on climate, soil condition, and the time that the NT approach was adopted (Six et al., 2004; Rochette, 2008; Van et al., 2013). Six et al. (2004) reviewed the first 10 years of data and found higher N_2O fluxes in NT than CT field in both humid and dry conditions, whereas the opposite results were observed after 20 years (Six et al., 2004). In the short term, NT in conjunction with residual cover maintains higher soil moisture, which stimulates denitrification and results in N_2O emission. However, in the long term, NT practice increases greater soil aggregation, which enhances the O_2 diffusion rate and decreases the N_2O production by anaerobic denitrification process (Six et al., 2004; Van et al., 2013). Moreover, the long term NT approach increases macroaggregates and improves macroporosity, which probably enhances CH_4 diffusion into soil and leads to CH_4 uptake by methanotrophs (Ussiri et al., 2009). However, some studies documented that higher soil bulk density and soil moisture as a result of the long-term NT practice hampered the supply rate of atmospheric CH_4 and its oxidation (Tian et al., 2012; Yonemura et al., 2013; Zhang et al., 2013). In contrast, tillage creates aerobic soil conditions by disturbing soil and strengthens CH_4 uptake. However, it is not clear if continued warming changes soil aeration and moisture conditions and subsequent GHGs exchanges between the soil and atmosphere in CT and NT fields. Simulation by the DAYCENT model showed that elevated temperature and decreased precipitation reduced N_2O and CO_2 but increased CH_4 flux in NT field (Rafique et al., 2014). The uncertainty regarding the main climate factor (*e.g.*, temperature and moisture) variability makes it difficult to accurately estimate the impact of global warming on cropland GHG fluxes (Ussiri et al., 2009; Van et al., 2013; Tellez-Rio et al., 2015). Therefore, a better understanding of the mechanisms of GHG fluxes responses to warming through field manipulative experiments is needed to improve the accuracy of regional and global C and N models.

We choose the winter wheat of CT and NT fields to determine the responses of N_2O, CH_4, and CO_2 fluxes to global warming in the NCP. Because the growth period of wheat (from October to June next year) is subject to the lower temperature and soil moisture from irrigation is relatively ample. Previous studies in this region were mainly focused on overall year time horizon, which showed that warming decreased N_2O emission or had no effect on C trace gases (CH_4 and CO_2) in arable soil (Hou et al., 2014; Liu et al., 2015, 2016). However, in winter wheat season, these GHG fluxes may be sensitive to warming as above-mentioned microclimate condition. In this case, we hypothesized that experimental warming would enhance GHG fluxes in wheat season in two tillage systems. As the strength C and N sequestration in surface soil (Six et al., 2004; He et al., 2011; Du et al., 2015), we also hypothesized the positive responses of GHG fluxes to warming in NT than in CT field. Therefore, the specific objectives of this study were to (1) observe temporal variation in GHG fluxes at different time scales (*e.g.*, monthly, seasonally, and annually) during the wheat season; (2) evaluate the effects of warming by infrared warming and tillage systems on GHG fluxes; and (3) investigate the relationships between GHG fluxes and soil temperature and soil moisture.

1. Materials and methods

1.1. Study site

The field experiment was conducted at the Yucheng Comprehensive Experiment Station of the China Academy of Science (36°50′N, 116°34′E). This site is representative of agriculturally intensive areas of the NCP that have an annual mean temperature of approximately 13.4°C and precipitation of 567 mm. For winter season (December to February next year) in this site, the mean temperature is about −0.5°C.