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Experimental warming-driven soil drying reduced N_2O emissions from fertilized crop rotations of winter wheat–soybean/fallow, 2009–2014

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ABSTRACT

Nitrous oxide (N_2O) emissions from agricultural soils play an important role in the global greenhouse gas budget. However, the response of N_2O emissions from nitrogen fertilized agricultural soils to climate warming is not yet well understood. A field experiment with simulated warming (*T*) using infrared heaters and its control (C) combined with a nitrogen (N1) fertilization treatment (315 kg N ha^{-1} y^{-1}) and no nitrogen treatment (N0) was conducted over five years at an agricultural research station in the North China Plain in a winter wheat–soybean double cropping system. N_2O fluxes were measured using static chambers about once every week during July 2009–June 2014. In the N1 treatment, warming decreased the soil moisture and N_2O emissions in spring, autumn and winter and the annual cumulative emissions. Across all years, N_2O fluxes were positively correlated with soil temperature and soil moisture. The effect of lower soil moisture on N_2O fluxes exceeded that of higher temperature, leading to less N_2O being released by the drier soils under warming. Nitrogen fertilizer increased N_2O emissions without warming, but did not routinely increase N_2O emissions under warming treatment. In the N0 treatment, warming neither decreased soil water content nor N_2O emissions. Temperature and nitrogen input had significant direct and antagonistic effects on cumulative N_2O flux in the N1 treatment. The decrease in N_2O emissions from N1*T* was due to the significant decrease of soil water content, soil total nitrogen and organic matter, which consequently accelerated N cycle dynamics and advanced wheat growth.

1. Introduction

The response of greenhouse gases (GHG) to global warming is at the heart of the debate on the need to reduce emissions (Solomon et al., 2010). N_2O is an important greenhouse gas which has a global warming potential (GWP) 265 times greater than CO_2 over a 100-year time horizon (IPCC, 2013), and contributes to stratospheric ozone depletion (Crutzen, 1970; Wuebbles, 2009). Agricultural land is the main source of N_2O, accounting for 60–80% of anthropogenic N_2O emissions (Davidson, 2009), especially when the contributions of nitrogen (N) from fertilizer and manure are considered (Smith, 1997; Reay et al., 2012). The pronounced effect of N input on N_2O emissions in croplands based on compiled data and mathematical models (Kim et al., 2013). Increasing global temperature has affected and will continue to affect N_2O emissions from agro-ecosystems, globally and regionally. For example, in China, where the intensification of farming systems has contributed greatly to food supply, there have been increases in emissions of reactive N to the atmosphere (Piao et al., 2010; Cui et al., 2013). Warming has the capacity to influence N_2O emissions, depending on how the N transformation processes in soils and plants are affected, resulting in increased or decreased GHG emissions (Dijkstra et al., 2012). Understanding the impact of warming on N_2O emissions is important for intensive agricultural systems such as the double cropping systems of the North China Plain, where high rates of N fertilizers are used, giving rise to a global hotspot of N_2O emissions (Cui et al., 2012).

Most experiments on the effects of warming on GHG emissions have concentrated on grassland, forest, tundra and ocean, and the results have shown widely different responses of N_2O emissions to

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warming from positive (Bijoor et al., 2008), to negative (Kamp et al., 1998; Cosentino et al., 2012) and no change (Patil et al., 2010; Dijkstra et al., 2012). Effects of warming climate on N_2O fluxes may not only depend on ecosystem types or soil chemical and physical properties, but also on soil and crop management including the intensity of fertilizer input (Dijkstra et al., 2012). So far little attention has been given to how climate change may affect N_2O fluxes from intensively managed agricultural systems (Abdalla et al., 2010; Reay et al., 2012). For agricultural land, wheat cultivation is of particular interest, since this crop is grown extensively across the world under widely differing climatic and management conditions covering 13% of global cropland (Leff et al., 2004). There is also growing uncertainty in how climate change is likely to affect grain yield of wheat under these diverse conditions (Asseng et al., 2013).

The projected increases in food demand conflict with the measures required to reduce N_2O emissions. However, the need for intensified crop production will require continued high N fertilizer inputs, which have often been found to be associated with high N_2O fluxes (Reay et al., 2012). The question is therefore how changing climate will affect the response of N_2O emissions to fertilizer N. Currently, the lack of data for the response of N_2O emissions from agricultural soils to warming increases uncertainties in the modeling of climate change to human activities (Dijkstra et al., 2012; Tian et al., 2012).

Among several warming experiments on farmland (Kamp et al., 1998; Patil et al., 2010; Dijkstra and Morgan, 2012; Dijkstra et al., 2012), most have been conducted only for a short period of time of less than 3 years (Patil et al., 2010), or they have only focused on summer months or the growing season. Kamp et al. (1998) suggested that to study how climate change affects arable soil, it is essential to include the whole year instead of only the growing season. Goulding et al. (2000) estimated that to obtain reliable results of how emissions would respond to environmental change, measurements covering at least 3–5 years would be needed to cover effects of natural variability in weather. The effect of warming on N_2O emissions from managed agricultural systems may be expected to be highly dependent on the seasonal cycles in temperature and precipitation and how changes in fertilization will be affected by climate change (Olesen et al., 2004). The warming effects on N_2O emissions in winter may be more significant (Hollesen et al., 2015), and it may reduce freeze–thaw cycles (Groffman et al., 2001). This makes it important to consider not only the main growing season of the crop, but the entire year. Only few of the reported experiments on warming have considered different rates of fertilizer N and none have considered how warming may affect N_2O emissions in the intensive crop production regions of China.

Up to now, the approach of simulating warming effect by using infrared heater has proven very effective and had the fewest drawbacks compared to other conventional warming methods (such as cables, tubes) (Harte and Shaw, 1995; Kimball et al., 2008). In this experiment, we used infrared heater to apply warming for five years, to study the effects of warming and fertilizer N application on N_2O emissions from a wheat–soybean rotation in the North China Plain. We hypothesized that increase of temperature itself would increase N_2O emissions, but that the warming-induced decrease in soil water content would result in decreased N_2O emissions. The objectives of the study were to (1) explore the differences in temporal dynamics of N_2O fluxes from agricultural soil between warming and control treatment, (2) estimate the interactive effect of warming and N fertilization on N_2O emissions, and (3) enhance the understanding the mechanisms of warming on N_2O emissions in agro-ecosystems.

2. Materials and methods

2.1. Experimental site

The experiment was performed from July 2009 to June 2014 on the Luancheng experimental farm station (37°53′N, 114°41′E, 50 m above sea level), which is part of a network focused on agro-ecosystem research under the Chinese Academy of Sciences and located in Hebei Province, China. Mean annual air temperature in 2009, 2010, 2011, 2012, 2013 and 2014 was 12.7, 12.3, 12.3, 12.3, 12.6 and 13.5 °C, respectively. Total annual precipitation was 557, 330, 415, 536, 657 and 247 mm, respectively. This location was classified as semi arid area based on Köppen–Geiger climate classification (Peel et al., 2007).

The crop rotation was winter wheat (*Triticum aestivum* L.) and soybean (*Glycine max* (L.) Merr) during 2009–2011. But considering the biological N fixation of soybean, no soybean plants or any plants were grown during the summers of 2012–2014, leaving the soil as a bare fallow. A common local winter wheat cultivar in Hebei, Shixin 828, was manually sown in October. The straw of wheat and soybean were removed after harvest. The details of field management activities are described in Table 1. The soil texture is sandy loam (54% sand, 34% silt and 12% clay), soil bulk density is 1.27 g cm^{-3}, with pH of 8.1, 15.1 g organic matter kg^{-1}, 1.1 g total-N kg^{-1}, 9.3 mg Olsen-P g^{-1} and 95.6 mg available K kg^{-1} in top 0–20 cm soil depth.

In October 2008, six pairs of infrared heaters (2 m × 0.02 m) with rated power of 1000 W were installed 2 m above ground in the center of six plots. The plots allocation to treatments were randomized. The plot size was 4 m × 4 m and the effective radiation area was 2 m × 2 m. Another six pairs of the same framework with

Table 1
Details of field operations of wheat and soybean during 2008–2014.

Crop	Sowing date (Month–day–year)	Cultivar	Seed rates (kg ha-1)	Harvest date (Month–day–year)	Irrigation date (Month–day–year)	Irrigation rates per time (mm)
Wheat	10/10/2008	Shixin 828	210	6/13/2009	4/9/2009, 6/3/2009	80
Soybean	6/24/2009	Qihuang 3	75	10/6/2009	6/25/2009	80
Wheat	10/15/2009	Shixin 828	225	6/17/2010	4/10/2010, 6/4/2010	80
Soybean	6/19/2010	Qihuang 3	75	10/2/2010	6/21/2010	80
Wheat	10/10/2010	Shixin 828	225	6/12/2011	4/12/2010, 5/21/2011	80
Soybean	6/4/2011	Qihuang 3	75	9/28/2011	6/15/2011	80
Wheat	10/3/2011	Shixin 828	165	6/7/2012	4/6/2012, 5/9/2012	80
Fallow						
Wheat	10/10/2012	Shixin 828	210	6/13/2013	4/10/2013, 5/7/2013	80
Fallow						
Wheat	10/10/2013	Shixin 828	210	6/9/2014	10/10/2013, 11/21/2013, 4/9/2014, 4/10/2014	80