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Significant residual effects of wheat fertilization on greenhouse gas emissions in succeeding soybean growing season

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A B S T R A C T

Many efforts have been made to learn the fertilization effects on greenhouse gas (GHG) emissions in the current crop season of multiple cropping systems, however, residual effects on the succeeding crop season are not clear. Based on a thirty-year fertilization experiment, we investigated the impacts of wheat fertilization on GHG emissions in the succeeding soybean season. There were five fertilization regimes for the wheat-soybean cropping system, including sole organic manure (M), balanced chemical NPK fertilizer (NPK), chemical NPK plus manure (NPKM), chemical NP plus wheat straw (NPS), and no fertilizer application (CK). Fertilization significantly affected GHG emissions not only in the current fertilizing season of winter wheat but also in the non-fertilizing season of summer soybean. Compared to the NPK treatment, the M and NPKM treatments stimulated annual soil CO_2 and N_2O emissions, and reduced CH_4 emissions. The M and NPKM treatments also significantly increased soil organic C and total N contents, soil microbial biomass C and N, and NH_4—N and NO_3—N concentrations, especially in the soybean season. Although fertilizers were only applied in wheat season, the emissions of CO_2 and N_2O were higher in the soybean season. At the cropping system scale, the treatments of M and NPKM significantly increased annual global warming potential (GWP) by 75.5% and 38.3%, respectively, compared to the NPK. Sole manure application (M) significantly increased greenhouse gas intensity (GHGI) in comparison with the NPK, while there was no significant increment in the GHGI caused by the treatments of chemical fertilizer plus manure (NPKM) and crop straw (NPS).

1. Introduction

Agriculture has been identified as one of the major sources of greenhouse gases (GHGs), accounting for approximately 12% of the global anthropogenic GHG emissions (IPCC, 2013). With growing world population, global grain production must increase by 60% from 2005 to 2050, suggesting a large increase in GHG emissions (FAO, 2013). Therefore, it is very important to create new agronomic practices for producing more grain with less GHG emissions. Fertilization is one of the most common practices to enhance crop yield. However, it also significantly affected GHG emissions (Qiao et al., 2014; Yao et al., 2013). Thus, it is necessary to quantify the effects of fertilizer application on GHG emissions for the agronomic practice innovation coping with climate change.

Increasing evidences demonstrate that there are significant differences in GHG emissions between fertilization regimes. For instance, Qiao et al. (2014) reported that chemical fertilizer plus manure stimulated CO_2 and N_2O emissions. Yao et al. (2013) found that wheat straw incorporation reduced N_2O emissions and increased CH_4 emissions. Up to now, however, existing studies mostly focused on the effects of fertilization in the current fertilizing season. In fact, fertilization can influence crop growth and soil physical-chemical-biological characteristics not only in the current season but also in the succeeding crop growing season (Eghball et al., 2004; Guo et al., 2014; Qin et al., 2015). It is well

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known that soil physical-chemical-biological processes regulate the GHG emissions (CO_2, N_2O and CH_4) caused by agronomic practices (Bolan et al., 2004; Denier van der Gon and Neue, 1996; Hanson et al., 2000; Lin et al., 2009). The GHG emissions can be greatly affected by soil O_2 contents, C availability, N species and availability, pH, microbial activity and plants (Knops et al., 2002; Thangarajan et al., 2013). Theoretically, fertilization in the preceding crop season can influence GHG emissions in the succeeding crop season. To our knowledge, few experiments have been so far implemented to assess the residual effects of preceding crop fertilization on GHG emissions in the succeeding crop season.

Wheat-soybean cropping system is an important cropping mode (Bhattacharyya et al., 2007; Cordell et al., 2007), including the most important staple crop of wheat and oil and protein crop of soybean in the world (FAOSTAT, 2014). Soybean is also an important leguminous crop that often used in crop rotation systems for soil fertility improvement. In most cases, fertilizers are applied in wheat season for the soybean-wheat cropping system (Qin et al., 2015). Therefore, we conducted a field observation of GHG emissions in a thirty-year fertilization experiment under soybean-wheat cropping system in North China Plain. The objectives of this study were to assess the fertilization effects on crop yields and GHG emissions, and especially the residual effects of wheat fertilization on GHG emissions in the succeeding soybean season.

2. Materials and methods

2.1. Experimental site

The long-term fertilization experiment established in 1983 is located in the Institute of Agricultural Science in Xiao County, Anhui Province, China (34°18′ N, 116°53′ E). The experimental site is in the south of North China Plain, with an average altitude of 180–350 m. It has a warm temperate continental monsoon climate, with an annual mean air temperature of 14.4 °C, annual precipitation of 855 mm, annual sunshine of 2228 h, and annual frost-free period of 208 days. The daily mean air temperature and total precipitation of the experimental site during the soybean-wheat cropping system was shown in Fig. 1. Soil classification in this site is Fluvisols (IUSS Working Group WRB, 2015). The basic characteristics of topsoil (0–20 cm) at the beginning of the long-term experiment were as follows: organic carbon, 6.4 g kg^{-1}; alkali-hydrolyzable nitrogen, 50.0 mg kg^{-1}; available phosphorus, 3.0 mg kg^{-1}.

2.2. Experimental design

A randomized block design was conducted with three replicates to monitor the effects of fertilization on GHG emissions, crop yields and soil properties under a soybean-wheat rotation system. Each replicate plot is 14.0 m × 7.9 m in size. The fertilization treatments were organic manure only (M), balanced chemical NPK fertilizer (NPK), chemical NPK fertilizer plus manure (NPKM), chemical NP fertilizer plus wheat straw (NPS), and no fertilizer as control (CK). A day before wheat sowing, all the chemical N, P, K fertilizers, manure and wheat straw were applied as basal fertilizer. These fertilizers were well incorporated into soil (0–20 cm) by rotary tillage. No fertilizer was applied in the soybean season. Cattle manure was used for the M and the NPKM treatments, which contained 3.2 g N kg^{-1}, 2.5 g P kg^{-1} and 1.5 g K kg^{-1} at a fresh base, respectively. Wheat straw from the preceding year was used for the NPS treatment, and contained 4.5 g N kg^{-1}, 2.2 g P kg^{-1} and 5.5 g K kg^{-1} at an air-dried base, respectively. Chemical N, P, and K fertilizers used in this experiment were urea, superphosphate, and potassium sulphate, respectively. The application amounts of different fertilizers and total contents of pure N, P, and K in each treatment are shown in Table 1.

Soybean (*Glycine max*) variety of Kedou 1 and wheat (*Triticum aestivum* L.) variety of Wanmai 36 were used during the investigating period from 2013 to 2014. Soybean was sown at a density of 150,000 plants ha^{-1} with a row interval of 40 cm in the middle of June and harvested in early October. Winter wheat was then sown at a rate of 180 kg ha^{-1} with a row interval of 25 cm by the end of October and harvested in early June. Field managements, apart from fertilization, were the same as local cropping managements for high yield. Key growth stages were described in terms of worldwide scales: Reproductive stage $(R)_1$, R_4 and R_8 represent flowering stage, pod setting stage and maturity stage of soybean, respectively (Fehr and Caviness, 1977). Growth stage (GS) 21, GS32, GS51, GS61 and GS92 represent tillering stage, jointing stage, heading stage, flowering stage and maturity stage of wheat, respectively (Zadoks et al., 1974).

2.3. Gas sampling and measurement

The measurements of CO_2, N_2O and CH_4 were continued from soybean planting in June 2013 to wheat maturity stage (GS92) in May 2014. Gas fluxes were measured using the static closed chamber method (Hutchinson and Livingston, 1993). During the entire growth period, a PVC rectangular chamber base (30 cm long; 15 cm wide; 10 cm high) was randomly inserted into the soil to a

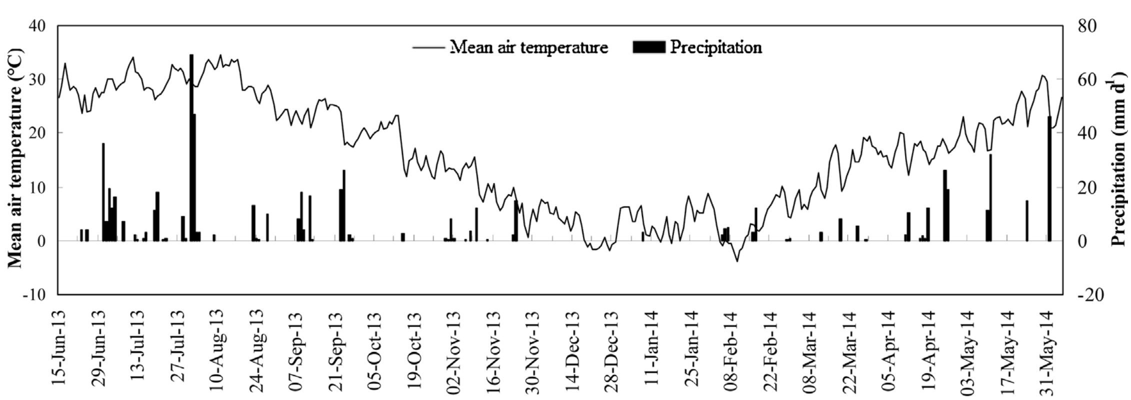

Fig. 1. Daily mean air temperature and total precipitation in the soybean-wheat cropping system from June 2013 to June 2014.