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Nitrous oxide and methane emissions from a Chinese wheat–rice cropping system under different tillage practices during the wheat-growing season

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ABSTRACT

The annual wheat (*Triticum aestivum* L.)–rice (*Oryza sativa* L.) cropping system is the most important cereal production system in the Yangtze River Valley of China, in which various tillage systems are currently implemented during the wheat-growing season. The emissions of nitrous oxide (N_2O) and methane (CH_4) from the different tillage systems in this system remain unclear. We conducted a 3-year field experiment in a wheat–rice cropping system in a silt clay loam soil to investigate the effects of the type of tillage employed during the wheat-growing season (no-tillage (NT), reduced tillage (RT) or conventional tillage (CT)) on the emissions of N_2O and CH_4 using the static chamber method over three annual rotation cycles from the 2008 wheat season to the 2011 rice season. The results revealed that the adoption of an NT system during the wheat-growing season significantly increased CH_4 emissions during both the wheat-growing season and the following rice-growing season. Over the three annual rotation cycles studied, the annual N_2O emissions from the NT (2.24 kg N_2O–N ha^{-1}) and CT (2.01 kg N_2O–N ha^{-1}) treatments were similar to each other and significantly higher than those from the RT treatment (1.73 kg N_2O–N ha^{-1}); the annual CH_4 emissions were significantly higher from the NT (100.1 kg CH_4–C ha^{-1}) than the CT (83.7 kg CH_4–C ha^{-1}) and RT (73.9 kg CH_4–C ha^{-1}) systems. The overall results regarding the net global warming potential associated with annual N_2O and CH_4 emissions indicate that the conversion of conventional tillage to no-tillage systems during the wheat-growing season would intensify the radiative forcing in wheat–rice cropping systems in China.

1. Introduction

Rising atmospheric concentrations of greenhouse gases (GHGs; CO_2, CH_4 and N_2O) have increased the radiative forcing of the earth's atmosphere. Although the role of CO_2 is dominant, N_2O and CH_4, which exhibit relative global warming potentials (GWPs) of 265 and 28 times that of CO_2, respectively, are also important because of their unique radiative properties and long residence time in the atmosphere (IPCC, 2013). Agriculture is assumed to be one of the main sources of GHGs, particularly of N_2O and CH_4, because it accounts for approximately 84% of N_2O and 52% of CH_4 of total anthropogenic emissions worldwide (Smith et al., 2008). N_2O and CH_4 emissions from agricultural soils were controlled by climatic and soil factors and agricultural managements, including precipitation amount and timing, soil texture, soil organic carbon and pH, water regime, soil tillage and fertilizer management, etc. (Le Mer and Roger, 2001; Luo et al., 2010; Smith et al., 2008; Soane et al., 2012; Venterea et al., 2012). Conservation tillage systems, including no-tillage (NT) and reduced tillage (RT), are increasingly used for crop production throughout the world (Holland, 2004; Robertson et al., 2000; Smith et al., 1998). In the Yangtze River Valley of China, NT and RT are typically only applied to the wheat crop in the double-cropped wheat–rice system, and the subsequent rice crop remains intensively tilled (Liu et al., 2005; Wang et al., 2009). Adopting NT or RT may potentially affect N_2O and/or CH_4 emissions from croplands through its effect on soil properties (Oorts et al., 2007); however, the net effects are inconsistent and have not been well quantified globally (Li et al., 2005; Pandey et al., 2012; Smith and Conen, 2004; Snyder et al., 2009).

Nitrous oxide is produced naturally in soils through the microbial processes of nitrification and denitrification (Conrad, 1996). Several studies have shown that N_2O emissions from NT can be less than (Chatskikh and Olesen, 2007; Mutegi et al., 2010) or equal to (Elmi et al., 2003; Metay et al., 2007; Venterea et al., 2005) those from tillage systems. Other studies have reported that NT

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resulted in higher N_2O emissions than did RT or CT (Baggs et al., 2003; Ball et al., 1999; Bhatia et al., 2010; MacKenzie et al., 1997; Rochette et al., 2008; Yao et al., 2009). Furthermore, Six et al. (2004) concluded that soil N_2O emissions are higher under NT, but this impact decreases with time.

In general, CH_4 is produced by methanogenic bacteria in anaerobic soil and is consumed by methanotrophic bacteria in aerobic soil (Le Mer and Roger, 2001). Available field experiment results have widely proved that NT results in lower CH_4 emissions than CT (Ahmad et al., 2009; Ali et al., 2009; Hanaki et al., 2002; Li et al., 2011). Most studies have demonstrated that the CH_4 oxidation potential can be well preserved by NT because soil tillage disturbs CH_4-oxidizing microorganisms by disrupting soil structure and releasing soil-entrapped CH_4 (Hütsch, 1998; Ussiri et al., 2009) or because NT results in higher levels of CH_4 oxidation due to the higher rates of CH_4 diffusion into the soil profile resulting from increased surface soil compaction (Ball et al., 1999; Smith et al., 2001). Moreover, Omonode et al. (2007) found that NT resulted in lower CH_4 uptake.

To our knowledge, however, no studies have examined the effects of tillage practices during the wheat-growing season on N_2O and CH_4 emissions during the subsequent rice-growing season in wheat–rice cropping systems. It is well documented that N_2O and CH_4 emissions from soil are closely associated with soil water and carbon contents, which are greatly dependent on soil properties (Cai et al., 2000; Smith et al., 2008; Snyder et al., 2009). Therefore, we hypothesized that the conversion of CT to NT or RT would have significant effects on N_2O and CH_4 emissions. To test this hypothesis, we performed a 3-year field measurement of N_2O and CH_4 emissions from a Chinese wheat–rice cropping system under NT, RT and CT during the wheat-growing season over three annual rotation cycles, from the 2008 wheat season to the 2011 rice season. The objectives of this study are (1) to examine the effect of the tillage practices employed during the wheat-growing season on N_2O and CH_4 emissions during the wheat-growing season and the subsequent rice-growing season, (2) to evaluate the effects of tillage practices on annual N_2O and CH_4 emissions, and (3) to assess the annual radiative forcing of N_2O and CH_4 emissions from Chinese wheat–rice rotation systems under various tillage treatments during the wheat-growing season.

2. Materials and methods

2.1. Experimental site

The experimental site is located at the Suzhou agricultural technology demonstration farm in Changshu City, Jiangsu Province, China (31°33′N, 120°37′E); at this site, the cropping regime is dominated by a winter wheat–paddy rice rotation system. This cropping system is characterized by alternating harvests of winter wheat and paddy rice throughout the year. The farm was selected to represent common land and soil types and farm management practices used in wheat–rice rotation systems of Southeast China. Reduced tillage in wheat and conventional puddling tillage in rice were used in this farm since 1993. The soil, which has developed from lacustrine sediment, is classified as a Gleyi-stagnic Anthrosol according to the FAO soil taxonomy system and has a silt clay loam texture (19 g kg^{-1} sand, 47 g kg^{-1} silt, and 34 g kg^{-1} clay). The physico–chemical properties of the topsoil measured at a depth of 0–20 cm were as follows: bulk density 1.21 g cm^{-3}, pH (soil:water, 1:2.5) 6.3, soil organic carbon (SOC) 19.1 g kg^{-1}, total N 1.9 g kg^{-1}, available P 7.1 mg kg^{-1}, and available K 101.4 mg kg^{-1}. This experimental site lies at 5 m above sea level in the subtropical climatic zone; the mean annual precipitation is in the range 1100–1200 mm, the mean annual temperature is 15.5 °C, the annual number of sunshine hours is 2130 h, and the frost-free period is 242 days. Climatic information was obtained from a nearby weather station. The monthly climate during the experimental period is shown in Fig. 1.

2.2. Field experiments

A tillage experiment was initiated in autumn 2007, and treatments were established using a randomized block design. There were three treatments, each with three replicates: no-tillage (NT: no-tillage before wheat sowing, wheat seeds broadcast onto the soil surface two days before rice harvest), reduced tillage (RT: rotary harrowing to 8–10 cm depth before wheat broadcast sowing), and conventional tillage (CT: moldboard plowing to 18–20 cm depth followed rotary harrowing before wheat broadcast sowing). Wheat and rice straws were removed from plots after

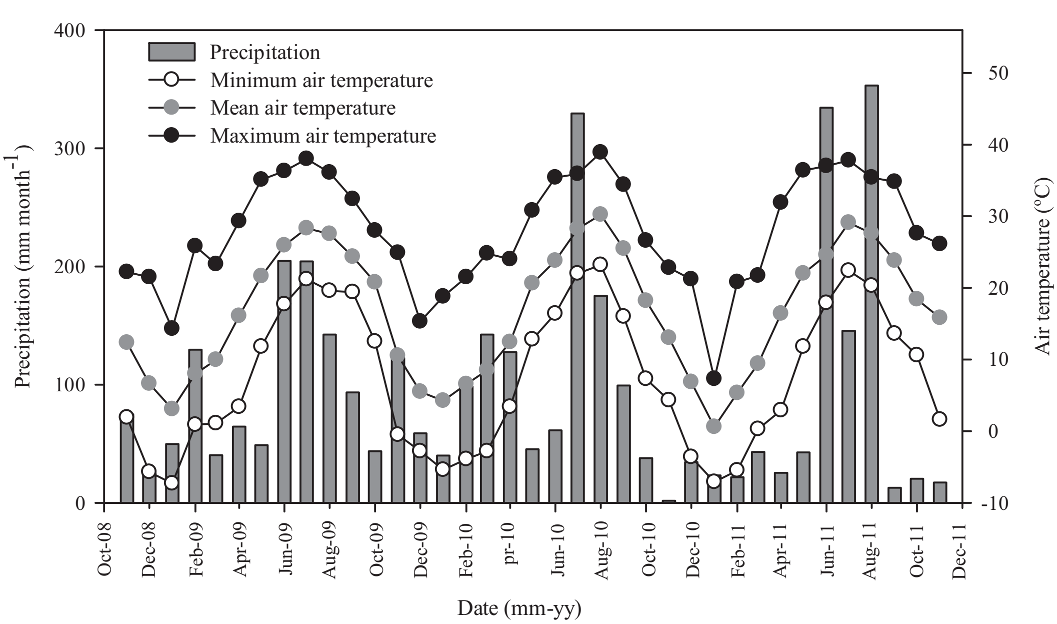

Fig. 1. Monthly precipitation and air temperatures (monthly minimum, mean and maximum) during the experimental seasons over the period 2008–2011.