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Exploring the relationships between soil fauna, different tillage regimes and CO_2 and N_2O emissions from black soil in China

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A B S T R A C T

Recent studies have shown that soil fauna can significantly affect greenhouse gas emissions. However, different functional groups and different soils can influence soil CO_2 and N_2O emissions to different extents. To date, little attention has been paid to whether soil fauna interactions with each other and their predators play a significant role in CO_2 and N_2O emissions under different tillage systems. Therefore, we studied how the interactions between soil fauna and their predators affect soil CO_2 and N_2O emissions from black soil following 13 years of conservation tillage (no-till) (NT) and conventional tillage (CT). We conducted a 35-day microcosm experiment with black arable soil and hay residue. The results indicated that the presence of earthworms and predator mites (EP) significantly increased the soil CO_2 and N_2O emissions in both NT and CT systems ($P < 0.05$). However, the addition of predator mites to microcosms with earthworms and Collembola treatments (ESP) did not significantly increase the soil CO_2 (900.7 mg CO_2-C kg^{-1} soil in NT, 991.0 mg CO_2-C kg^{-1} soil in CT) or N_2O (75.9 μg N_2O-N kg^{-1} soil in NT, 79.0 μg N_2O-N kg^{-1} soil in CT) emissions compared to earthworms and springtail (ES) treatments (CO_2: 924.7 mg CO_2-C kg^{-1} soil in NT, 914.4 mg CO_2-C kg^{-1} soil in CT; N_2O: 72.5 μg N_2O-N kg^{-1} soil in NT, 251.4 μg N_2O-N kg^{-1} soil in CT). Therefore, adding predators does not always increase the CO_2 and N_2O emissions, and the different body lengths of predators and the effect of predator-prey interactions on soil physicochemical properties should be considered. We found much higher dissolved organic carbon and nitrate availability in the E, ES and EP treatments at the time of high gas emissions on day 18, indicating that the major increase in CO_2 and N_2O emissions in these treatments may be due to enhanced denitrification. Our study indicates that under different tillage regimes, the interaction between soil fauna functional groups on the availability of C and N can decrease or increase soil CO_2 and N_2O emissions. Compared with CT soils, CO_2 and N_2O emissions from NT soils were lower, which demonstrates that long-term conservation tillage can reduce CO_2 and N_2O emissions from soil. The findings indicate that a more stable soil environment and food web with more intact functional groups are built in NT and may be more conducive to carbon and nitrogen sequestration for reducing soil CO_2 and N_2O emissions in the black soil region of Northeast China.

1. Introduction

Soils can act as an important source or sink for carbon dioxide (CO_2) and nitrous oxide (N_2O), which are both important greenhouse gases. Approximately 20% of global CO_2 emissions and 66.7% of N_2O emissions originate from soils (Rastogi et al., 2002; Smith et al., 2003). CO_2 and N_2O production from soils are the result of

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several complex biotic processes. Soil CO_2 is released from the respiration of soil fauna, microbes and plant roots (Rastogi et al., 2002; Lubbers et al., 2013; Marhan et al., 2015). Soil N_2O is produced through the biochemical pathways of nitrification, denitrification and nitrifier denitrification (Wrage et al., 2004; Kool et al., 2011), and agriculture is the largest source of anthropogenic N_2O emissions (Porre et al., 2016). All these processes are triggered by soil microbial activity and are controlled by the availability of carbon and nitrogen and by soil physical and chemical factors (Lubbers et al., 2013; Thakur et al., 2014).

Despite many studies analyzing soil CO_2 and N_2O emissions, ranging from the laboratory to fields, there are still some knowledge gaps and challenges; for example, soil physicochemical characteristics, soil biology and soil fauna all have an influence on soil gas emissions (Blagodatsky and Smith, 2012). Among these knowledge gaps, the potential roles that soil fauna may play in increasing, delaying or decreasing soil CO_2 and N_2O emissions from different tillage regimes have rarely been explored. Numerous studies have shown that earthworms can affect soil CO_2 and N_2O emissions resulting from feeding, burrowing and casting impacts on soil biological, physical and chemical properties (Rizhiya et al., 2007; Kuiper et al., 2013; Lubbers et al., 2013; Wu et al., 2015a). Recently, a meta-analysis suggested that earthworms increased soil CO_2 emissions by 33% and soil N_2O emissions by 42% (Lubbers et al., 2013). Zhang et al. (2013) found that earthworms accelerate soil carbon mineralization but do not increase the total amount of mineralized carbon.

Moreover, different functional groups of earthworms and soils have different effects on soil gas emissions (Zhang et al., 2013). However, other soil fauna (such as predator mites, Collembola and Enchytraeids) can also influence soil CO_2 and N_2O emissions (Kuiper et al., 2013; Thakur et al., 2014; Wu et al., 2015b; Porre et al., 2016), and different functional groups of soil fauna can influence soil CO_2 and N_2O emissions to different extents. Wu et al. (2015b) found that mesofauna (Collembola and mites) increased only N_2O emissions, with no significant effects on soil CO_2 emissions. Microbial-feeding soil fauna interactions with predators can affect microbial activities and N_2O emissions (Thakur et al., 2014). As a large soil fauna group, mesofauna are composed primarily of species of mites and Collembola, and most of them feed on fungi and therefore play an important role in carbon and nitrogen mineralization (Seastedt, 1984). Competition or predation risk interactions can influence mineralization rates and affect the translocation of litter-derived carbon and nitrogen into soil (Hawlena and Schmitz, 2010; Chang et al., 2016). For example, predator mites feeding on Collembola, as well as nematodes and Enchytraeids (Wallace and Walters, 1974; Thakur et al., 2014), can influence prey during their feeding and other activities (Schmitz et al., 2004). This process may lead to changes in carbon and nitrogen mineralization, thereby causing soil CO_2 and N_2O emissions.

Conventional tillage (CT) in the black soil of Northeast China has been widely used for decades. Conservation tillage (no-till, NT) has attracted considerable attention and has been proposed to farmers as an alternative to CT in parts of Northeast China. Several studies have indicated that compared with NT, CT may lower the stability of soil structure (Six et al., 2000), thereby increasing soil CO_2 and N_2O emissions (Rastogi et al., 2002). However, other research has indicated that NT does not decrease soil CO_2 and N_2O emissions (Baggs et al., 2006) but, rather, increases emissions (Li et al., 2012; Pandey et al., 2012). To date, little attention has been paid to whether the interactions of earthworms and mesofauna with each other and their predators play a significant role in CO_2 and N_2O emissions under different tillage systems. Therefore, we conducted a 35-day microcosm experiment with black arable soil under 13-year (NT) and CT regimes. Our aims were as follows: (1) to explore how interactions among earthworms, soil mesofauna and predatory mites affect soil CO_2 and N_2O emissions; (2) to analyze the effects of different tillage systems (NT and CT) on soil CO_2 and N_2O emission rates and cumulative production; and (3) to assess the relationships between soil parameters and CO_2 and N_2O emissions. We hypothesized that (1) the combination of two or three groups of soil fauna increases soil CO_2 and N_2O emissions compared with situations when only one or two groups are present, (2) the addition of predatory mites further enhances soil CO_2 and N_2O emissions, and (3) soil CO_2 and N_2O emissions from NT are lower than from CT soils.

2. Materials and methods

2.1. The microcosm experiment

A microcosm was set up for a 35-day experiment (between September and October 2015) to test the effect of soil fauna interactions with each other and their predators on CO_2 and N_2O emissions. The microcosms were constructed from glass jars (diameter = 7.5 cm, height = 12 cm, volume = 500 cm^3) and were filled with soil (clay loam texture) from the Experimental Station (44°12′N, 125°33′E) at the Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, in Dehui County, Jilin province, China. Two types of soil were used in the microcosm experiment, one of which was collected from a 13-year (2002–2015) conservation tillage (no-till) program and the other from a conventional tillage program. The soil is a typical black soil (Typic Hapludoll, USDA, 1993) with a clay loam texture, the average soil texture is comprised of 36.0% clay, 39.5% sand and 24.5% silt (Zhang et al., 2015). The content of soil organic carbon (SOC) was 21.8 g kg^{-1} in the NT soils, and 16.0 g kg^{-1} in the CT soils.

The soil was first passed through 2 mm mesh to remove stones and plant material and was then heated for 24 h at 70 °C to remove macro- and mesofauna while minimally affecting soil microbes (Kaneda and Kaneko, 2011). Each microcosm was filled with 200 g of dry soil, and distilled water was added (150 ml/kg) to reach 70% water-filled pore space (WFPS). Hay residue (C/N ratio of 14.01) was fragmented into small pieces and sterilized by autoclave for 15 min at 121 °C to remove microbes. The hay (1.34 g of dry matter) was mixed with 30 g of dry soil and distilled water (150 ml/kg), and this hay-soil mixture was added to the top of the soil layer of the microcosms. Thus, each microcosm was packed with 230 g of dry soil and 1.34 g of dry hay. Subsequently, the microcosms were pre-incubated in darkness for three days at a constant temperature of 15 °C and 60% humidity to allow the microbes to colonize before soil fauna inoculation. After the stabilization period, all microcosms were maintained in the dark for 35 days at a constant temperature of 20 °C. To maintain 70% WFPS, the microcosm experiments were weighed after each gas measurement and distilled water added.

Eisenia fetida, Collembola (*Thalassaphorura encarpata* Denis, 1931 and *Allonychiurus songi* Sun and Wu, 2012) and predatory mites (*Hypoaspis kirinensis* Chang et al., 2016) were used in the microcosm experiments; all the fauna were common species in the field. The faunal treatments (Collembola and mites) for the experiment as well as the number of individuals used per microcosms, and their density were based on realistic densities as can be found in the field (Table 1). Given that earthworms seemed to show an aggregate distribution in the field, a relatively higher population density of earthworm (2 ind. $microcosm^{-1}$, approximately 398 m^{-2}) was used to make it easier to detect the effects of earthworms on soil CO_2 and N_2O emissions (Boag et al., 1994; Decaëns and Rossi, 2001; Zhang et al., 2013). All the soil fauna were obtained from the field a week in advance: *Eisenia fetida* was kept in composting horse manure, and Collembola and mites were