Soil Biology & Biochemistry 95 (2016) 243–249

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Lasting effect of soil warming on organic matter decomposition depends on tillage practices

Ruixing Hou [a, b], Zhu Ouyang [a, b, *], Dorodnikov Maxim [c], Glenn Wilson [d], Yakov Kuzyakov [c]

[a] Key Lab. of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research Chinese Academy of Sciences, Beijing 100101, China
[b] Yucheng Comprehensive Experiment Station, China Academy of Science, Beijing 100101, China
[c] Department of Soil Science of Temperate Ecosystems, University of Göttingen, 37077 Göttingen, Germany
[d] USDA-ARS, National Sedimentation Lab, Oxford, MS 38655, USA

ARTICLE INFO

Article history:
Received 24 July 2015
Received in revised form
9 December 2015
Accepted 17 December 2015
Available online 19 January 2016

Keywords:
Thermal adaptation
Warming
Extracellular enzyme activity
No-till
Soil organic matter
Q_{10}

ABSTRACT

Global warming accelerates soil organic matter (SOM) decomposition with strong feedback to atmospheric CO_2. Such an effect should be especially important for no-till agricultural practices, where SOM accumulates in the topsoil as compared with conventional tillage. We incubated soil samples (0–5 cm) at three temperature levels (15, 21 and 27 °C) from long-term till and no-till systems that were *in situ* warmed and non-warmed to assess the temperature sensitivity of CO_2 efflux, labile organic carbon and extracellular enzyme activities. Thermal adaptation to prolonged warming was observed resulting in a lasting effect on SOM decomposition. On average, 26, 14 and 12% more CO_2 was emitted at each incubation temperature from the warmed soils compared to the non-warmed soils. The Q_{10} value was lower for the warmed than the non-warmed soils. Soil microbial biomass C and dissolved organic C declined with warming. The activities of three extracellular enzymes, β-glucosidase, chitinase, and sulfatase, were higher under warming and no-till as compared to non-warmed and tilled soil. We concluded that the increased SOM decomposition due to the stimulation of microorganisms by warming was long-lasting. Predictions of C accumulation in the topsoil by no-till farming should be taken with caution, as this C pool is especially vulnerable to global warming.

1. Introduction

Given the tremendous amount of organic carbon (C) in soil, understanding the feedback between soil organic matter (SOM) decomposition and global warming is critical for predicting future atmospheric CO_2 concentrations. The response of SOM decomposition to temperature changes has received considerable attention during the last decade (Melillo et al., 2002; Davidson and Janssens, 2006; Allison et al., 2010). How long the effects of warming could last on decomposition remains unclear: will this effect be ongoing for extended periods, or will the processes adapt to the warmer conditions and stabilize to the previous decomposition level after exhausting available organics? Numerous studies have reported that increased temperature significantly alters microbial community structure and functioning by affecting substrate and nitrogen availability (Melillo et al., 2011; Bradford, 2013; Steinweg et al., 2013; DeAngelis et al., 2015). However, an understanding of microbial feedback to global warming remains limited, especially for the utilization of substrate and microbial activity associated with soil C cycling (Wallenstein et al., 2009).

Microbial controls on soil C cycling can be affected by global warming, primarily through two mechanisms. First, microbially-driven decomposition of SOM is regulated by the quantity and quality of substrates comprising the SOM, which can be affected by temperature increase. Warming often results in an increase in substrate input from litter and root exudates due to an increase in plant growth (Oberbauer et al., 2007). Warming can also stimulate the use of the easily available SOC pool, change the microbial community structure, and lead to an alteration in C use by microorganisms. There are debates on the relationship between the

* Corresponding author. Key Lab. of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research Chinese Academy of Sciences, Beijing 100101, China. Tel.: +86 01064856514; fax: +86 01064854230.
E-mail address: ouyz@igsnrr.ac.cn (Z. Ouyang).

http://dx.doi.org/10.1016/j.soilbio.2015.12.008
0038-0717/

decline in available substrates and weaker response of warming-induced soil respiration (Bengtson and Bengtsson, 2007; Fissore et al., 2013). Second, warming may increase microbial activity, leading to acceleration of SOM decomposition. This acceleration may come from long-term (Billings and Ballantyne, 2013) or temporary thermal adaptation of the microbial community to the warmer conditions (Bradford, 2013). An increasing number of studies have shown that warming changes microbial community structure, and warming increases the rate of enzymatically-catalyzed reactions up to a temperature optimum (Wallenstein and Weintraub, 2008; Burns et al., 2013). However, only a few studies have measured extracellular enzyme activities (EEA) in field warming experiments and just some of those studies found warming to have a consistent positive effect on EEA (Bell and Henry, 2011; Jing et al., 2014; Schindlbacher et al., 2015). A reliable and sensitive proxy for the total microbial activity is the activity of key enzymes responsible for nutrient acquisition by microorganisms and SOM degradation.

No-till (No-Till) farming sequesters more C close to the soil surface than does conventionally tilled (Till) farming, whereas Till stores more C deeper in the profile (Baker et al., 2007; Hou et al., 2012). However, the fate of this surface-sequestered C in No-Till soil is unclear under warming and post-warming conditions. To better project the responses of SOM decomposition under two tillage systems to future warmer world, we incubated the topsoil (0–5 cm) from four years *in situ* warming filed experiment, analyzed the released CO_2 at three temperatures (15, 21 and 27 °C) and estimated the temperature sensitivity of SOM decomposition (Q_{10}). The objective of this study was to determine the lasting effect of warming on microbial activity under long-term No-Till and Till management systems to answer the following research questions: (i) is there a difference in CO_2 production and extracellular enzyme activities between *in situ* warmed and non-warmed soils? (ii) are the differences in CO_2 and enzyme activities temperature sensitive and (iii) are the sensitivities dependent upon the tillage system?

2. Materials and methods

2.1. Site description

This study was conducted on long-term (since 2003) experimental field plots in the North China Plain (NCP) (36°50′N, 116°34′E, 20 m above sea level). The site is located in a temperate semi-arid climate, with an annual mean temperature of 13.6 °C and mean precipitation of 553 mm during the past 29 years (from 1985 to 2013). Approximately 70% of the annual precipitation occurs between June and September. The soil is classified as a Calcaric fluvisol according to the FAO-UNESCO system, and the surface soil texture is silt loam (12% sand, 66% silt; 22% clay), according to the USDA classification system, with a pH of 6.9. Winter wheat (*Triticum aestivum* L.) and summer maize (*Zea mays* L.) were double cropped, which is common in the NCP. Depending on precipitation, winter wheat was irrigated two to three times each season (70–80 mm each time), while summer maize was irrigated only in dry summers. Each year, crop residues (including straw and stover) were retained on the soil surface for No-Till but removed for Till. The study involved four treatments: Till with and without warming (TW and TN, respectively) and No-Till with and without warming (NW and NN, respectively). The warmed block in each pair was continuously heated using an MSR-2420 infrared heater (Kalglo Electronics Inc., Bethlehem, PA, USA) beginning on the 4th of February, 2010. The infrared heater was placed 3 m above ground. Soil moisture and temperature were measured by probes at 5 cm depth. The details of the set-up are provided in the previous study of the same field (Hou et al., 2014).

2.2. Sampling and incubation

Soil samples (0–5 cm) were taken on 13th May, 2013 and stored at 4 °C before incubation. Soil sampled from the four long-term field treatments (TN, TW, NN, NW) were weighed in equivalent 30-g air-dried soil samples and placed into air-tight vessels (120 ml). These samples were incubated at 15, 21 and 27 °C for 59 days, with four replications for each treatment and temperature. The soil moisture was kept at 70% of its water holding capacity (i.e. 30% gravimetric moisture content) with deionized water. Thus, the microbial activities observed were in response to the soil properties established by the long-term management systems and exposure or non-exposure to warming at the time of sampling.

2.3. Measurements

Soil CO_2 efflux was trapped by 3 ml of 1 M NaOH in small vials placed in vessels. The traps were changed eight times during the 59-day incubation, and the CO_2 efflux was determined. The temperature sensitivity (Q_{10}), which is a measure of the rate of a parameter change as a consequence of increasing the temperature by 10 °C, was estimated based on the CO_2 fluxes at three temperatures at the beginning and end of the incubation periods (0–6th day and 35th to the 59th day, respectively). Mean respiration rates at each incubation temperature were fitted with an exponential model to calculate Q_{10} value:

$$Rs = ae^{bT} \quad (1)$$

$$Q_{10} = e^{10b} \quad (2)$$

where Rs is soil respiration, T is soil temperature, and a and b are two regression coefficients (Luo et al., 2001).

Soil pH was measured using a 1:2.5 (w/v) soil to 0.01 M $CaCl_2$ ratio with a glass electrode. The concentrations of soil organic C and total N were determined with a LECO CN2000 analyzer. Soil microbial biomass carbon (MBC) and K_2SO_4-extracted carbon – dissolved organic carbon (DOC) were determined by the fumigation-extraction method before and after incubation (Vance et al., 1987). A K_C value of 0.45 was used to calculate the C content of the SMBC, and this factor was empirically defined in earlier studies (Vance et al., 1987) based on cell survival after fumigation with chloroform to correct for the carbon that could not be extracted.

To analyze the responses of microorganisms to warming, the activity of three extracellular enzymes was determined: β-Glucosidase, N-acetyl-β-D-Glucosaminidase (chitinase) and sulfatase, which reflect C (β-Glucosidase, chitinase), N (chitinase) and S (sulfatase) cycling, respectively. Extracellular enzyme activities were measured using fluorogenically labeled substrates according to a modified technique (Marx et al., 2001; Stemmer, 2004). Three fluorogenic enzyme substrates based on 4-methylumbelliferone (MUF) were used: MUF-b-D-glucopyranoside (MUF-G; EC 3.2.1.21, for the detection of b-glucosidase), MUF-N-acetyl-b-D-glucosaminide dihydrate (MUF-NAG; EC 3.2.1.14) for chitinase, and MUF-sulfate potassium salt (MUF-S; EC 3.1.6) for sulfatase activity. To dissolve the MUF-substrates, 2 ml of 2-methoxyethanol was used. Pre-dissolved MUF-substrates were further diluted with sterile distilled water to give the desired concentrations. The soil samples (1 g) were suspended in water (20 ml) and shaken on an overhead shaker for 15 min at room temperature at maximum speed to ensure thorough mixing. A subsample of the soil suspension (50 μL) was added to 100 μL MUF-substrate solution and 50 μL MES-buffer, which were pre-pipetted in deep-well microplates (96-well, 0.5 ml, HJ-Bioanalytik GmbH, Monchengladbach, Germany). Fluorescence was measured at an excitation wavelength of 360 nm and an