Soil Biology & Biochemistry 43 (2011) 866–869

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

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

Short Communication

Constant and diurnally-varying temperature regimes lead to different temperature sensitivities of soil organic carbon decomposition

Biao Zhu*, Weixin Cheng

Department of Environmental Studies, University of California, Santa Cruz, CA 95064, USA

ARTICLE INFO

Article history:
Received 18 September 2010
Received in revised form
19 December 2010
Accepted 20 December 2010
Available online 12 January 2011

Keywords:
Decomposition
Q_{10}
Soil warming
Soil microbes

ABSTRACT

In a 122-day incubation experiment with two soil types under four temperature treatments, we examined whether the temperature sensitivity of soil organic carbon (SOC) decomposition differed between constant and diurnally-varying soil temperature regimes. We calculated the Q_{10} values after accounting for changes in substrate availability and quality among treatments over time. The Q_{10} values under constant temperature regime were consistently and significantly higher than those under diurnally-varying temperature regime, particularly in the later stages of decomposition (by up to 30%). This result indicated that different temperature regime was one of the important factors causing the current controversy about the temperature sensitivity of SOC decomposition in published reports.

The temperature dependence of soil organic carbon (SOC) decomposition effectively controls whether and how much CO_2 will be released to the atmosphere under global warming, and to what extent this release of CO_2 from SOC may lead to further climatic warming (Davidson and Janssens, 2006; Heimann and Reichstein, 2008). Despite the appreciable amount of experimental and modeling work in the past few decades, there is still no scientific consensus on the temperature sensitivity of SOC decomposition (Kirschbaum, 2006; von Lützow and Kögel-Knabner, 2009), largely due to the fact that different experimental settings have often been used in separate studies (Davidson et al., 2006; Subke and Bahn, 2010). Among these experimental settings, temperature control regimes, e.g. diurnally and seasonally varying temperatures vs. preset constant temperatures, may play a significant role in causing this controversy.

In most lab incubation experiments (e.g. Reichstein et al., 2000; Conant et al., 2008), jars filled with soil samples were incubated in several incubators where temperature was maintained at a constant level throughout the entire experimental duration. The temperature sensitivity of SOC decomposition (Q_{10}) was calculated based on CO_2 efflux measurements at different temperatures. In contrast, in most field warming experiments (e.g. Luo et al., 2001; Hartley et al., 2007), soil CO_2 efflux was measured under both ambient and warming treatments in which soil temperature varied diurnally and seasonally. The calculated Q_{10} values based on CO_2 efflux measurements under both ambient and warming treatments were usually lower than those from lab incubation experiments (Kirschbaum, 2006). To what degree the difference in temperature regimes between these two groups of experiments has resulted in inconsistent Q_{10} values remains unexplored.

In this study, we incubated two soils (a farm soil and a grassland soil) under two temperature regimes (constant vs. diurnally-varying), each of which has two average temperatures. Soil CO_2 efflux was measured five times during the 122-day incubation period and Q_{10} was calculated for the two soil temperature regimes. Our main objective was to determine whether Q_{10} differs significantly between the two soil temperature regimes.

The experiment was conducted in three growth chambers. We filled 16 bottom-capped PVC pots (diameter 15 cm, height 40 cm) with either 8.3 kg air-dried "farm" soil or 7.5 kg air-dried "grassland" soil. The farm soil and the grassland soil were both sandy loam, collected from the top 0–30 cm of an organic farm (converted from the nearby grassland in 1974) and an annual grassland on University of California at Santa Cruz campus, respectively. After four decades of farming, the farm soil has less carbon (0.94% vs. 1.20%) and nitrogen (0.11% vs. 0.13%) compared to the grassland soil. To minimize the initial disturbance effect on CO_2 efflux due to air-drying, sieving, packing, and rewetting the soils, all pots were pre-incubated at room temperature (22 °C) for 30 days before the 122-day experiment started. There were four soil temperature

* Corresponding author. Tel.: +1 831 331 3627; fax: +1 831 459 4015.
E-mail address: biaozhu@gmail.com (B. Zhu).

0038-0717/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soilbio.2010.12.021

treatments in this study. Eight pots were incubated in growth chamber #1 with constant 25 °C air and soil temperature ("constant-high" treatment); another eight pots were incubated in growth chamber #2 with constant 20 °C air and soil temperature ("constant-low" treatment"). The other 16 pots were incubated in growth chamber #3 with air temperature changing from 15 to 25 °C diurnally and a time-weighted average of 20 °C. Using automatically controlled electric heating cables buried in the pots, we heated eight pots ("varying-high" treatment, 21–28 °C range and 24.5 °C average) by 4.5 °C compared to the other eight pots ("varying-low" treatment, 16.5–23.5 °C range and 20 °C average) based on soil temperature measurements by thermocouples at 15 cm depth (Zhu and Cheng, 2011). Gravimetric soil moisture content in each pot was maintained at 25% throughout the experiment by periodic weighing and watering with deionized water. Anaerobic conditions were prevented by forcing the ambient air through each pot for 30 min every 6 h using an aeration pump.

During 10–12, 20–22, 40–42, 80–82 and 120–122 days after the start of the incubation experiment, we measured SOC decomposition rate using a closed-circulation CO_2 trapping system (Cheng et al., 2003). Briefly, we sealed the pot with non-toxic silicone rubber and removed CO_2 inside the pot by circulating the isolated air through a soda lime column for 1 h. Then CO_2 produced in the sealed pot was trapped in a 400 mL 0.5 M NaOH solution for 30 min every 6 h during a 48-h period. Four blanks were included to correct for possible contamination from carbonate in the NaOH stock solution and from sample handling. An aliquot of each NaOH solution was analyzed for inorganic C using a Shimadzu TOC-5050A Total Organic Carbon Analyzer.

To account for the possible confounding effect of differences in substrate availability and quality among different temperature treatments in parallel incubation, we calculated Q_{10} using the following equation (Conant et al., 2008; Xu et al., 2010):

$$Q_{10} = \left(t_{low}/t_{high}\right)^{(10/\Delta T)}$$

where t_{high} and t_{low} are the time required to respire the same fraction of SOC at the higher (T_{high}) and lower (T_{low}) temperatures, and ΔT is the actual incubation temperature differential ($\Delta T = T_{high} - T_{low}$). We used a Monte Carlo method to estimate the 95% confidence interval of the Q_{10} values (Fig. 1C–D). Briefly, first we calculated 16 Q_{10} values based on all 16 combinations of 4 replicates at high temperature (t_{high}) and 4 replicates at low temperature (t_{low}). Then we randomly selected 4 numbers from the 16 Q_{10} values and got a mean Q_{10} value ($n = 4$); repeated this process 1000 times and got 1000 mean values; calculated the mean and SD of these 1000 values; and finally calculated the 95% confidence interval (mean ± 1.96 (SD/n^0.5); $n = 4$).

Instantaneous respiration rate declined by 45–51% in farm soil and by 39–43% in grassland soil over the 122 days of incubation (Fig. 1A–1B), while cumulative respiration rate during the 122-day period accounted for 3.9–5.5% of original farm SOC and 4.0–5.1% of

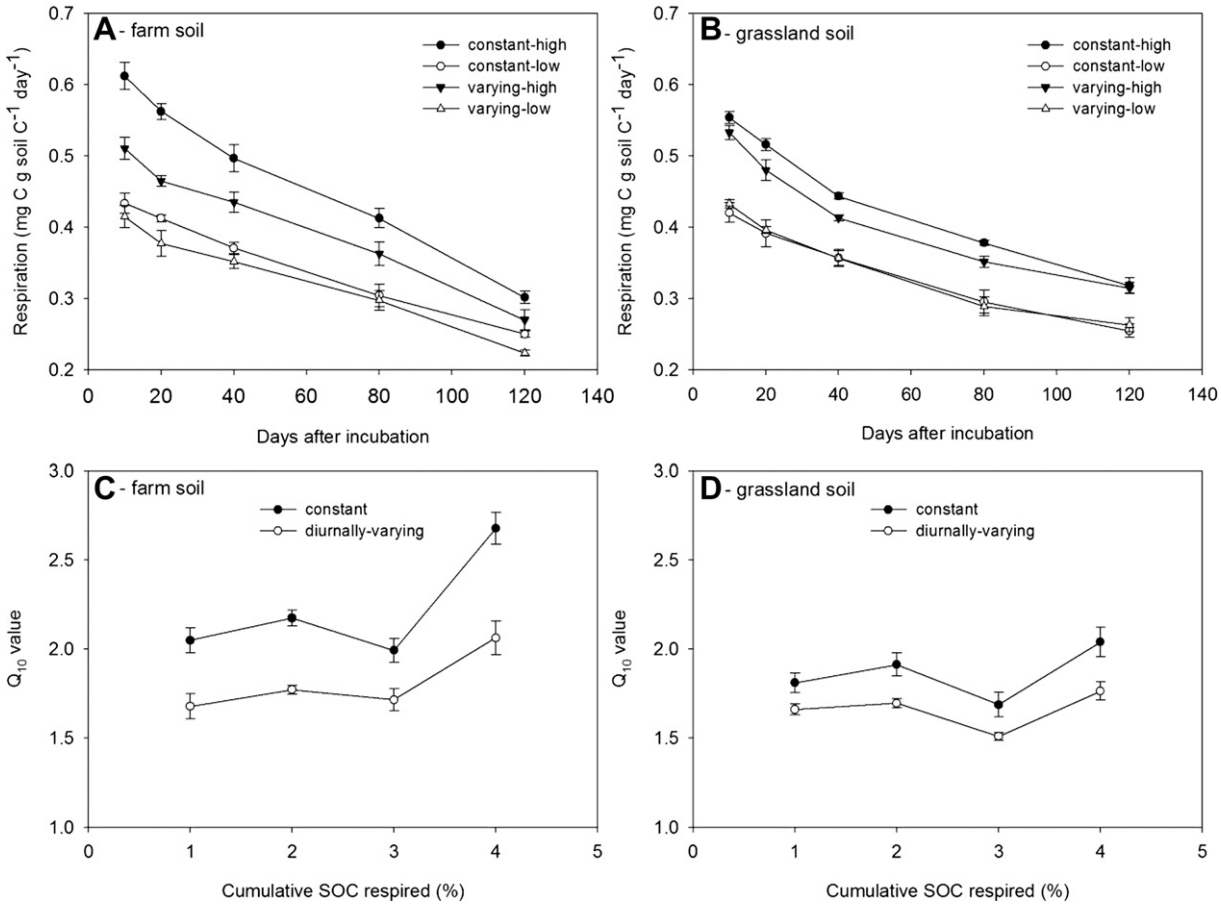

Fig. 1. A–B: changes in instantaneous soil respiration rate (mg C g soil C^{-1} day^{-1}) with days after incubation during the 122-day incubation period in four different soil temperature treatments and two soil types. Error bars represent standard deviation (SD, $n = 4$). C–D: changes in temperature sensitivity of SOC decomposition (Q_{10} value) with cumulative SOC respired during the 122-day incubation period under two soil temperature regimes and two soil types. Error bars represent 95% confidence interval estimated by the Monte Carlo method ($n = 4$).

original grassland SOC (data not shown). Both instantaneous and cumulative respiration rates did not differ markedly between "constant-low" treatment and "varying-low" treatment, while they were higher in "constant-high" treatment than in "varying-high" treatment.

The Q_{10} values were higher in farm soil than in grassland soil and appeared to increase at the last stage of incubation in both soils (Fig. 1C–1D). More importantly, Q_{10} values under constant temperature regime were consistently and significantly ($P < 0.05$) higher by 9–30% than those under diurnally-varying temperature regime. This result is observed in both soils and is more significant at the last stage of incubation (Fig. 1C–1D).

The mechanisms leading to the higher Q_{10} under constant temperature regime than under diurnally-varying temperature regime are not clear at this point. We have ascertained that the reported negative curve–linear relationship between Q_{10} value derived from short-term lab incubations and the mean temperature used for each Q_{10} value determination ($Q_{10} = \exp[10 \times 241.5/(T + 31.79)^2]$, Kirschbaum, 2000) does not result in any meaningful difference in Q_{10} values between the two temperature regimes. A potential cause may be associated with possible differences in microbial community composition between the two temperature regimes. Soil microbes are a diverse mixture of different species with different optimum temperatures (T_{opt}) for growth and respiration (Balser and Wixon, 2009). Under constant temperature regimes, species whose T_{opt} is close to the constant soil temperature may have a competitive advantage than other species whose T_{opt} is away from the constant soil temperature. Over time, the constant temperature regime may selectively favor microbes already genetically better adapted to the temperature level. By contrast, under diurnally-varying temperature regimes, a more diverse community of microbes may coexist because more species are likely to experience their T_{opt} during this diurnal temperature range. Therefore, compared to the more diverse community including a wide range of microbes under diurnally-varying temperature regime, the community dominated by few genetically more adapted microbes under constant temperature regime may produce more CO_2 and thus lead to higher Q_{10}. This hypothesis has been indirectly supported by an empirical study which showed that different soil temperatures progressively selected microbial communities growing better at the specific temperatures ("species sorting" hypothesis; Bárcenas-Moreno et al., 2009). Therefore, microbial community composition may progressively diverge among different temperature regimes, which can lead to different Q_{10} of SOC decomposition. Unfortunately, we don't have data on microbial community composition in this study. There are some evidence in the literature that microbial community composition will be increasingly different between constant-high and constant-low temperature treatments in lab soil-incubation experiments (e.g. Zogg et al., 1997; Pettersson and Bååth 2003; Balser and Wixon, 2009), but direct evidence of different microbial community composition between constant and diurnally-varying temperature treatments (but with same/similar time-weighted mean temperature) are not yet available. More studies are needed to further test the generality of our findings and to explore the mechanistic explanations.

There is a long-lasting debate on the temperature sensitivity of SOC decomposition between different studies, particularly between lab incubation experiments and field warming experiments (Davidson and Janssens, 2006; Kirschbaum, 2006; von Lützow and Kögel-Knabner, 2009). Other than the factors already advanced to explain the difference, such as substrate availability (Gu et al., 2004; Gershenson et al., 2009), root/rhizosphere respiration (Hartley et al., 2007; Schindlbacher et al., 2009), rhizosphere priming effect (Bader and Cheng, 2007; Zhu and Cheng, 2011), our results suggest that different soil temperature regimes (constant vs. diurnally-varying) can contribute to different Q_{10} between studies. When soils are maintained at constant temperatures (e.g. in lab incubation studies), genetically better adapted soil microbes may progressively outcompete other less well-adapted microbes at each temperature level. In contrast, when soils are subjected to diurnally-varying temperatures (e.g. in field warming studies), a more diverse community of soil microbes are likely to coexist in this more variable temperature regime. The intrinsic temperature dependence of SOC decomposition may be realized to a different extent by different microbial communities between constant and diurnally-varying temperature regime. Therefore, our study, for the first time, identified an important factor – difference in soil temperature regime – that can contribute to the lack of scientific consensus on the temperature dependence of SOC decomposition.

Acknowledgments

This study was supported by grants from the National Research Initiative of the USDA Cooperative State Research, Education and Extension Service, from the U.S. Department of Energy's Office of Science through the Midwestern Regional Center of the National Institute for Climatic Change Research at Michigan Technological University, and from the Kearney Foundation of Soil Science. We thank Dr. Peter Raimondi and Mr. Han Yue for statistical advice, and two anonymous reviewers and Dr. Rainer Joergensen for helpful comments that greatly improved this manuscript.

References

Bader, N.E., Cheng, W.X., 2007. Rhizosphere priming effect of *Populus fremontii* obscures the temperature sensitivity of soil organic carbon respiration. Soil Biology and Biochemistry 39, 600–606.
Balser, T.C., Wixon, D.L., 2009. Investigating biological control over soil carbon temperature sensitivity. Global Change Biology 15, 2935–2949.
Bárcenas-Moreno, G., Gómez-Brandón, M., Rousk, J., Bååth, E., 2009. Adaptation of soil microbial communities to temperature: comparison of fungi and bacteria in a laboratory experiment. Global Change Biology 15, 2950–2957.
Cheng, W.X., Johnson, D.W., Fu, S.L., 2003. Rhizosphere effects on decomposition: controls of plant species, phenology, and fertilization. Soil Science Society of America Journal 37, 1418–1427.
Conant, R.T., Drijber, R.A., Haddix, M.L., Parton, W.J., Paul, E.A., Plante, A.F., Six, J., Steinweg, J.M., 2008. Sensitivity of organic matter decomposition to warming varies with its quality. Global Change Biology 14, 868–877.
Davidson, E.A., Janssens, I.A., 2006. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature 440, 165–173.
Davidson, E.A., Janssens, I.A., Luo, Y.Q., 2006. On the variability of respiration in terrestrial ecosystems: moving beyond Q_{10}. Global Change Biology 12, 154–164.
Gershenson, A., Bader, N.E., Cheng, W.X., 2009. Effects of substrate availability on the temperature sensitivity of soil organic matter decomposition. Global Change Biology 15, 176–183.
Gu, L.H., Post, W.M., Hanson, P.J., 2004. Fast labile carbon turnover obscures sensitivity of heterotrophic respiration from soil to temperature: a model analysis. Global Biogeochemical Cycles 18, GB1022. doi:10.1029/2003GB002119.
Hartley, I.P., Heinemeyer, A., Evans, S.P., Ineson, P., 2007. The effect of soil warming on bulk soil vs. rhizosphere respiration. Global Change Biology 13, 1654–1667.
Heimann, M., Reichstein, M., 2008. Terrestrial ecosystem carbon dynamics and climate feedbacks. Nature 451, 289–292.
Kirschbaum, M.U.F., 2000. Will changes in soil organic carbon act as a positive or negative feedback on global warming? Biogeochemistry 48, 21–51.
Kirschbaum, M.U.F., 2006. The temperature dependence of organic-matter decomposition – still a topic of debate. Soil Biology and Biochemistry 38, 2510–2518.
Luo, Y.Q., Wan, S.Q., Hui, D.F., Wallace, L.L., 2001. Acclimatization of soil respiration to warming in a tall grass prairie. Nature 413, 622–625.
Pettersson, M., Bååth, E., 2003. Temperature-dependent changes in the soil bacterial community in limed and unlimed soils. FEMS Microbiology Ecology 45, 13–21.
Reichstein, M., Bednorz, F., Broll, G., Kätterer, T., 2000. Temperature dependence of carbon mineralization: conclusions from a long-term incubation of subalpine soil samples. Soil Biology and Biochemistry 32, 947–958.
Schindlbacher, A., Zechmeister-Boltenstern, S., Jandl, R., 2009. Carbon losses due to soil warming: do autotrophic and heterotrophic soil respiration respond equally? Global Change Biology 15, 901–903.
Subke, J.A., Bahn, M., 2010. On the 'temperature sensitivity' of soil respiration: can we use the immeasurable to predict the unknown? Soil Biology and Biochemistry 42, 1653–1656.

von Lützow, M., Kögel-Knabner, I., 2009. Temperature sensitivity of soil organic matter decomposition – what do we know? Biology and Fertility of Soils 46, 1–15.

Xu, X., Zhou, Y., Ruan, H.H., Luo, Y.Q., Wang, J.S., 2010. Temperature sensitivity increases with soil organic carbon recalcitrance along an elevational gradient in the Wuyi Mountains, China. Soil Biology and Biochemistry 42, 1811–1815.

Zhu, B., Cheng, W.X., 2011. Rhizosphere priming effect increases the temperature sensitivity of soil organic matter decomposition. Global Change Biology. doi:10.1111/j.1365-2486.2010.02354.x.

Zogg, G.P., Zak, D.R., Ringelberg, D.B., MacDonald, N.W., Pregitzer, K.S., White, D.C., 1997. Compositional and functional shifts in microbial communities due to soil warming. Soil Science Society of America Journal 61, 475–481.