



Decomposition of particulate organic matter is more sensitive to temperature than the mineral associated organic matter



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ABSTRACT

Temperature sensitivity of soil organic matter decomposition is important in determining the role of soils in future climate change. We isolated coarse and fine particulate organic matter (cPOM and fPOM) and mineral associated organic matter (MinOM) to represent labile, relatively less labile and stable pools of soil organic matter (SOM), respectively and incubated each at four different temperatures to determine temperature sensitivity of decomposition. The coarse particulate organic C, which comprised the smallest pool of soil organic C (SOC) was most decomposable and the mineral associated organic C that accounted for more than half of the SOC was least decomposable. At all the temperatures, the C mineralization rate followed the order $cPOM \geq fPOM > \text{whole soil} > \text{MinOM}$. The disparity in the mineralization rates between cPOM and the other two SOM fractions and the whole soil widened with increase in temperature from 15° to 45 °C indicating that the labile pools of SOM were more sensitive to temperature than the stable pool. The Arrhenius, the Llyod and Taylor and the Gaussian models well-described the temperature dependence of organic matter decomposition, but the shape of the temperature response curve for different models varied considerably. Gaussian model yielded the highest decomposition Q_{10} and the Arrhenius model the lowest Q_{10} for different SOM fractions and whole soil. The decomposition temperature response of isolated SOM fractions mainly differed at temperatures below 25 °C beyond which the response tended to converge suggesting that the differential response of labile and stable pools to temperature will be foremost at temperatures below 25 °C beyond which the effect will be small and similar for SOM pools of different lability. The decomposition of cPOM fraction is likely to be influenced to the greatest extent and the MinOM at the least as a result of global warming.

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1. Introduction

In the terrestrial C cycle soil respiration represents the second largest flux ($\sim 60 \text{ Gt C yr}^{-1}$) between ecosystems and the atmosphere and a small change in soil respiration could significantly intensify or mitigate atmospheric increase of CO_2 (Baveye, 2007; Reichstein and Beer, 2008). The decomposition of soil organic matter (SOM), which is a primary source of soil respiration, is significantly influenced by temperature (Kirschbaum, 1995; Zhang et al., 2006). It is, therefore, speculated that increase in temperature due to global warming can accelerate the decomposition of SOM and consequently increase the release of soil organic carbon (SOC) to the atmosphere (Davidson et al., 2000). These concerns have stimulated interest in understanding the temperature sensitivity of soil respiration and organic matter decomposition,

especially with regard to the factors that determine the temperature dependence of C mineralization (e.g., Lloyd and Taylor, 1994; Kätterer et al., 1998; Luo et al., 2001; Sandermann et al., 2003; Reichstein et al., 2005; Conant et al., 2011; Curtin et al., 2012; Wagai et al., 2013). Several studies have shown that C mineralization increases with increase in temperature and the relative increase depends on reference temperature (Field et al., 2007; Zheng et al., 2009). The relative increase in mineralization is greater at low reference temperature than at high temperature. Q_{10} values ranging from about 8 at 0 °C to 2.5 at 20 °C have been reported (Kirschbaum, 1995; Zhang et al., 2006). However, these studies described the decomposition temperature sensitivity of bulk SOM without recognizing the effect of organic matter quality.

The quality of SOM is the foremost factor that could influence the temperature response of organic matter decomposition. Questions have arisen, whether the temperature sensitivity of SOM decomposition varies with the composition of organic matter, that is, labile Vs stable soil C pools (Liski et al., 1999; Davidson et al., 2000; Giardina and Ryan, 2000). A number of models and methodologies have been used to express temperature sensitivity of the

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decomposition of labile and stable SOM pools with contradictory results (Powlson, 2005; Kirschbaum, 2006; von Lütow and Kögel-Knabner, 2009). Knorr et al. (2005) postulated that the dominant slow pools of organic carbon are more sensitive to temperature than the faster pools causing a larger positive feedback in response to global warming. On the contrary, Reichstein et al. (2005) showed that this conclusion is equivocal and argued that it is premature to conclude that stable soil C is more sensitive to temperature than labile C and there could be very similar responses of labile and stable SOM decomposition to temperature (Fang et al., 2005). The conflicting results may partially be attributed to the range of methods used to estimate SOM decomposition temperature sensitivity, and the inability to consistently define and quantify labile and stable SOM (Kirschbaum, 2006; von Lütow and Kögel-Knabner, 2009).

A variety of physical and chemical fractionation methods have been developed to characterize SOM pools with distinct physico-chemical properties, functions, and turnover times (Hassink et al., 1997; Christensen, 2001; Six et al., 2001). Recent findings suggest that C turnover in soils is only weakly controlled by the molecular structure (Marschner et al., 2008). Similarly, it has also been suggested that decomposition of SOM is independent of microbial biomass size, community structure or specific activity, but is governed by abiological processes (Kemmitt et al., 2008). Therefore, studies that described the decomposition temperature sensitivity of chemically or kinetically defined SOM fractions were unable to precisely characterize labile and stable SOM pools and yielded conflicting results (e.g., Conant et al., 2008b; Plante et al., 2010). In contrast, physical stabilization mechanisms such as adsorption on mineral surfaces and occlusion in aggregates have been suggested to effectively stabilize soil C and thus influence turnover rates (Torn et al., 1997; Marschner et al., 2008). Studies published in the last three decades have shown that physical fractionation of SOM according to size provides a useful tool for the study of its functions and turnover in soil (Cambardella and Elliott, 1992; von Lütow et al., 2007). Soil organic matter is generally fractionated into coarse particulate organic matter (cPOM; size >250 μm), fine particulate organic matter (fPOM; size 53–250 μm) and mineral associated organic matter (MinOM; size <53 μm). Measures of POM have been tied to microbial growth and nutrient supply and suggest that it is closely related to biologically mediated C and N, and aggregation (Buyanovsky et al., 1994; Hassink et al., 1997; Gregorich and Beare, 2007). Accordingly, POM is commonly used as an index of the labile SOM pool and cPOM and fPOM are considered to represent active or labile and slow or relatively less labile pools of SOM, respectively (Benbi et al., 2012). The mineral associated organic carbon (MinOC) that includes physically and chemically stabilized organic carbon with low bioavailability and long turnover times is resistant to decomposition and is considered to represent passive pool of SOC (Parton et al., 1988; Six et al., 2002; Krull and Skjemstad, 2003; Benbi et al., 2012). Although cPOM, fPOM and MinOM have been suggested as SOM pools with differential turnover times, little information exists about the actual decomposability and temperature sensitivity of isolated SOM fractions (Swanston et al., 2002; Leifeld and Fuhrer, 2005; Mutuo et al., 2006; Plante et al., 2010). Knowledge about temperature dependence of mineralization of SOC fractions will help in understanding the mechanism of C-turnover in soils. Focus on POM, instead of other measures of labile SOM, is warranted mainly because this fraction typically has a higher proportional response to management than do other measures of labile SOM (Conteh et al., 1998; Alvarez and Alvarez, 2000; Carter, 2002). Recalcitrant SOM fractions that are equated with the passive or resistant pools have greater relevance for long-term C sequestration, sorption, and cation exchange capacity. Therefore, in order to predict the influence of global

warming on SOM decomposition, it is crucial to understand the decomposition temperature sensitivity of physically separated labile and recalcitrant SOM fractions. We hypothesized that labile SOM fraction reacts faster to temperature changes than the stable pools because it has shorter turnover times, easily available to microorganisms and rapidly decomposable. Conversely, the stable SOM fraction that is bonded onto the surface of minerals such as clay and silt and might be biochemically recalcitrant will react slowly to temperature changes. To test this hypothesis, we studied the decomposition temperature sensitivity of physically isolated labile and stable SOM fractions. The results of the study will help in understanding the feedback of SOM to global warming. If labile SOM pools exhibit greater temperature sensitivity than the stable SOM pools, the response to CO_2 evolution would be relatively small in magnitude and short-lived and vice versa. We used different temperature response models (see Appendix A) for upscaling experimental results and to predict the influence of warming on SOM decomposition.

2. Materials and methods

2.1. Site characteristics and soil sampling

Soil samples were collected from the surface layer (0–15 cm) of four selected treatments of two on-going field experiments on rice-wheat system at Punjab Agricultural University research farm Ludhiana (30° 56' N, 75° 52' E and 247 m above sea level), India. The aim was to select soils with variable input of organic matter so that these differed in organic C content. The selected soils had received one of the following treatments for 6-years preceding sampling: i) RS—an annual input of rice straw at 10 Mg ha^{-1} and fertilizer NPK at 90 kg N, 30 kg P_2O_5 and 30 kg $\text{K}_2\text{O ha}^{-1}$ ii) IN-application of fertilizer NPK as per (i) above, iii) FYM—an annual input of FYM at 40 Mg ha^{-1} on dry weight basis, and iv) CONT—no input of organic and inorganic sources. Samples were collected after wheat harvest (end of crop cycle) in May, 2012 from three replicates of each treatment. The soils from both the experiments were sandy loam in texture (Typic Ustorthents; USDA, 1999), non-saline and neutral in reaction (pH = 7.03).

The experimental area is characterized as semiarid sub-tropical with monsoonal climate. Annual rainfall ranges between 700 and 800 mm and more than 70% of it occurs during the monsoon months of July to September. The mean monthly minimum and maximum air temperature averages 18° and 35 °C during rice growth season (June–October) and 7° and 23 °C during wheat season (November–April), respectively. The daily maximum temperature during May and June frequently exceeds 43 °C (Kaur and Hundal, 2008).

2.2. Size fractionation of soil organic matter

The samples were air-dried and passed through 2 mm sieve. The plant residues retained on the sieve were discarded. Each soil sample was divided into two parts. One portion of the sample was separated into three SOM fractions viz. cPOM, fPOM and MinOM and the other portion was kept as whole soil for subsequent incubation studies. Particulate organic matter (POM) was separated by dispersing soil in 0.5% sodium hexametaphosphate solution and shaking for 15 h on a reciprocal shaker (Cambardella and Elliott, 1992; Benbi et al., 2012). The dispersed soil sample was passed through a set of 250 and 53 μm sieves. The material retained on the 250 μm sieve consisted of cPOM and coarse sand (250–2000 μm size). The material retained on the 53 μm sieve comprised fPOM and fine sand (53–250 μm size). After rinsing several times with water, the material retained on the sieves was dried at 40 °C in a

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