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Both priming and temperature sensitivity of soil organic matter decomposition depend on microbial biomass – An incubation study

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ABSTRACT

The effect of temperature and the influence of fresh substrate addition on soil organic matter decomposition are two key factors we need to understand to forecast soil carbon dynamics under climate change and rising CO_2 levels. Here we perform a laboratory incubation experiment to address the following questions: 1) Does the temperature sensitivity differ between freshly added organic matter and bulk soil carbon? 2) Does the addition of fresh organic matter stimulate the decomposition of soil organic matter ("priming effect")? 3) If so, does this priming effect depend on temperature? In our study, we incubated sieved soil samples without and with two labelled plant litters with different ^{13}C signals for 199 days. The incubations were performed with two diurnal temperature treatments (5–15 °C, 15–25 °C) in a flow-through soil incubation system. Soil CO_2 production was continuously monitored with an infrared gas analyser, while the ^{13}C signal was determined from gas samples. Phospholipid fatty acids (PLFA) were used to quantify microbial biomass. We observed that the instantaneous temperature sensitivity initially did not differ between the original and the amended soil. However in the amended treatment the temperature sensitivity slightly but significantly increased during the incubation time, as did the PLFA amount from microbial biomass. Further, we found that addition of fresh plant material increased the rate of decomposition of the original soil organic matter. On a relative basis, this stimulation was similar in the warm and cold treatments (46% and 52%, respectively). Overall our study contrasts the view of a simple physico-chemically derived substrate–temperature sensitivity relationship of decomposition. Our results rather request an explicit consideration of microbial processes such as growth and priming effects.

1. Introduction

Soils contain the largest carbon pool in terrestrial ecosystems which consists of diverse materials with a broad spectrum of different molecular structures. They range from fresh organic matter (FOM), such as plant litter and root exudates, to soil organic matter (SOM) which refers to material no longer recognizable as plant litter. FOM is often referred to be a more easily degradable labile pool due to the more rapid degradation compared the bulk of SOM (Blagodatskaya and Kuzyakov, 2008). On the contrary, soil organic carbon is assumed to consist of more complex or low quality carbon compounds which decompose more slowly and is often referred to as a more recalcitrant carbon pool.

Heterotrophic microorganisms are able to oxidise the carbon in soil and produce CO_2, which diffuses into the atmosphere. This respiration flux is one of the largest fluxes of C from terrestrial ecosystems to the atmosphere (Schlesinger and Andrews, 2000). It is well established that overall soil respiration and soil organic matter decomposition depend on abiotic factors such as temperature and soil moisture (Kirschbaum, 2004) and may be altered by future climate change (IPCC, 2007). The degree to which increasing temperatures cause decomposition to deplete SOM stores and provide a positive feedback to global warming is still a major uncertainty in our ability to predict future CO_2 levels. In most environments the stocks of labile and recalcitrant compounds are not equal, with recalcitrant compounds being much more abundant than easily degradable compounds (Davidson and Janssens, 2006). As prediction from the kinetic theory of Arrhenius the temperature sensitivity increases with increasing activation energy. It is expected from this theory, that if the differences in decomposition rate are entirely due to the activation energy (as a measure of the energy required for decomposers to access the material), the temperature sensitivity should increase with the 'recalcitrance' of the organic material (Davidson and Janssens, 2006; Hartley and Ineson, 2008).

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Slight changes in the turnover of SOM could change the CO_2 concentration in the atmosphere dramatically. However, if the processes slowing decomposition are not related to the molecular nature of organic matter but to a process like sorption, it is unclear what the temperature dependence should be, or if there should be short term temperature dependence at all. Results from past studies are inconsistent and until now no agreement has been reached on temperature sensitivity and its dependence on the complexity of SOM (Conant et al., 2011; Gershenson et al., 2009). Some observations suggest that more resistant SOM decomposition is less (Liski et al., 2000; Luo et al., 2001; Rey and Jarvis, 2006) or more (Conant et al., 2008; Haddix et al., 2011; Hartley and Ineson, 2008) temperature sensitive than the decomposition of more labile substrates. Other studies found equal temperature sensitivity (Fang et al., 2005; Conen et al., 2006; Reichstein et al., 2005) of FOM and SOM.

Not only abiotic effects can influence carbon turnover in soils. Recently biotic effects on decomposition have received increasing attention (e.g. the priming effect, Kuzyakov, 2010). Carbon storage in soils is also driven from aboveground and belowground biomass inputs and losses due to carbon degradation by soil microbial biomass (Pendall et al., 2011). One of the mechanisms linking C input and output in soils is the priming effect (PE) (Guenet et al., 2010b). The real PE has been defined as a change in decomposition rate of SOM as a response to some FOM addition (Bingeman et al., 1953). Real PEs are observed in several studies after the application of different kinds of FOM. The added substrates were varied from easy to more complex degradable carbon sources, e.g. amino acids (Hamer and Marschner, 2005), sugars (Nottingham et al., 2009; Garcia-Pausas and Paterson, 2011), plant litter (Bell et al., 2003; Fontaine et al., 2004, 2007; Nottingham et al., 2009) and biochar (Jones et al., 2011; Zimmerman et al., 2011; Wardle et al., 2008). It could also be shown that rhizodeposition of plant roots influences SOM degradation (Cheng, 2009; Dijkstra et al., 2006; Fu and Cheng, 2002). Up to now the mechanism driving priming is not fully understood (Blagodatskaya and Kuzyakov, 2008) and in the literature positive PE (Garcia-Pausas and Paterson, 2011; Guenet et al., 2012; Nottingham et al., 2009) and negative PE (Guenet et al., 2010a; Zimmerman et al., 2011) were observed. A better knowledge of priming is important because especially real priming can influence turnover times of the large amount of old SOM. A decrease in SOM degradation (negative PE) could increase carbon stocks, while an increase in degradation of SOM (positive PE) might result in a depletion of soil carbon stocks (Kuzyakov et al., 2000). PEs were also observed without influence on SOM decomposition, this was explained by a change in turnover of microbial biomass and is defined as apparent priming (Blagodatskaya and Kuzyakov, 2008).

Up to now the interaction between biotic and abiotic effects has so far not received much attention. Therefore the objective of this study was to investigate the temperature sensitivity of freshly added organic matter and bulk soil carbon to test the kinetic assumption of substrate quality. We applied fresh plant litter with two distinct carbon isotope ratios to a soil from which fresh plant matter was removed. We partitioned between the different carbon sources by using the change in the $^{13}C/^{12}C$ ratio in the different compartments, which is related to the proportion of carbon derived from the new added material (Gleixner et al., 2002). We additionally investigated, if the addition of fresh organic matter accelerated decomposition of soil organic matter ("priming effect") and whether this priming effect was dependent on temperature.

2. Materials and methods

2.1. Soil sampling and preparation

The arable soil used in this experiment was sampled in August 2008 from Großobringen (Thuringia, Germany), a continuous observation plot of the Thuringian regional office for environment and geology (TLUG). The mean annual temperature for this site is 8.4 °C, and average annual precipitation is 556 mm. The dominant soil type found is Chernozem from Loess (pH = 6.6; sand = 16.9%; silt = 54.7%; clay = 28.0%; N_{total} = 0.14%; C_{org} = 1.7% (TLUG, 2012)) with a value of $\delta^{13}C = -26.57 \pm 0.08‰$. Soil was randomly sampled from the first 30 cm of the plough layer. The field moist soil was sieved through a 2 mm mesh sieve and remaining roots and stones were carefully removed at the laboratory. The prepared soil was stored at 4 °C in the dark for 28 months prior to the start of the incubation experiment, to ensure that only more stable carbon was left in the soil.

2.2. Experiment design and addition of fresh plant material

An automated incubation system to perform multiple environmental manipulations of up to 80 constructed soil columns was developed for this experiment (Fig. 1). The homogenised, prepared soil was used to fill closed mesocosm columns (10 cm diameter, 20 cm height) with glass suction plate at the bottom. The connection of the suction plates was achieved by a 1.5 cm slurry soil layer (150 g) and then the column was filled up with 850 g of the same soil. Afterwards the columns were manually moistened with water until

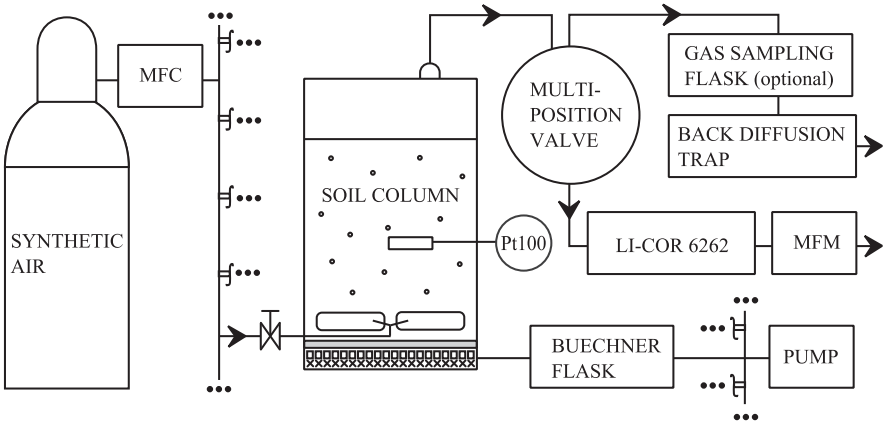

Fig. 1. Schematic diagram of the soil incubation system. Black arrows show the way of the air from gas bottle with mass flow controller (MFC) through the soil column to the LI-COR 6262 or alternatively, the air flow during the non-measuring period, through the gas sampling flasks and then into the atmosphere. The soil column bottom was equipped with suction plate and connected via the Buechner flask to a pump.