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The temperature sensitivity of organic carbon mineralization is affected by exogenous carbon inputs and soil organic carbon content

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ABSTRACT

Temperature sensitivity of organic carbon (C) mineralization is affected by C inputs, but predicting the magnitude of the response remains a challenge. We investigated how temperature and exogenous C inputs affected the apparent organic C mineralization in soils with a range of soil organic C (SOC) contents. Soils with 2.9, 4.0, and 6.8% SOC content were incubated with or without C sources (either plant residues or glucose), at two temperatures (15 or 25 °C) for 120 days. Apparent organic C mineralization was significantly affected by SOC content and C inputs. Cumulative CO_2 production in soils with a higher SOC content was less sensitive to C inputs. Glucose was always more effective in stimulating CO_2 production than plant residue. Without exogenous C inputs, the temperature sensitivity of organic C mineralization (described by Q_{10} value) was higher in the 4.0% SOC soil (2.31) than in the 2.9% (1.12) and 6.8% SOC soils (1.30). The addition of exogenous C decreased Q_{10} values by up to 131% in the 4.0% SOC soil, which was not observed in other two soils. In general, C inputs increased the Q_{10} of the estimated active (C_a) and stable C (C_s) pools in all the tested soils, especially the C_s pool in the 4.0 and 6.8% SOC soils. Results indicated that the effect of C inputs on apparent organic C mineralization (either stimulatory or inhibitory) is influenced by SOC content and C source, and that temperature sensitivity of organic C mineralization in the presence of exogenous C is highly sensitive to SOC content.

1. Introduction

Soil organic carbon (SOC) is the largest carbon (C) reservoir in the biosphere, containing more than twice the C found in the atmosphere and three times the size of vegetation pool [1]. The balance between inputs from primary production and outputs as heterotrophic microbial respiration (i.e. mineralization) controls the size of the organic C pool [2]. Many factors affect organic C mineralization through their impacts on soil decomposer communities [3–5]. For instance, temperature influences organic C mineralization by its effects on microbial metabolic activity [6,7]. It has been widely observed that increasing temperature enhanced microbial activity and therefore increased the turnover rate of SOC [8–11]. However, transient [12], neutral [13], and negative effects of temperature on organic C mineralization [14,15] have also been documented. The observed discrepancies suggest that other factors may confound the temperature effect.

Substrate availability and quality influences organic C mineralization [16,17]. Field and laboratory studies have demonstrated that organic substrate input stimulated microbial respiration and SOC mineralization [18–21]. It is therefore expected that substrate availability and quality may affect the temperature response of organic C mineralization. Indeed, Gershenson et al. [3] observed positive effects of substrate availability in a range of soils, while similar studies also suggested that the temperature response of SOC mineralization depends on SOC content [22,23]. Studies have also indicated that temperature sensitivity of organic C mineralization increased with substrate recalcitrance generally following Arrhenius kinetics [24,25], while other studies reports the opposite [7]. It

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is apparent that the interactions of substrate with temperature likely affect the mineralization of SOC. However, the magnitude [16] and direction [26] of the response are challenging to predict.

The objective of the present study was to investigate how exogenous C inputs affect organic C mineralization (combinative decomposition of the added organic C and native SOC) and its temperature sensitivity in similarly classified soils with contrasting SOC contents. It was hypothesized that 1) exogenous C inputs stimulate apparent organic C mineralization and the stimulatory effect is more significant in higher SOC soils, and 2) exogenous C inputs increase the temperature sensitivity of organic C mineralization.

2. Materials and methods

2.1. Field sites and soil sampling

Field sites are located at Bei'an City (48.170 N, 126.738 E) and Hailun City (47.433 N, 126.633 E), Heilongjiang Province, China, which have a typical temperate continental monsoon climate with mean annual temperature of 1.5 °C and mean annual precipitation of 550 mm. The soil (Mollisols) is classified as Typic Hapludoll, with a loamy clay texture from the same parent materials (Quaternary clay loess-like sediments) under continuous cultivation of maize (*Zea mays*) and soybean (*Glycine max*) in rotation for more than 50 yr. Soils with different SOC content (2.9, 4.0, and 6.8%) were used in the present study. The soils contained no carbonates. The 2.9% SOC soil was sampled from Hailun City, near the National Field Observation and Research Station of Hailun Agroecosystems of the Chinese Academy of Sciences, while the other two were collected from the Bei'an City area. The SOC contents likely varied due to the amount of crop residue over the decades removed by tenant farmers for feed and fuel. The clay contents of the soils at the two sites were not significantly different and ranged between 33 and 39% (w/w). After maize harvest in October 2013, eight soil cores were randomly collected to a depth of 0–10 cm from each site, composited after the removal of visible plant residues and roots, sieved (2 mm) and stored at 4 °C until used. Selected soil properties are presented in Table 1. Soil pH was measured in a soil to water ratio of 1:2.5 (w/v) after equilibrium for 30 min. Total C and nitrogen (N) were measured with a CNH elemental analyzer (Vario EL III, Elementar, Germany). Mineral-associated organic C (MOC) was determined following Lian et al. [27].

2.2. Exogenous C sources

The plant residue utilized were maize leaves collected directly from the fields in Hailun during the harvest in October 2013. Approximately 20 leaves from different plants were randomly collected to form a composite sample. The residue was oven-dried at 60 °C until constant weight, followed by grinding in a ball mill and stored in a desiccator until used. The residue used in the incubation contained 422.3 g kg^{-1} C and 10.4 g kg^{-1} total N (TN). Glucose was prepared with deionized water at a final concentration of 5 g L^{-1}. The labile residues and glucose were assumed to increase the substrate availability and quality of soils.

2.3. Laboratory incubation

The experiment was a randomized completely crossed factorial design with three factors, namely soils (2.9, 4.0 or 6.8% SOC soils), exogenous C sources (control, plant residue, or glucose solution), and temperature (15 or 25 °C), and with four replicates. The fresh soils (equivalent to 20 g oven-dry soil) were placed in a 250-mL mason jar and incubated at 40% of water-holding capacity (WHC) at 25 °C in dark for 7 d. The WHC was measured according to Alef and Nannipieri [28]. After the pre-incubation, plant residue and glucose were added at an equivalent of 2.2 g C kg^{-1} soil, corresponding to approximately 0.5% of the dry mass of soil. The rate of residue application equates to approximately 5500 kg ha^{-1} aboveground biomass incorporated into surface layer (0–10 cm), which is the typical amount of residue production in northeast China. Residues were mixed thoroughly with soil using a spatula, while glucose was added uniformly in the form of solution by injection to uniformly wet soils. Soil moisture was adjusted to 60% of WHC of the soils with deionized water. Controls without exogenous substrate addition (soil only) were prepared in parallel. Samples were incubated at specific temperatures (15 or 25 °C) in dark for 120 days.

2.4. CO_2 measurement

A beaker containing 10 mL 1.0 mol L^{-1} NaOH solution was placed in each jar to trap evolved CO_2. The trap solution was replaced 1, 2, 3, 5, 7, 15, 30, 60, 90, and 120 days after incubation. The trapped CO_2 was quantified by titration with 0.5 mol L^{-1} HCl in an excess of $BaCl_2$ [29]. Organic C mineralization was calculated as the cumulative CO_2 production during the two consecutive sampling intervals. The rate was expressed as both g CO_2-C kg^{-1} soil and g CO_2-C kg^{-1} SOC, representing the total mineralizable C pool and proportion of mineralized C to the total C pool [30].

2.5. Calculations

Carbon mineralization was fitted to a two-compartment kinetic model [31] with SigmaPlot 12.0 (Systat Software, Inc., San Jose, U.S.A.). The model is expressed as:

$$C_t = C_a \times \left(1 - e^{-kat}\right) + C_s \times \left(1 - e^{-kst}\right) \quad (1)$$

where C_t is the cumulative mineralized C (g CO_2-C kg^{-1} soil) at time t (day), C_a and C_s represent the sizes of the active C and stable C pools (g CO_2-C kg^{-1} soil), respectively. The k_a and k_s are rate constants for the active C and stable C pools (day^{-1}), respectively.

The effect of C inputs on C mineralization was described as a response ratio (Ln*RR*) [32]:

$$\mathrm{Ln}RR = \mathrm{Ln}(CO_2)_t / \mathrm{Ln}(CO_2)_c \quad (2)$$

Table 1
Selected soil properties.[a]

Soils	Soil pH	Organic C	Total N	Total P	Total K	MOC	Soil texture (% w/w)		
		(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	Clay	Silt	Sand
2.9% SOC	6.21	28.8	1.95	1.06	42.86	10.1	33.1	29.0	37.9
4.0% SOC	6.09	40.0	3.01	0.95	39.01	20.0	37.0	32.8	30.2
6.8% SOC	6.52	68.3	5.49	1.26	36.12	40.1	39.0	32.9	28.1

[a] Values attained from composited soil samples, and thus no standard errors of mean were reported.