Soil Biology & Biochemistry 107 (2017) 85–93

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

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

Interactions of soil particulate organic matter chemistry and microbial community composition mediating carbon mineralization in karst soils

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ARTICLE INFO

Article history:
Received 24 February 2016
Received in revised form
19 September 2016
Accepted 23 December 2016
Available online 5 January 2017

Keywords:
Carbon mineralization
Particulate organic matter chemistry
Microbial community composition
Pyrolysis-GC/MS
Phospholipid fatty acids

ABSTRACT

Particulate organic matter (POM) chemistry and microbial degraders are important determinants of soil carbon (C) mineralization, but the effects of their interactions on C mineralization are largely unknown. Two contrasting soils with different POM chemical composition from karst ecosystems were sampled, sterilized, and cross-inoculated with microorganisms for 124 days to explore the relationships between POM chemical composition, microbial community composition, and soil organic C (SOC) mineralization. Pyrolysis-gas chromatography/mass spectrometry analysis was used to determine POM chemistry, and phospholipid fatty acid (PLFA) analysis was used to characterize the soil microbial community. Microbial cross-inoculation showed that the microbial community composition did not change in response to changes in soil C and that the relatively labile POM components, *e.g.*, fatty acids and *n*-alkenes, explained 61.2% of the variation in microbial community composition. Microbial community composition, such as PLFAs cy19:0, i17:0, 10Me16:0, and 18:2ω6,9c, strongly influenced POM chemical composition, explained 94.5% of the variation in POM chemical composition. These results indicated that soil microbial communities could adapt to changes in POM and served as main drivers of POM chemistry alterations. In addition, mineralized soil C (% of SOC) was significantly influenced by microbial community composition, soil source, and their interactions. Redundancy analysis and Mantel tests further revealed that SOC mineralization was strongly affected by POM chemical composition (*e.g.*, the content of ketones and *p*-hydroxyphenyl) and microbial community composition (*e.g.*, the content of PLFAs 16:1ω7c and 10Me16:0), and that the influence of microbial community composition on SOC mineralization was highly dependent on POM chemical composition, suggesting that the interactions of POM chemistry and microbial community composition mediate SOC mineralization. These analyses indicate a tight relationship between POM chemistry and microbial community composition, and highlight the importance of their interactions in mediating the persistence of organic matter in karst soils.

1. Introduction

As the largest active terrestrial reservoir of global carbon (C) stocks, soil plays an important role in the regulation of global C cycling (Kleber and Johnson, 2010). Soil organic C (SOC) is represented by many compounds that differ greatly in chemistry (Baldock et al., 2004), and these chemical differences greatly affect the microbial-mediated cycling of C in soils (Ng et al., 2014). With the goal of mitigating climate change by increasing soil C stocks,

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http://dx.doi.org/10.1016/j.soilbio.2016.12.025

researchers should clarify the relationships between C chemistry and soil microorganisms. This is a challenging goal because of the complexity of SOC and the diversity of soil microorganisms.

Soil particulate organic matter (POM) is defined as fine root fragments and other sand-sized organic debris (Cambardella and Elliott, 1992), which is generally enriched in plant-derived lignins, waxes, and fungal amino compounds (Kögel-Knabner, 2002; Simpson et al., 2004). POM is considered as a rapidly changing pool of soil organic matter (SOM) because it is readily decomposed by soil microorganisms (Mrabet et al., 2001) and therefore responds rapidly to environmental changes (*e.g.*, changes in climate and land use) (Six et al., 2002). POM chemistry may influence microbial community structure because microorganisms prefer some substrates over others (Fierer et al., 2007). For example, POM with a higher C to nitrogen (C/N) ratio and a higher lignin content tends to support large numbers of actinobacteria and fungi, which adapt to nutrient-poor environments (Eskelinen et al., 2009), whereas fresh organic C of higher quality tends to support large numbers of gram-negative bacteria (Bastian et al., 2009). Recent studies showed that labile C inputs can alter microbial communities and microbial substrate utilization patterns (Wang et al., 2014), suggesting that labile POM components could affect the composition of soil microbial communities. Despite this research, the influence of POM chemical composition on microbial community composition remains poorly understood.

Soil microorganisms are considered as important contributors to POM formation (Simpson et al., 2004) and chemistry alterations (Sinsabaugh, 2010). Fungal hyphae, for example, can increase soil structural stability by depositing fungal-derived C (indicated by glucosamine content) in POM (Simpson et al., 2004). Furthermore, POM chemistry alterations are primarily mediated by the production of microbial extracellular enzymes, such as phenol oxidases, which generally act on phenolic-containing compounds including lignin and polyphenols (Sinsabaugh, 2010). Thus, soil microorganisms have a direct and rapid effect on the formation and chemistry of POM and on the stabilization of newly generated SOC (Six and Paustian, 2013). In addition, the contribution of dead microbial cells to POM differs among microbial groups (Six et al., 2006). For instance, fungi contribute more chemically recalcitrant C to POM than bacteria (Six et al., 2006), because fungal cell walls are chitin enriched, contain diverse pigments, and have high C/N ratios, they are more resistant to decay than bacterial cell walls (Holland and Coleman, 1987). However, the interactions between POM chemistry and microbial community composition are not well understood.

Although SOC mineralization is influenced by the size, activity, and composition of the soil microbial community (Six et al., 2006; Tardy et al., 2015), Kemmitt et al. (2008) suggested that the mineralization rate is limited by abiotic factors, while Marschner et al. (2008) reported that SOC can be protected by its ‘inherent recalcitrance’. For example, phenolic compounds can protect organic matter from oxidation by neutralizing free radicals (Rimmer and Abbott, 2011). In addition, the quantity of POM is often positively correlated with SOC mineralization rates, and microbial activity generally increases with the lignin and secondary compound content in SOM (Sinsabaugh, 2010). Thus, substantial evidence indicates that POM chemistry and microbial community composition greatly affect SOC mineralization. Although much progress has been made in elucidating the effects of abiotic and biotic factors on SOC stability (Schmidt et al., 2011), how the linkages between soil microbial community structure and POM chemistry affect SOC mineralization is still unclear. Elucidating these linkages should increase our understanding of the persistence of organic matter in soils.

Karst landforms are widely distributed and account for approximately 15% of the world's land area (Sweeting, 2012). It follows that slight changes in karst SOC stocks may significantly affect atmospheric CO_2 concentration. The karst region of Southwest China covers an area of 550,000 km^2 and is one of the main regions involved in the ‘Grain-for-Green’ project in which abandoned agricultural lands are being colonized by forest or other secondary vegetation (Liu et al., 2015). Although soil C accumulation during ecosystem restoration in the karst region has been well documented (Zheng et al., 2012; Liu et al., 2015), little is known about the mechanisms underlying SOC accumulation in different vegetation types in the karst region of Southwest China. Therefore, “How fast does soil C respond to environmental changes?” under the scenario of such land-use conversion in the karst region is an important question.

In this study, we selected two types of soil with contrasting organic matter and microbial properties: a surface soil from a primary forest vs. a deep soil from a tussock. By using these soils and conducting a microbial cross-inoculation experiment, we attempted to answer the following questions: (1) How does POM chemistry affect soil microbial community structure? (2) How does microbial community structure affect POM chemistry? and (3) How do POM chemistry, microbial community structure, and their interactions affect SOC mineralization? We hypothesized that 1) the microbial community composition changes in response to changes in soil C and especially to changes in POM (for example, we expected that fungi would be more abundant in the inoculated deep soil, which contains a relatively large amount of recalcitrant C, than in the inoculated surface soil, which contains a relatively large amount of available C); 2) Changes of the soil microbial community composition would result in changes in POM chemistry; and 3) the interactions between POM chemical composition and microbial community composition would affect SOC mineralization (Fig. 1).

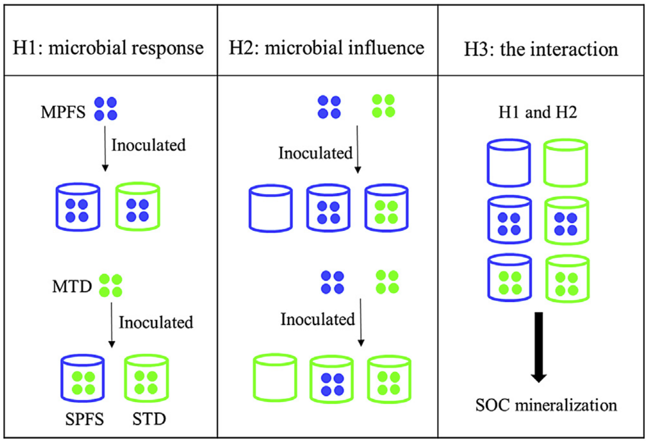

Fig. 1. The hypotheses tested in this research. Left panel – microbial response hypothesis: the microbial community composition changes in response to changes in POM; after the two soils (with different POM) were sterilized and then inoculated with MPFS and MTD, the changes in the microbial community composition were assessed. The testing of hypothesis 1 did not involve unsterilized soil or uninoculated soil. Center panel – microbial influence hypothesis: POM chemical composition changes in response to inoculation with different microbial communities; each sterilized soil was separately inoculated with each microbial community or were not inoculated, and changes in POM were subsequently characterized. Right panel – interaction hypothesis: the interactions between POM chemical composition and microbial community affect SOC mineralization; the sterilized soils were separately inoculated with each microbial community or were not inoculated, and SOC mineralization was subsequently assessed. MPFS (blue circles) and MTD (green circles) indicate microorganisms from a primary forest surface soil and tussock deep soil, respectively. The primary forest soil (SPFS) is indicated by blue beakers, and the tussock deep soil (STD) is indicated by green beakers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)