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Shifts in soil organic carbon dynamics under detritus input manipulations in a coniferous forest ecosystem in subtropical China

Junjun Wu[a], Dandan Zhang[a,b], Qiong Chen[a,b], Jiao Feng[a], Qianxi Li[a], Fan Yang[a,b], Qian Zhang[a,b], Xiaoli Cheng[a,*]

[a] Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academy of Sciences (CAS), Wuhan, 430074, China
[b] Graduate University of Chinese Academy of Sciences, Beijing, 10039, China

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ABSTRACT

The underlying mechanism of how shifts in plant detritus input impact soil organic carbon (SOC) dynamics is not fully understood. Here we investigated the soil C content in different fractions (aggregates, labile and recalcitrant pool) after two years of detritus input manipulations (i.e. detritus input and removal treatment–DIRT: control, CK; double litter, DL; no litter, NL; no roots, NR; no aboveground litter and no roots, NRNL) in a coniferous forest (*Platycladus orientalis* (Linn.) Franco) ecosystem in subtropical China. The root exclusion treatments (NR and NRNL) significantly decreased the macro-aggregate (> 2000 μm) fraction by 23.4%–27.7% compared to CK after two-year detritus input manipulation, and accordingly decreased the C content in macroaggregates. In contrast, the aboveground litter removal and addition (DL and NL) did not significantly impact those properties. Labile SOC significantly declined in the detritus removal treatments, while recalcitrant SOC remained relatively stable. In addition, root exclusion significantly reduced total microbial biomass and most of the taxonomic biomarkers compared to the CK. Fungal biomass were positively correlated with the proportion of macroaggregates across treatments. Principal component analysis revealed the separation of root exclusion treatments from the other detritus input manipulations was based on lower soil C content and proportion of macroaggregates. Overall, our results suggest that future shifts in plant detritus input, especially decreases in belowground litter inputs, can strongly and rapidly reduce SOC pools by reducing the proportion of macroaggregates and the C content in macroaggregates, highlighting the importance of root in regulating soil C sequestration in response to future climatic scenarios.

1. Introduction

Global change exerts a large influence on the primary productivity of terrestrial ecosystems and consequently alters the above- and belowground litter inputs to soils (Peng et al., 2017; Liu et al., 2018). As a key component of the ecosystem carbon (C) pool, shifts in plant litter inputs can simultaneously enhance the decomposition and formation of soil organic matter (SOM) (Paul, 2016; Tamura et al., 2017) and ultimately have profound influences on soil organic carbon (SOC) dynamics (Giardina et al., 2014; Bradford et al., 2016). Although the effects of changes in above- and belowground inputs of plant detritus on SOC dynamics have been extensively studied (Crow et al., 2009; Leff et al., 2012; Fekete et al., 2014; Huang and Spohn, 2015), there are still many controversies among these studies and our mechanistic understanding is still limited.

So far, the importance of the contribution of aboveground litter to SOC dynamics is not clear (Cotrufo et al., 2015; Kögel-Knabner, 2017). It has been suggested that aboveground litter removal could generally reduce SOC content (e.g., Leff et al., 2012; Bowden et al., 2014). For instance, some studies have reported that SOC content decreases by 24% after 20-year aboveground litter removal in temperate forests (Bowden et al., 2014) and declines by 23% only after 2-year aboveground litter removal in a lowland primary tropical rain forest (Leff et al., 2012). Conversely, Huang and Spohn (2015) found that the SOC content is not affected by aboveground litter removal even after 14 years of treatment. In addition to litter removal, there are also many conflicts among the various studies about litter addition on SOC content. For instance, Leff et al. (2012) found that 2-year litter addition enhanced SOC content by 31% in a tropical forest, whereas other studies demonstrated that litter addition did not always increase the SOC pool and sometimes even reduced it (Sayer et al., 2011; Bowden et al., 2014; Lajtha et al., 2014; Pisani et al., 2016). In response to litter

* Corresponding author.
E-mail address: chengxiaoli@wbgcas.cn (X. Cheng).

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addition, priming effects can initially decrease mineral soil C, and it may take several decades to replenish the C released by priming and increase mineral soil C through litter addition (Lajtha et al., 2014). Especially in N-limited forest ecosystems, litter addition could also enhance the degradation of labile SOM and, hence, cause a decrease in the SOC pool (Pisani et al., 2016). Thus, a better understanding of the underlying mechanisms of SOC changes in response to changes in aboveground litter input is critical for the accurate prediction of the SOC pool in response to future climate change.

Meanwhile, there is increasing evidence that organic matter from belowground input is a major contributor to SOC (Rasse et al., 2005; Schmidt et al., 2011; Xia et al., 2015; Jackson et al., 2017). Root-derived C has been reported to be 2.4 times higher than shoot-derived C in the SOC pool (Rasse et al., 2005). There are several mechanisms that can combine to result in higher root-derived C in the SOC pool. First and foremost, roots are in direct contact with the mineral soil, while leaf litter has to be translocated from the soil surface, e.g., by bioturbation and leaching. Meanwhile, root litter is more chemically resistant than aboveground litter. Fine roots contain 2–3 times higher contents of compounds (e.g. lignin, tannins) that are more difficult to decompose than leaf litter; root-derived C therefore has a longer mean residence time in soil (Xia et al., 2015). Crow et al. (2009) also found that root-derived aliphatic compounds are a source of SOC, which accumulate in soil to a greater extent than those derived from leaf litter. Second, roots improve soil aggregation by releasing organic materials and enmeshing soil particles through fine root and mycorrhizal hyphae (Rillig et al., 2015; Gould et al., 2016); the formation of aggregates in turn can provide physical protection of organic carbon (Six et al., 2002b). The physical protection within stable aggregates has been considered as one of the major stabilization mechanisms of SOC, and aggregate-associated C has been used as an indicator for assessing the sequestration of SOC (Lehmann and Kleber, 2015; Zhong et al., 2017; Chen et al., 2017). Finally, the rhizosphere has been considered a major microbial hotspot through the input of labile root exudates (Kuzyakov and Blagodatskaya, 2015). This type of root-derived C is processed faster and can be incorporated more rapidly into microbial biomass (necromass) than leaf litter (Kong et al., 2011). It became increasingly recognized that up to 80% of stabilized SOC exists in the form of microbial-derived necromass and products (Liang and Balser, 2011).

Since the 1970s, the 'Grain-for-Green' Program (i.e., afforestation) has been carried out nationally in China (Zhang et al., 2010). A large area of coniferous (*Platycladus orientalis* (Linn.) Franco) plantation has been established around the Danjiangkou reservoir area, which is the main water source for the Middle Route of the South-to-North Water Transfer Project of China, to preserve the ecological environment (Cheng et al., 2013; Deng et al., 2014). Our previous studies in this ecosystem have found that coniferous plantations increase SOC due to the large inputs of low-quality (with high C:N ratio) plant litter and its slow decomposition rate (Cheng et al., 2013; Deng et al., 2014). Meanwhile, it has been widely accepted that the macroaggregate formation plays vital role in SOC stabilization (Six et al., 2000), due to its faster turnover rates and more sensitive to environment change compared with the microaggregate (Tisdall and Oades, 1982). However, how this type of plant litter input impacts SOC dynamics, particularly, SOC content in different aggregates remains unknown. The detritus input and removal treatment (DIRT) experiment has been considered as a unique approach to explore how changes in the quality and quantity of detritus inputs affect soil organic matter composition and content (Nadelhoffer et al., 2004). To identify the underlying mechanisms of how plant detritus input affects SOC dynamics, we conducted a DIRT experiment in a conifer (*Platycladus orientalis* (Linn.) Franco) plantation in subtropical China since September 2014. Thus, the objectives of this study were to test the following hypotheses: 1) SOC content is more susceptible to root exclusion than to aboveground litter removal, possibly due to the special role that roots play in the formation and stabilization of soil aggregates; and 2) aboveground litter removal or addition has little effect on the proportion and the organic C content of macroaggregates, while root exclusion decreases both.

2. Materials and methods

2.1. Study site

The DIRT experiment was conducted at the Wulongchi Experiment Station (32°45′N, 111°13′E; 280–400 m a.s.l) in the Danjiangkou Reservoir area. The forest is a pure conifer (*Platycladus orientalis* (Linn.) Franco) plantation, and the plant litter input to soil was characterized by high C:N, with the mean C:N ratios of leaves (40.6 ± 4.3) and roots litter (129.8 ± 5.4). The understory vegetation is dominated by *Coriaria sinica*, *Sophora davidii* and *Vitex negundo*. However, these plants are distributed sporadically. The climate in this region belongs to the subtropical monsoon climate of the north subtropical zone. Based on climate data of approximately 50 years (1963–2010), the mean annual temperature is 15.7 °C, with monthly averages of 27.3 °C in July and 4.2 °C in January. Mean annual precipitation is 749.3 mm, of which 70–80% occurs between April and October. The soil is classified as yellow-brown soil in Chinese soil classification, equivalent to haplic luvisols in the USDA Soil Taxonomy. In the 0–30 cm soil layer, the soil pH was 8.09 and contained 11% sand, 41% silt, and 48% clay. The mean annual production of leaf litter was 369.5 ± 70.6 $g\ m^{-2}\ yr^{-1}$ from 2014 to 2016.

2.2. Experimental design and soil sampling

The DIRT experimental plots were established in September 2014. We randomly selected six 10 m × 10 m study sites, and the sites were approximately 30 m away from each other. In each study site, five 1 m × 1 m plots free of trees and saplings were randomly selected, and above- and belowground plant C inputs were manipulated in a number of ways (Nadelhoffer et al., 2004). The treatments included control (CK, normal annual aboveground litter inputs), double litter (DL, twice the litter inputs of the control plots), no litter (NL, annual aboveground litter inputs excluded), no roots (NR, plots trenched and root regrowth into plots prevented), and no input (NRNL, plots trenched and annual aboveground litter excluded). In the NL and NRNL plots, the standing litter with different stages of decomposition was removed carefully. The fresh litter in these plots was excluded with 1 mm mesh screens placed 0.5 m above the plots. For the NR and NRNL plots, we dug a trench of 0.1 m width and 0.6–0.8 m in depth (reaching to the bottom of the root zone and bedrock) along the four sides of the plot. Then 0.35 mm-thick polyethylene sheets were placed along the sides of the trench to prevent roots from entering the trench. Aboveground litter inputs were augmented in the DL plots monthly by adding litter taken from NL plots. The setup is therefore composed of five DIRT treatments nested in each 10 m × 10 m site and replicated six times. The surface solar radiation was approximately the same in all treatments, as the distribution and slope of land was not greatly different (average slope of 5°) and the site faced south. Therefore, the climatic effect was similar in all plots. Moreover, the plots were established at random, thus reducing the effects of incidental minor differences.

In September 2015 (1 year of treatment) and 2016 (2 years of treatment), three soil cores (diameter = 5 cm) from each plot were collected from the top layer of soil (0–10 cm) after removing the litter and organic horizon, respectively. The cores were combined to yield one composite sample per plot and taken back to the laboratory on dry ice. After the removal of visible plant residues and stones, the soil samples were passed through a 10-mm screen by gently breaking the large clods by hand along the natural fractures. A small subsample (approximately 50 g) was removed from each soil sample, immediately sieved through a 2-mm mesh, and then stored at −80 °C for phospholipid fatty acid (PLFAs) extraction. The remaining soil samples were air dried. A small air-dried subsample (approximately 50 g) was passed

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