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Dynamics and speciation of organic carbon during decomposition of leaf litter and fine roots in four subtropical plantations of China

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Plant litter and fine roots turnover are important carbon (C) inputs to soil and a direct emission source of CO_2 to the atmosphere. C dynamics during litter decomposition provide an insight into C flow in soils. To quantitatively assess how decomposition processes vary with litter types, the solid-state ^{13}C nuclear magnetic resonance spectroscopy with cross-polarization and magic-angle spinning (CPMAS-NMR) technique was applied to analyze the organic C dynamics of conifer (*Pinus massoniana*) and broadleaf (*Castanopsis hystrix*, *Michelia macclurei* and *Mytilaria laosensis*) leaf litter and fine roots which had degraded during one year litterbag experiment in four subtropical plantations of China. The results were used to estimate decomposition rates of different C types and compositional changes of leaf litter and fine roots during decomposition. The mass loss rates of different C fractions during decomposition varied significantly between litter types. Site environment and initial litter quality played more critical roles in regulating decomposition of fine roots than of leaf litter. The significant changes in the proportion of C forms and degree of humification occurred during leaf litter decomposition, but not during fine roots decomposition. The proportions of alkyl C and carbonyl C and alkyl/O-alkyl C ratio varied with leaf litter types, with an increase for the proportion of alkyl C and alkyl/O-alkyl C ratio in broadleaf leaf litters and an enhanced trend for the proportion of carbonyl C for *P. massoniana*. The results suggest that the patterns and main controlling factors of litter C compositional change during decomposition differed between above- and belowground, and the dynamics of leaf litter C fractions during decomposition differed between conifer and broadleaf species. The findings of litter C compositional decomposition of the main tree species in this study could contribute to the accurate estimation of soil C sequestration in subtropical plantation ecosystems.

1. Introduction

Litter decomposition is a fundamental ecosystem process and has traditionally received more research attention. Organic matter fixed by photosynthesis in plant tissues is deposited in soils and on soil surfaces, decomposed and utilized by soil organisms, or converted into humic substances (Ono et al., 2011). While the biotic and abiotic mechanisms controlling litter decomposition rates have been well studied (Adair et al., 2008), the factors that contribute to the chemical complexity of decomposing litter and litter-derived soil organic matter remain unresolved (Poirier et al., 2005; Grandy and Neff, 2008; Vancampenhout et al., 2009). Application of the solid-state ^{13}C nuclear magnetic resonance spectroscopy with cross-polarization and magic-angle spinning (CPMAS-NMR) spectroscopy may help to characterize the chemical composition changes during the transformation process from fresh plant material and litter to humic substances in soil (Kögel-Knabner, 1997; Ono et al., 2012).

Many of previous studies demonstrated that temperature and moisture are the most important controls on litter mass loss (Jansson and Berg, 1985; Hobbie, 1996; Adair et al., 2008; Cusack et al., 2009). Litter chemistry, including nitrogen (N), phosphorus (P), calcium (Ca) and lignin concentrations, lignin/N and C/N ratios, not only affects rates of mass loss, but also determines rates of nutrient cycling (McClaugherty and Berg, 1987; Ryan et al., 1990; Grabovich et al., 1995; Gijsman et al., 1997; Scott and Binkley, 1997). Previous solid-state ^{13}C NMR studies identified the chemical changes that occur in litter, woody debris and other materials during decomposition and humification, and provided

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Table 1
Stand characteristics and soil properties from 0 to 20 cm in the four plantations.

Plantation type	*P. massoniana*	*C. hystrix*	*M. macclurei*	*M. laosensis*
Diameter at breast height (cm)	24.6	24.9	22.9	25.8
Tree height (m)	17.2	17.8	20.1	22.6
Stem density (trees ha^{-1})	404	415	449	470
Soil bulk density (g cm^{-3})	1.21	1.19	1.22	1.19
Soil pH (KCl)	3.79	3.77	3.80	3.71
Soil organic C (Mg ha^{-1})	46.9	49.6	54.5	51.5
Soil total N (Mg ha^{-1})	2.58	3.28	3.29	3.32
Sand (%)	57	59	58	58
Silt (%)	8	7	9	7
Clay (%)	35	34	34	35

some information on relative decomposability of different C components of organic matter (Baldock and Preston, 1995; Osono et al., 2008; Preston et al., 2010; Ono et al., 2012). However, effects of climate and litter chemistry on mass loss rates of different organic C chemical compositions are not well documented.

In addition, belowground productivity can be of similar magnitude to foliar productivity (Norby et al., 2004) and estimating roots decomposition is challenging because roots are hidden from view (Bloomfield et al., 1996). Ono et al. (2012) found that different decomposition processes among aboveground litter types might be related to different aromatic and aliphatic C behaviors, as affected by lignin stability and lipid leachability and biosynthesis; whereas it remains unclear that chemical changes in organic C during decomposition of different belowground litter types. To more accurately estimate the C flow in soil during decomposition, it is necessary to understand the dynamics of the above- and belowground organic C fractions with decomposition.

Plantations are being established at an increasing rate throughout the world, and now account for 5% of the global forest cover (FAO, 2001). There is also growing recognition of the conservation value of plantations in off-setting logging on natural forests, sequestering C, and restoring degraded lands (Kelty, 2006). In China, the total plantation area reached 6.2×10^7 ha in 2011, accounting for 31.8% of the total forest area of China, ranking the first in the world (SFA, 2010). South China is suitable for developing plantations because of warm temperature and rich precipitation and has 63% of the total plantation area of China (SFA, 2007). However, most of these plantations were planted with single conifer tree species (e.g. *Pinus massoniana* and *Cunninghamia lanceolata*) or exotic tree species (*Eucalyptus*) (SFA, 2007), leading to a lack of biodiversity and ecosystem stability and degradation of soil fertility (Peng et al., 2008). The indigenous broadleaf plantations with high economic value, which can supply high quality timber while enhance biodiversity and ecosystem services, are increasingly being developed as a good alternative to replace large conifer plantations in subtropical China as well as in other countries (Borken and Beese, 2006; Vesterdal et al., 2008). Studies on changes in the chemistry of litter entering soil of main tree species for afforestation and reforestation can provide a better understanding of soil C stabilization dynamics in subtropical plantation ecosystems.

Our objectives were to determine: (1) decomposability of different C fractions among tree species and factors that lead to

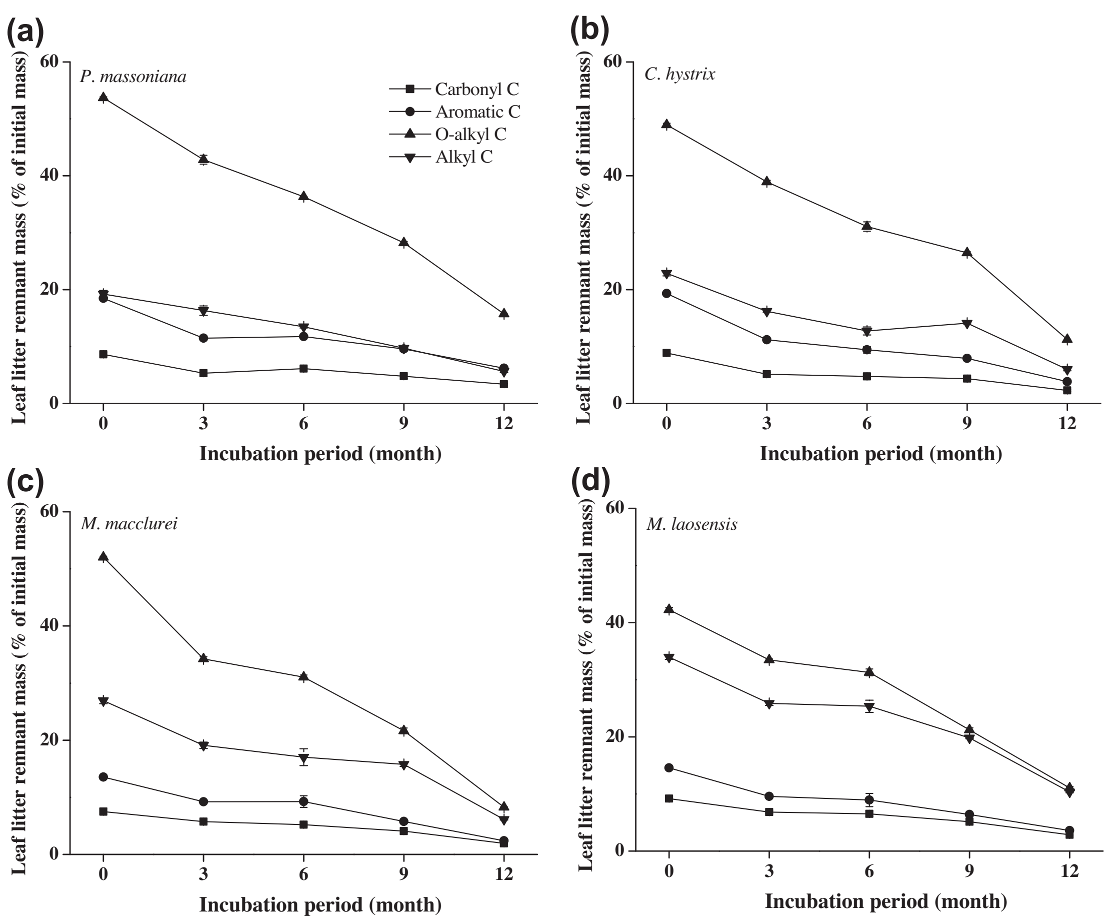

Fig. 1. Remnant mass of each carbon fraction in leaf litter of four plantations during decomposition. Error bars are the standard errors ($n = 3$).