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Diameter-related variations in root decomposition of three common subalpine tree species in southwestern China

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ABSTRACT

Despite the importance of root quality for its decomposition, the effects of forest conversion and diameter size on root decomposition still remains poorly understood. A two-year field experiment was conducted to examine the mass loss and nutrient release of three root diameter classes (0–2 mm, 2–5 mm and 5–10 mm) in three subalpine tree species (*Abies faxoniana*, *Picea asperata* and *Betula albosinensis*) using a litter-bag method on the eastern Tibetan Plateau of China. The roots of *B. albosinensis* decayed faster compared to those of two conifer trees (*A. faxoniana* and *P. asperata*) in the 2–5 mm and 5–10 mm roots. Root diameter and decay rate exhibited a significantly negative correlation for two conifer trees. Regardless of tree species and diameter classes, all root litters experienced significant net nitrogen (N) and phosphorus (P) immobilization during the first winter. Both 2–5 mm and 5–10 mm roots tended to release more N than fine roots after 2-year incubation. Almost no obvious P release was observed for all root litters over the experimental period. Irrespective of tree species, both C:N and C:P ratios followed a trend of 0–2 mm roots < 2–5 mm roots < 5–10 mm roots during the experimental period. The root decomposition and N release were strongly associated with initial root quality (e.g., N and C:N). Our results suggest that diameter-associated variations in substrate quality could be an important driver of root decomposition and nutrient dynamics. Moreover, the diameter effects are dependent on tree species and decomposition period.

1. Introduction

The decomposition of root litter is crucial to soil carbon (C) and nutrient cycling in terrestrial ecosystems (Lal, 2004). Recent evidence indicates that plant roots could be more important to accumulate stable soil organic matter as compared to aboveground leaves (Mambelli et al., 2011). Given the importance of fine root in C and nutrient cycling, it arose a great interest in unraveling the decomposition patterns of fine root. Traditionally, coarse roots (> 2 mm) plays a key role in the transport and storage of C and nutrients (Fogel, 1983; Palviainen and Finér, 2015). Coarse roots comprise over 80% of total root biomass (Butnor et al., 2014), which has important implications for long-term ecosystem productivity and C dynamic (Sierra et al., 2007). However, the decomposition dynamic of coarse roots and its controls are not as well understood as those on fine roots, especially in boreal forests at high-latitude and high-altitudes sites.

At the global scale, substrate quality is one of the most important factors controlling decomposition process (Lin et al., 2011). For a given site, the rates of root decomposition could be primarily controlled by substrate properties (Silver and Miya, 2001). In general, root quality largely depends on tree species and root size in forest ecosystems (e.g., Makita et al., 2015; Sariyildiz, 2015). Forest land-use change often result in complete shift of tree species, which could, in turn, exert significant effects on ecosystem C cycling by altering root quality. For example, conifer tree roots generally have more recalcitrant C components and lower N and P contents as compared to broadleaf tree roots (Yang et al., 2004; Sun et al., 2013). Root diameter is a key factor that regulates root decay because it integrates physico-chemical traits associated with root development (Fahey and Arthur, 1994). Different root diameters generally show marked differences in tissue substrate chemistry, with higher nutrients (e.g., N and P contents) in small roots (Birouste et al., 2012; Goebel et al., 2011). Thus, diameter-associated differences in root quality have the potential to affect the decomposition patterns of the root system (Silver and Miya, 2001; Sun et al., 2013). Available studies have mainly focused on diameter-related variations within a fine root system (e.g., < 0.5 mm vs. 0.5–1 mm or 0.5–2 mm) (e.g., Yang et al., 2004; Sun et al., 2013; Wang et al., 2014). However, the decomposition heterogeneity between fine root and

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larger root components is still poorly understood in forest ecosystems.

Tibetan forests are typical subalpine boreal forests at low latitudes with important consequences for regional C balance (Xu et al., 2015). Over the last decades, natural coniferous forests (dominated by *Abies faxoniana*) have been harvested in large-scale industrial logging, and replaced by secondary birch forest and dragon spruce plantation under national restoration programs (Xu et al., 2015). Currently, Minjiang fir (*Abies faxoniana*), dragon spruce (*Picea asperata*) and red birch (*Betula albosinensis*) are the three dominant tree species in this area. Forest type conversion could result in significant shifts in root quality, which in turn could affect the belowground decomposition dynamics. Additionally, root decomposition is also complicated by diameter size. Therefore, it is very important to synchronously explore the diameter-related variations in root decomposition of dominant tree species from different forest land-use types in a field incubation experiment. In general, subalpine forests are covered by seasonal snowpack in wintertime and snow cover is an important environmental factor modifying litter decomposition process in snowy regions (Ni et al., 2014). The decomposition pattern of forest roots could differ between growing and non-growing seasons due to environmental differences in two contrasting seasons (growing season vs. winter season). Most decomposition studies, to date, have mainly focused on aboveground parts (leaves) in Tibetan forests (e.g., Xu et al., 2015; Ni et al., 2014). Both forest conversion and root diameter have the potential to affect root quality that regulates decomposition dynamics in Tibetan forests, but the nature of these processes remains poorly understood. Here, we conducted a 2-year field experiment to investigate the mass loss and nutrient release of three root size classes (0–2 mm, 2–5 mm and 5–10 mm) in three subalpine tree species (*A. faxoniana*, *P. asperata* and *B. albosinensis*) using a litter-bag method on the eastern Tibetan Plateau of China. The specific objective of this work was to test the following hypotheses: (i) root decay would decrease with increasing root diameter; (ii) the rate of root decomposition would differ among tree species; (ii) the pattern of nutrient release would differ between growing and non-growing seasons.

2. Materials and methods

2.1. Site description

The experiment was conducted at the Long-term Research Station of Alpine Forest Ecosystem of Sichuan Agricultural University (31°14′–31°19′N, 102°53′–102°57′E, 2458–4619 m a.s.l), which is located on the eastern Tibetan Plateau of China. Annual mean precipitation is approximately 850 mm and annual mean temperature is about 3 °C. In general, the ground is covered with seasonal snow from mid-November to early April. The soils are typical dark brown forest soils and are classified as a Cambic Umbrisols according to the IUSS Working Group (IUSS, 2007). Natural coniferous forest, secondary birch forest and dragon spruce plantation are the three dominant forest types due to local forest management practice since 1960s. Correspondingly, *A. faxoniana*, *P. asperata* and *B. albosinensis* are the three key tree species in this area. In this study, we selected three forest types for the collection of root samples and the basic conditions of the three forests were shown in Table 1.

2.2. Litter collection and litterbag construction

In July 2013, we carefully excavated root samples from the upper 20 cm soil within approximately 2-m distance of tree stem in the three forest stands mentioned above. For each species, roots were gently separated from soil particles and other materials by washing and brushing with deionized water, and then separated into diameter classes (0–2 mm, 2–5 mm and 5–10 mm). Root samples were air-dried to constant mass at room temperature. Root decomposition was determined with a litterbag method. Litter bags were constructed with 20 × 20 cm nylon mesh bags. The litter bags had a 1 mm mesh top and a 0.2 mm mesh bottom. Each litterbag was filled with 5.000 ± 0.010 g of air-dried root segments for each class of 3 tree species. Six plots (10 m × 10 m) were randomly set up in the spruce forest stand. For each root class, duplicate sets of litterbags were placed horizontally at a soil depth of 10 cm in each subplot late in the growing season (mid-October) 2013. Meanwhile, one litterbag of each root size class of tree species was retrieved from each plot for determination of initial water content and chemical properties. The moisture of root samples were used to correct initial root dry mass. One litterbag of each diameter class of tree species was harvested in each plot on early spring 2014 (mid-April), late autumn 2014 (mid-October), early spring 2015 and late autumn 2015. In the laboratory, soil particles and other extraneous materials were removed. Cleaned roots were oven-dried at 65 °C to constant mass and weighed.

Table 1
Basic properties of three forest stands in the southwestern China.

Variables	Natural forest	Secondary forest	Spruce plantation
Stand age (years)	> 150	~70	~60
Dominant tree species	*A. faxoniana*	*B. albosinensis*	*P. asperata*
Forest coverage	0.9	0.8	0.8
Soil properties (0–20 cm)			
Organic carbon ($g\ kg^{-1}$)	163.3	153.7	68.6
Total nitrogen ($g\ kg^{-1}$)	10.2	10.6	4.1
Total phosphorus ($g\ kg^{-1}$)	0.5	0.5	0.4
Bulk density ($g\ cm^{-3}$)	0.8	0.9	1.1
pH	5.3	6.9	6.6

2.3. Chemical analysis

For each sampling date, the harvested root litters were pooled for chemical analyses after determination of the dry mass. The organic carbon (C), total nitrogen (N) and total phosphorus (P) concentrations were measured using the methods of dichromate oxidation, Kjeldahl determination (KDN, Top Ltd., Zhejiang, China) and phosphomolybdenum yellow spectrophotometry (TU-1901, Puxi Ltd., Beijing, China), respectively. The lignin and cellulose concentrations were determined using the acid detergent method (Vanderbilt et al., 2008).

2.4. Calculations and statistical analysis

Decomposition rates were calculated from dry mass remaining using a single negative exponential decay model: $X_t/X_0 = e^{-kt}$, where X_t/X_0 is the fraction of mass remaining at time t, t the time elapsed in years and k the annual decay constant (Olson, 1963). The proportion of element (C, N and P) on each sample was determined by multiplying the root elements (C, N and P) concentration by root mass and comparing it to the initial root elements (C, N and P) mass. The stoichiometric ratios (C:N, C:P and N:P) were calculated on an element mass basis.

Repeated-measures analysis of variance (ANOVA) was used to examine the effects of tree species, root diameter, sampling date and their interactions on root mass and element (C, N and P) remaining and stoichiometric ratios. Two-way ANOVA was used to test the effects of tree species, root diameter and their interaction on decay constant (k value) and initial root chemistry. A step-wise regression analysis was conducted to test the initial root quality factors that affect k values or elements (C, N and P) release over the experimental period. Differences among means were considered significant at the $P < 0.05$ level. All statistical tests were performed using the Software Statistical Package for the Social Sciences (SPSS) version 22.0.