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# Effects of understory plant root growth into the litter layer on the leaf litter decomposition of two woody species in a subtropical forest

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ABSTRACT

Root growth into the litter layer occurs in many forest ecosystems, but its effect on litter decomposition is not well understood. An experiment with two factors and two levels (the litters of *Pinus elliottii* needles with higher carbon/nitrogen (C/N) and carbon/phosphorous (C/P) ratios vs. *Liquidambar formosana* leaves with lower C/N and C/P ratios, with and without *Loropetalum chinense* roots grown into the litters) was conducted *in situ* using the nylon net bag method in a subtropical forest. Organic C (OC), N, and P concentrations in decomposing litters, as well as litter and root masses, were measured at 3, 9, 12, 18, and 24 months. Our results showed that the presence of roots generally increased the rates of mass loss, and OC, N, and P releases, and decreased the OC and N concentrations, but did not alter the P concentration and the C/N, C/P, and N/P ratios in the decomposing litters of both woody species. The influencing intensity of root presence was stronger on the decomposition of *L. formosana* than *P. elliottii* litters. Root proliferation percentage in decomposing litters was generally lower in *P. elliottii* than in *L. formosana* litters from months 1–12, but showed opposite trend in months 12–24. In conclusion, the interaction between root growth and litter decomposition might depend on litter quality, and it might vary with the stage of decomposition.



## 1. Introduction

Decomposition is a vital process in ecosystem carbon (C) and nutrient cycling, as well as to understand the functioning of forest soils and forest ecosystems (Attiwill and Adams, 1993; Berg and McClaugherty, 2008; Prescott, 2010). Studies have shown that litter decomposition is regulated by intrinsic qualities (such as nutrient concentrations and the carbon/nitrogen (C/N) ratio) and extrinsic abiotic (such as temperature and water conditions) and biotic factors, including soil animals and microorganisms (Aerts, 1997; Chen et al., 2012, 2014; Berg, 2014). However, we know little root presence effect on litter decomposition (Cuenca et al., 1983; Luizao et al., 2007), although roots often grow into the litter layer in many forest ecosystems (Subke et al., 2004; Sayer et al., 2006; Achat et al., 2008; Hodge and Fitter, 2010).

Decomposing litter can provide favorable conditions, such as abundant nutrients and water, for root growth (Robinson et al., 1999; Fujimaki et al., 2004), and roots may grow into the litter layer to obtain N and phosphorus (P) (Allison et al., 2010; Wright et al., 2011). Sayer et al. (2006) found that the addition of litter modified the root distribution pattern, with much higher fine-root production in the litter layer than in relatively fertile soils, which indicated that roots have a higher nutrient absorption efficiency in litters than in soils. Other studies showed that roots preferred to grow into middle and lower litter layers that are enriched with water and nutrients compared with the upper layer, in which nutrients are often immobilized by microorganisms (Fujimaki et al., 2004; Ma et al., 2012). In contrast, roots can influence litter decomposition possibly through mycorrhizal fungi, nutrient uptake, and a priming effect (Cotrufo, 2006; Ma et al., 2012). For example, mycorrhizal fungi have been found to increase organic matter decomposition and N release rates in many cases (Hodge et al., 2001; Hodge and Fitter, 2010), but negative (Tiunov and Scheu, 2005; Orwin et al., 2011) and insignificant effects on these parameters (Koide et al., 2011) were also found. Now, the interaction between root growth and litter decomposition is still unclear and requires further study (Ma et al., 2012; Berg, 2014).

In subtropical China, slash pine (*Pinus elliottii* Engelm.) has been widely planted since the 1970s, and pine plantations account for more than 60% of the total plantation area because of their fast growth and large economic benefits (Wang et al., 2012). Sweetgum (*Liquidambar formosana*) is the main deciduous broad-leaved tree species in subtropical China, and it often invades coniferous for-

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ests. Recently, it has been recommended that mixed forests of coniferous species, such as slash pine, and broad-leaved trees, such as sweetgum, should be established and managed by the government because they provide many ecosystem services (Chen et al., 2014). In these forests, abundant understory plants may play an important role in maintaining ecosystem material cycling, but this has not been widely studied (Qiao et al., 2014).

In our previous investigations, the roots of an understory plant, *Loropetalum chinense*, in all Pinus-dominated plantations, including pure pine and mixed forests, were found to widely grow into the litter layer, especially during the rainy spring (see SM1). This phenomenon provides an opportunity to understand the interaction between root growth and litter decomposition, and to assess the potential function of understory plants in subtropical forests. Therefore, we examined the effect of *L. chinense* root growth on the litter decomposition of two woody species litters (slash pine, a coniferous tree, and sweetgum, a broad-leaved tree). We determined the effects of root growth on the N and P concentrations and the C/N and N/P ratios of the leaf litters of these woody species using the *in situ* nylon net bag method. Mass loss, the organic C (OC), N, and P concentrations, and root biomass in decomposing litters were regularly measured during a 2-year incubation period to test the following hypotheses: (1) root growth into litter accelerates litter decomposition and nutrient release through a priming effects, mycorrhizal fungi and/or nutrient uptake (Ma et al., 2012); (2) root growth has a greater effect on sweetgum litters with lower C/N and C/P ratios than on slash pine litters with higher C/N and C/P ratios, as the decomposition rate and nutrient release pattern differ with litter quality (Berg and McClaugherty, 2008); and (3) root proliferation is faster, and roots play a greater role in later decomposition stages, as roots are more likely to grow into old, fragmented litter than fresh litter (Fujimaki et al., 2004). Our results will increase the understanding of interaction between root growth and litter decomposition in subtropical forests.

## 2. Materials and methods

### 2.1. Study area

The study site is located at the Qianyanzhou Ecological Research Station, Chinese Academy of Sciences, in Taihe County, Jiangxi Province, in southern China. The site, which lies on red, nutrient poor soil, has a subtropical moist monsoon climate, with a warm, dry summer and a cool, wet winter. The average annual precipitation is 1700 mm, with about 50% of the total precipitation occurring from April to June. Maximum and minimum average monthly temperatures are 29.8 °C in July and 6.6 °C in January, while the average annual temperature is 18.0 °C. The monthly dynamics of air temperate and rainfall amounts from 2012 to 2014 are shown in SM2. Most local soils are typical Hapludult Ultisols (locally "red soil"), which developed from Quaternary red clay and cover over 60% of the 1.14 million $km^2$ total land area in southeast China. The elevation ranges from 30 to 200 m above sea level (Zou et al., 2015).

Our study was conducted in a mixed forest of coniferous (slash pine) and broad-leaved trees (such as sweetgum and *Schima superba*) (26°44′38″N, 115°03′32″E, elevation 85 m) with a stand density of 850 trees $ha^{-1}$, an average diameter at breast height (DBH) of 20 cm, and an average height of 16 m. This even-aged slash pine plantation was established in 1985. Some broad-leaved trees, such as sweetgum, *Paulownia tomentosa*, and *S. superba*, also emerged after afforestation. Dominating understory plants included *Adinandra millettii*, *Eurya japonica*, and *L. chinense*. The surface soil (0–15 cm) bulk density was 1.48 g $cm^{-3}$; the porosity was 41%; the pH was 4.6; the organic matter and total N concentrations were 15.6 g $kg^{-1}$ and 0.62 g $kg^{-1}$, respectively; and the soil texture was sandy loam with 70% sand and 16% clay. The litter layer was about 3–5 cm thick in our 100 × 100 m study plot.

### 2.2. Experimental design

In April 2012, 30 understory *L. chinense* plants with about a 2.5 cm DBH and 3 m height were selected in a 100 × 100 m plot in the slash pine plantation (completely randomized design with six replicates). All the selected *L. chinense* plants were located under the tree canopy, but were more than 2 m away from any trees. For each selected plant, three 50-cm-long coarse roots with moderate fine roots growing into the litter layer were separated from the litters and photographed (SM3) in order to identify the potential effect of root presence on litter decomposition. In our study, *L. chinense* was the only selected understory plant because of its abundance and its well developed fine roots in the litter layer (see SM1).

The nylon net litter bag technique was used to assess the effect of fine roots on leaf litter decomposition (Berg and McClaugherty, 2008; Chen et al., 2012). The leaves of coniferous slash pine and broad-leaved sweetgum were used to compare the effects of root growth on litters of different quality, as assessed by their N and P concentrations and their C/N and C/P ratios. We collected the leaf litters using litter boxes from October 2011 to March 2012. Ten g of oven-dried (at 50 °C) fresh leaf litter was placed into 2-mm mesh nylon bags measuring 15 × 15 cm. Two bags containing slash pine and two bags containing sweetgum leaf litter were placed under each selected understory *L. chinense* plant in April 2012. Two 50-cm-long coarse roots were placed into one of the two bags containing the slash pine or sweetgum leaf litters, and the bags were sealed *in situ*; control bags were placed near the corresponding treatment bags. In order to prevent the roots to grow in the control bags, we removed all the roots around the bags away 5 cm before buried bag, and used the scissors to cut the new roots around the bags each month during the whole incubation period. In addition, another 50-cm-long coarse root was placed into a bag containing 100 g of soil to compare the responses of roots to a simulated litter layer and the soil environment (see SM3). All roots were photographed on a graduated plate to record their initial state before placing them into the bags. Meanwhile, to improve the root growth, we performed this experiment after a moderate rainfall, and irrigated them every 2 days during the following 2 weeks. In April 2013, this process was repeated for all uncollected litter bags (new, living roots were placed in the litter bags) to ensure that we could determine the role of roots in litter decomposition.

### 2.3. Sampling collection

Litterbags were retrieved after 3, 9, 12, 18, and 24 months. During each retrieval, 30 litter bags under six random understory plants (five bags for each plant) were removed. The roots were cut out of the bags using scissors, and the litter bags were immediately brought to the laboratory. Each bag was opened, and all fine roots inside the bag were carefully removed, and placed on a graduated plate and photographed to attain the state of the roots following the field incubation. The difference between the initial and post-incubation root amounts was measured using an image processing tool (LA-S, Wanseng, Guangzhou, China) to determine the root growth. The leaf litters and roots from each bag were washed using deionized water and dried to a constant weight at 50 °C to obtain the mass loss remaining (%) and the root proliferation percentage (%) between sampling time and initial stage. All samples were ground and passed through a 0.25-mm sieve prior to chemical analysis.