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Leachate from fine root litter is more acidic than leaf litter leachate: A 2.5-year laboratory incubation

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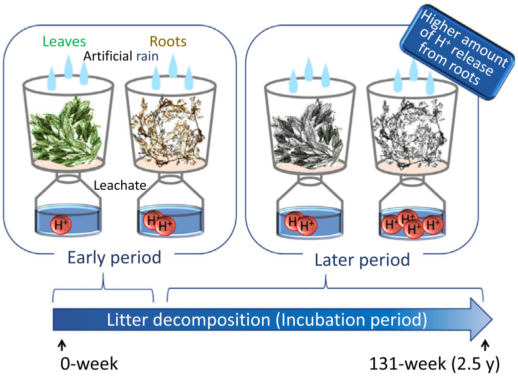
HIGHLIGHTS

- Litter leachates released during decomposition may facilitate soil acidification.
- We compared leachate properties of fresh roots and leaves in a 2.5-y incubation.
- Roots released a greater amount of acidic materials than leaves.
- Dissolved humic-like substances contributed to the lower pH of root leachates.
- An increase of root biomass in response to acidic soil may increase soil acidity.

GRAPHICAL ABSTRACT



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ABSTRACT

Some tree species increase fine root production under soil acidification, thus changing the balance of litter input from leaves and roots. Litter leaches a significant amount of acidic materials during its decomposition, which might facilitate soil acidification. In this context, we focused on dissolved organic matter (DOM) as the major component of acidic materials. We hypothesized that both the quality and quantity of DOM, which control its function (i.e., proton supply), differ between leaf and root litter. To test this hypothesis, we conducted a 2.5-year laboratory incubation experiment using fresh fine roots and fresh green leaves as litter of two coniferous species (*Cryptomeria japonica* and *Chamaecyparis obtusa*) and investigated the leachate pH and DOM composition based on the optical properties. After the early stage of decomposition when flash leaching of DOM converged, the amount of dissolved organic carbon (DOC) leached from roots increased again and leachate pH declined. In contrast, DOC concentrations continued to decrease in leaf leachates during the incubation period, and the pH decrease was not as striking as that of root leachates. Optical properties (ultraviolet visible absorption and fluorescence) of DOM revealed that humic-like substances in DOM played a central role in the acidic pH of root leachates. The total amount of protons released from roots of *C. japonica* and *C. obtusa* is about 13 and 18 times higher, respectively, than that from leaves.

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These results imply that the increase of fine root biomass may induce a positive plant–soil feedback in acidic soils, affecting soil biogeochemical functions of terrestrial ecosystems.

1. Introduction

One of the goals of the United Nations' 2030 Agenda for Sustainable Development is to “sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss” (Griggs et al., 2013). Soil acidification is a type of degradation that affects the provision of ecosystem services (e.g., water, food, and energy security), the protection of biodiversity, and the abatement of climate change (McBratney et al., 2014). Although soil acidification can be caused by acidic deposition derived from anthropogenic nitrogen and sulfur emissions (Seinfeld and Pandis, 2016), it also occurs naturally during the growth process of many tree species (e.g., Hallbäcken and Tamm, 1986). Thus, to prevent soil degradation for both the continuity of ecosystem functioning and sustainable forest management, we need to suppress excess acid production by trees planted commercially.

Plant–soil feedbacks represent changes in soil properties caused by plants that can in turn influence plant growth (Bever et al., 1997; Wardle, 2002; Ehrenfeld et al., 2005; Kulmatiski et al., 2008). Many tree species induce soil acidification, but some trees are able to reduce soil acidity due to the circulation of a large pool of base cations between the plant and soil systems, which results in a large accumulation of base cations in soils (Finzi et al., 1998; Dijkstra and Smits, 2002; Hamburg et al., 2003; Schaetzl and Anderson, 2005). Previous studies reported that trees act in only one direction, either soil acidification or base cation enrichment (e.g., Jobbágy and Jackson, 2003; De Schrijver et al., 2012). However, one of Japan's primary plantation species, *Cryptomeria japonica*, plays a positive feedback role in soil acidity, such that soil acidity increases in soil with low base cation and high exchangeable aluminum concentrations and decreases in soil with high base cation and low exchangeable aluminum concentrations (Tanikawa et al., 2014). The bidirectionality indicates that this species-specific trait depends on soil environmental conditions (Tanikawa et al., 2014, 2017). One possible reason for the additional soil acidification is a smaller calcium cycle between plant and soil systems in the stands with higher acidity soils than those with lower acidity soils (Tanikawa et al., 2017). Moreover, the fine root biomass of *C. japonica* was greater in the former soils than in the latter soils (Hirano et al., 2017). This finding implies that the larger fine root biomass may further contribute to soil acidification by releasing a greater amount of organic acids both from root litter during decomposition and from living root exudates.

Plant litter can alter soil properties by inputting chemical compounds and organic matter, which supply habitats and/or resources for the soil biological community (van Dam, 2009; Bardgett and Wardle, 2010; Baldrian, 2017a). Generally, a species' root litter decomposes more slowly than its leaf litter, possibly because of greater chemical recalcitrance, and roots therefore contribute more residues to the soil organic pool (Xiong et al., 2013; Xia et al., 2015; Ma et al., 2016; Campos et al., 2017). The recalcitrance is mostly derived from roots' high concentration of lignin (Fujii and Takeda, 2010; Xia et al., 2018), which is the most abundant aromatic biopolymer on Earth (Dashtban et al., 2010). Thus, decomposition residue of root litter also contains higher phenolic, aromatic, and o-alkyl carbon proportions than those of leaf litter (Lemma et al., 2007). Dissolved compounds leached from decomposing litter provide nutrient elements for soil microorganisms and plants, and, in turn, can alter soil chemical properties. Few studies, however, have investigated the components in leachates from root litter in detail.

Hansson et al. (2010) analyzed leachates from roots and leaves separately in a 19-week laboratory experiment. They found that old root litter had a different dissolved organic matter (DOM) release pattern from that of young litter, indicating that roots at late stages of decomposition can significantly contribute to carbon buildup in mineral soils. Litter decomposition is a lengthy process, however, generally requiring years to decades for completion (Parton et al., 2007; Baldrian, 2017b). Therefore, long-term incubation experiments are required to elucidate the release pattern of DOM and its impact on the soil biogeochemical cycle.

The aim of this study is to characterize and compare the dissolved organic components released from fine roots and leaves during decomposition, with particular focus on whether more protons are generated during root or leaf decomposition. We conducted an open-system laboratory incubation experiment using fresh fine roots and leaves as litter of two tree species, *C. japonica* and *Chamaecyparis obtusa*, and compared the compositions of DOM in leachates and their temporal patterns. Because the purpose of this study was to detect differences in leachates between the root and leaf, we used fresh organs to minimize the heterogeneity of decomposition stages. We hypothesize that, given the amount of plant material is equal, decomposition of roots produces a greater quantity of aromatic organic acids than decomposition of leaves due to the difference in initial lignin concentrations. Aromatic organic acids derived from roots would thus induce further soil acidification, which represents the positive feedback of soil acidification derived from the physiological reaction of fine roots to soil acidity.

2. Materials and methods

2.1. Preparation of plant materials

Fresh fine roots (<2.0 mm in diameter) and leaves were collected from three mature trees each of *C. japonica* and *C. obtusa* in the arboretum of the Forestry and Forest Products Research Institute, Kyoto, Japan (34°56′31″N, 135°46′29″E, 68 m a.s.l.). Both species are members in the family Cupressaceae, and are arbuscular mycorrhizal conifers (Yamato and Iwasaki, 2002). These trees are the two main plantation species in Japan; they account for about 70% of the country's plantation area, and they are often planted together or in neighboring stands across the same mountain slope. The harvested roots were carefully washed with running tap water to remove adhering soil and then rinsed with deionized water, and the leaves were washed with deionized water to remove dust. Then the four different types of substrate (i.e., two species and two organs) were air-dried at room temperature to constant weights.

2.2. Open-system incubation experiment

The substrates were incubated in columns for a maximum of 131 weeks in a temperature-controlled room at 20 °C, during which about 50% of the substrate mass was lost for the fast decomposing samples. The constant temperature was intended to eliminate seasonal effects, and here we focus