Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Mass, nutrient pool, and mineralization of litter and fine roots in a tropical mountain cloud forest

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HIGHLIGHTS

- We used fine root and litter to assess nutrient pool and mineralization processes.
- Fine root mass followed an exponentially declining trend with soil depth.
- Nutrient pool was greater in litter than in fine roots.
- Litter and fine roots have different mineralization dynamics.
- Fine root mass is more chemically-resistant to mineralization.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 9 May 2016
Received in revised form 15 September 2016
Accepted 16 September 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Multi-element
C and N mineralization
Fine root mass density
Litter mass density
O horizon
Forest soil

ABSTRACT

We used fine root and litter mass from a tropical mountain cloud forest to assess their relative contribution to nutrient content and to examine mineralization processes during a laboratory incubation experiment. Our results showed that average fine root mass density ranged from 2.86 kg m^{-3} to 11.59 kg m^{-3}, while litter mass density ranged from 72.5 kg m^{-3} to 177.3 kg m^{-3}. On average, fine root mass density represented 4.7% of the mass density of the O horizon. Fine root mass density followed an exponentially declining trend with soil depth. On average, 83% of fine root mass density within the soil profile was concentrated in the O horizon. Mean element pools in litter decreased from 44.08 mg cm^{-3} to 0.49 μg cm^{-3} in the following sequence: C > N > Fe > S > Ca > P > K > Mg > Na > Mn > Zn > Cu. For fine roots, a different mean element pool sequence (C > N > Ca > K > Fe > S > Mg > Na > P > Mn > Zn > Cu) in decreasing abundance (from 2.88 mg cm^{-3} to 0.13 μg cm^{-3}) was observed with respect to litter. Regarding C, litter mineralized faster than fine roots, with a mean k value of 0.25 d^{-1} for litter and 0.13 d^{-1} for fine roots. Principal component analysis (PCA) combined with stepwise regression analysis revealed that the main mass density predictors were N, S, Zn, and Mn for litter ($p < 0.0001$, $R^2 = 0.92$), and S and C/N ratio for fine roots ($p < 0.0001$, $R^2 = 0.82$). These results demonstrate the potential of chemical composition to influence the mineralization of fine root and litter mass and therefore the nutrient availability and C sequestration.

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http://dx.doi.org/10.1016/j.scitotenv.2016.09.126

Please cite this article as: Campos C., A., et al., Mass, nutrient pool, and mineralization of litter and fine roots in a tropical mountain cloud forest, Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.09.126

1. Introduction

Aboveground and belowground plant detritus are primary precursors to soil organic matter and constitute the main source of matter and energy for soil organisms in forest ecosystems, and they have considerable impact on nutrient cycles (Hättenschwiler et al., 2005). The forest floor is comprised of litter (leaf, root, and fine woody material) and partially decomposed organic matter that accumulates above the mineral soil in many forest ecosystems (Yanai et al., 2003). Litter is physically fragmented and redistributed by biotic activity, and then a more intensive decomposition process take place due primarily to microbial activity (Steinberger et al., 1995; Berg and Laskowski, 2006; Ono et al., 2013). In fact, litter decomposition produces humic substances that contribute to soil fertility as well as long-term C storage in soil and is linked to nutrient cycling (Koehler and Tranvik, 2015). Research has indicated that nutrients released by litter decomposition make up 70–90% of the total nutrient requirement of plants (e.g., Waring and Schlesinger, 1985). Therefore, understanding litter decomposition is crucial to the study of carbon and nutrient cycling within the soil system of forest ecosystems in a context of global change.

In forest biomes, the litter layer is often amply colonized by fine roots (Jackson et al., 1996). Fine root decomposition also plays an important role in nutrient cycling by mineralizing and releasing nutrients for plant and microbial uptake (Jackson et al., 1997; Matamala et al., 2003; Roderstein et al., 2005). In such ecosystems, fine roots ($\leq$2 mm in diameter) are the most active part of belowground mass. While representing only a small fraction of total forest mass, they play a central role in regulating terrestrial biogeochemical cycles due to their short lifespan and high decomposition rate (Jackson et al., 1997; Schenk and Jackson, 2002). Forest ecosystems supply a substantial portion of the carbon fixed through photosynthesis to fine roots, which in turn are the primary pathway for nutrients and water uptake by plants (Matamala et al., 2003; Pregitzer, 2002). Field studies have indicated that up to 76% of annual total net primary production by forests may be allocated to fine roots (Gower et al., 1996), but fine root mass contributes relatively little to total forest mass, usually $<$5% (Vogt et al., 1996). Research has indicated that fine root production may contribute about one-third of global annual net primary production (Vogt et al., 1996; Jackson et al., 1997), indicating the primary role of fine root mass in soil nutrient stocks, fluxes, and sequestration (Gill and Jackson, 2000).

Consequently, plants' fine roots and litter are active components of belowground mass, and they play a significant role in ecosystem nutrient cycling (Roderstein et al., 2005). Although the importance of fine roots and litter is well recognized, estimates of their decomposition are still required. Fine root and litter decomposition studies are highly relevant in the context of improving our understanding of soil nutrient stocks, fluxes, and sequestration within forest ecosystems, especially in tropical mountain cloud forest.

Tropical mountain cloud forests comprise an important component of terrestrial ecosystems around the world, playing a crucial role in the global carbon and nutrient cycles (Gradstein et al., 2008; Bruijnzeel et al., 2010). Topography affects the soil environment: soil depth, soil formation processes, and nutrient status are key variables along steep slopes (Hook and Burke, 2000; Gerold, 2008). In Mexico, tropical mountain cloud forests constitutes $<$1% of the country but contains about 10% of its plant species, which grow preferentially or exclusively in this type of forest (Rzedowski, 1996; Williams-Linera, 2007). The role of tropical mountain cloud forest soil, on the eastern slope of the Cofre de Perote Volcano (Mexico), as both a carbon reservoir and source of CO_2, is a crucial aspect of the global carbon cycle (Campos et al., 2007; Campos, 2014). However, despite the importance of tropical mountain cloud forest, little is known about litter and fine root nutrient pools and their response to mineralization process in these regions. For this reason, we used litter and fine root mass from a tropical mountain cloud forest to estimate their relative contribution to nutrient content and to examine mineralization processes during a laboratory incubation experiment. Specifically, we hypothesize that: (1) the mass of litter and fine roots represents a valuable resource for nutrient availability in forest mountain cloud forest soil, (2) during the laboratory incubation period, the dynamics of N and C mineralization of fine roots and litter respond asymmetrically, mainly due to chemical composition, (3) litter and fine root mass density will depend on nutrient contents, creating different C and N dynamics at the regional scale. Our specific objectives were (1) to estimate mass density and nutrient pools in fine roots and litter, (2) to record C and N mineralization from litter and fine roots mass in a laboratory incubation experiment, and (3) to analyze the relationships between mass density and the nutrient pool of fine roots and litter.

2. Materials and methods

2.1. Description of research site

Litter and fine root materials used in the laboratory incubation experiment were collected from two small adjacent watersheds (Fig. 1) covered with tropical mountain cloud forest. Found in the middle section of the eastern side of the Cofre de Perote Volcano, they are located between 19°29′28.8″N, 97°02′23.9″W and 19°29′36.2″, 97°02′40.8″W; their size is approximately 25.0 and 25.6 ha, and the altitude ranges from 2169 to 2059 m above sea level, respectively. Each watershed includes a small perennial stream fed by baseflow. The arboreal species of this forest mainly consist of *Parathesis melanosticta* (Schltdl.) Hemsl., *Hedyosmum mexicanum* Cordem, *Alchornea latifolia* Sw., *Clethra mexicana* DC., *Quercus laurina* Humb. & Bonpl., *Quercus xalapensis* Humb. & Bonpl., and *Quercus corrugata* Hook (García-Franco et al., 2008). The climate is temperate humid with abundant rainfall during the summer (García, 1988). Total average annual rainfall at the research site is around 3200 mm, of which 80% generally falls during the wet season (May–October) (Holwerda et al., 2010; Muñoz-Villers and McDonnell, 2013). Fog is a typical phenomenon, especially between November and April, when it is present approximately 20% of the time (Holwerda et al., 2010). Mean monthly temperature at the research site ranges from 15.4 °C in the wet season to 13.4 °C in the dry season (Gotsch et al., 2014). January is the coldest month, while April and May are the hottest (Holwerda et al., 2010). Soils originate from volcanic ash, and classification according to Soil Taxonomy indicates that most are Acrudoxic Hydrudand, Alic Hapludand, and Lithic Haplofibrist (Soil Survey Staff, 2014). In terms of soil classification according to World Reference Base (WRB, 2014), most of these soils are Histic Hydric Andosol, Umbric Hydric Andosol (Thixotropic), and Leptic Folic Histosol.

2.2. Litter and fine root sampling

At each of the small watersheds, two typical slopes were chosen. The slopes have a gradient of 40°, 33°, 25°, and 20° and a length of 194, 235, 254, and 105 m, respectively. Their orientation is south, southwest, and southeast. The slopes were divided into three positions according to topography: shoulder, backslope, and footslope. At the center of each position, one transect perpendicular to the slope gradient was established for litter layer sampling. At each transect, four sub-samples, spaced 3 m from the main transect plane, were collected. A column of 20 cm × 20 cm × litter depth was removed using a plastic shovel, and each litter layer was placed in a plastic bag. Litter layers (O horizon) had a thickness ranging from 5 to 10 cm in depth (except at one site, which reached 20 cm) and were sampled in total (Oi, Oe, Oa). Typically on these sites, the litter layer was on top of an A horizon, under which was a Bw horizon. Litter layer collection was done carefully in order to avoid contamination with A horizon material.

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