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Effects of reduced precipitation on litter decomposition in an evergreen broad-leaved forest in western China

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ABSTRACT

Litter decomposition is a fundamental process of biogeochemical cycles and plays a critical role in regulating carbon (C) and nutrient mineralization in terrestrial ecosystems. Examining responses of litter decomposition to altered precipitation is crucial to understand terrestrial C dynamics and its feedback to climate change. To understand the effects of reduced precipitation on litter decomposition, a two-year throughfall reduction experiment was carried out in a natural evergreen broad-leaved forest in western China. Five throughfall reduction levels were investigated: control without throughfall reduction (Ctr), 5% (W1), 10% (W2), 20% (W3) and 50% throughfall reduction (W4). Throughfall reduction significantly reduced soil moisture, which was most pronounced in W3 and W4 treatments, and this was associated by significantly reduced cumulative litter mass loss and lower decomposition constants. Also, throughfall reduction significantly altered litter C, N and P dynamics. In particular in W2, W3 and W4 treatments the release of C and N was significantly reduced, whereas in W2 and W3 the immobilization of P was increased. Overall, the results suggest that future decrease in precipitation will suppress litter decomposition, whereas microbial P limitation in litter may be aggravated in broad-leaved forest ecosystems.

1. Introduction

In terrestrial ecosystems plant-litter input constitutes the main resource of matter and energy for a diverse community of soil biota. Litter decomposition is central to carbon (C) and nutrient cycling (Hättenschwiler et al., 2005; Mooshammer et al., 2012; Handa et al., 2014), and is tightly linked to key ecosystem attributes such as productivity and community structure (Aerts, 1997; Hättenschwiler et al., 2005; Cornwell et al., 2008). Litter decomposition is modulated by both biotic and abiotic factors including temperature and humidity (Couteaux et al., 1995; Gholz et al., 2000; Parton et al., 2007), as well as soil decomposer organisms (Hättenschwiler et al., 2005; Berg et al., 2010; Garcia-Palacios et al., 2016). Further, litter characteristics determine decomposition processes including nutrient concentrations as well as physical characteristics (Couteaux et al., 1995; Hättenschwiler et al., 2005; Garcia-Palacios et al., 2016).

Apart from changes in temperature, global climate change is associated with changes in precipitation (IPCC, 2014) which is predicted to change across the globe (Parmesan and Yohe, 2003; Shi et al., 2017). Depending on the region precipitation is predicted to increase or decrease. With the latter drought events are becoming more common and this will strongly impact ecosystems functioning (Hasibeder et al., 2015). Decreasing precipitation and associated drought can reduce primary productivity (Ciais et al., 2005) and induce tree mortality (Allen et al., 2010; Peng et al., 2011), thereby reducing the C-sink strength of forests (Ma et al., 2012; Zhao et al., 2016), or even impose regional forest decline or dieback (Allen et al., 2010; Carnicer et al., 2011; Rowland et al., 2015). However, the full range of changes associated with decreasing precipitation remain elusive (Lu et al., 2017). Decreasing precipitation is likely to impact litter decomposition and the mineralisation of nutrients thereby altering leaching losses (Couteaux et al., 1995) as well as the activity and composition of decomposer communities (Clein and Schimel, 1994; Salamanca et al., 2003; Xu et al., 2012). However, research on implications of reduced precipitation focused on ecosystem productivity, whereas the response of litter decomposition processes remains poorly studied (Santonja et al., 2015).

The rainy area of western China is a large ecotone, on the western edge of the Sichuan Basin ranging 50–70 km east to west and 400–450 km north to south, with an area of about 25,000 km^2 (Zhuang and Gao, 2002). Due to the effect of the East Asian Monsoon and Indian

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Monsoon and the rise in elevation, warm moist air from the Sichuan Basin is readily condensed into rain on the western edge of the basin resulting in abundant rainfall (Zhuang and Gao, 2002; Peng et al., 2017). Precipitation has been decreasing in most parts of the Sichuan Basin in the last 50 years (1961–2008), with a remarkable decrease in the western and central parts of the basin averaging about 40 mm every 10 years (Zhou et al., 2011). Moreover, Li et al. (2016) found that the annual precipitation of Ya'an city, located in the central area of the rainy area of western China, decreased markedly in the last 20 years (1991–2011) (Fig. S1). Knowledge on effects of decreasing precipitation on the structure and functioning of forest ecosystems, especially litter decomposition, is critical for predicting how ecological services in this region will change in future.

Effects of reduced precipitation on litter decomposition are best studied using manipulative throughfall reduction experiments (Rustad, 2008; Beier et al., 2012; Lu et al., 2017). Aiming at investigating effects of reduced precipitation/throughfall on litter decomposition of a natural evergreen broad-leaved forest, we performed a field throughfall reduction experiment in the rainy area of western China over a two-year period. We sheltered the forest floor area to impose 5–50% reduction of annual throughfall. Effects on litter mass loss, element dynamics [C, nitrogen (N), phosphorus (P)], and soil temperature and moisture were studied. We hypothesized that (1) throughfall reduction significantly decreases soil moisture, (2) as a consequence litter mass and C loss are reduced, and (3) mineralization of N and P from litter are retarded.

2. Materials and Methods

2.1. Study site

The study was carried out in a natural evergreen broad-leaved forest at Bi Feng Gorge Scenic Spot, Yucheng District, Ya'an City, Sichuan Province (102°59′E, 30°03′N, altitude 1170 m). The region is located in a subtropical moist forest zone experiencing a monsoon climate. Mean annual precipitation is about 1700 mm (average of 1961 to 2011) with approximately 60% falling from July to September. The mean annual air temperature is 16.2 °C with the average daily temperature ranging from 6.1 (January) to 25.4 °C (July). The soil is classified as a Lithic Dystrudepts (according to USDA Soil Taxonomy), derived from purple sandstone and shale, with a depth of more than 60 cm. The mean concentrations of total C, total N, nitrate N and ammonium N in soil (0–20 cm depth) were 17.17 ± 1.54 $g{\cdot}kg^{-1}$, 1.14 ± 0.13 $g{\cdot}kg^{-1}$, 9.45 ± 1.03 $mg{\cdot}kg^{-1}$ and 6.87 ± 0.56 $mg{\cdot}kg^{-1}$, respectively, and the pH value was 6.21 ± 0.13 (November 2013) (Zhou et al., 2017a, 2017b). The dominant tree species include *Schima superba*, *Lithocarpus hancei*, *Machilus pingii*, *Pittosporum tobira*, *Eurya japonica*, *Symplocos botryantha*, *Acer davidii*, *Lithocarpus megalophyllus, Acer sinense*, *Machilus lichuanensis*, *Camellia japonica*, *Cinnamomum cassia* and *Rhus succedanea*. There are few shrubs and herbs in the understory of the stands.

2.2. Experimental treatments

In October 2013, 15 plots (3 × 3 m) at intervals of 3 m were randomly established in a representative natural evergreen broad-leaved forest at the Bi Feng Gorge Scenic Spot. Five throughfall reduction levels were established: control (Ctr; without throughfall reduction), W1 (5% throughfall reduction), W2 (10% throughfall reduction), W3 (20% throughfall reduction), and W4 (50% throughfall reduction). Three replicates were established for each level. Throughfall was excluded by covering 5–50% of the plot area with roofs using different numbers of sheets (Fig. 1). A 4 × 4 m roof with a rain gutter, covered with 4 × 0.05 m translucent V-shaped PVC sheets mounted to wood frames were installed above each throughfall reduction plots (Borken et al., 2006a; Cleveland et al., 2010; Vogel et al., 2013; Liu et al., 2016; Chen et al., 2017). The numbers of sheets for W1, W2, W3, and W4 treatments were 3, 6, 12, and 30, for covering 5%, 10%, 20%, and 50% of the plot area (9 m^2), respectively. The sheets were evenly mounted to the roof. The roof was positioned at approximately 18° slope by setting the two sides at different heights (2.5 m above the ground for one side and 1.5 m for the other) to ensure quick drainage of ambient throughfall by gravity. Litter on the plastic sheets were swept onto the plots every 15 days.

In October 2013 freshly fallen leaves were collected in the broad-leaved forest and transported to the laboratory. The leaves comprised *Schima superba*, *Pittosporum tobira* and *Lithocarpus hancei* at a ratio of 5:2:2 resembling the ratio in the field. They were dried at room temperature, mixed evenly and 20.0 g was filled into nylon-mesh litter bags of 20 × 20 cm with 0.5 mm mesh size. Five litterbags were randomly selected, and dried to constant weight at 65 °C to determine water content and initial chemical composition. Concentrations of total C, total N, total P, total potassium, total calcium, total magnesium, lignin, and cellulose of the mixed litter were 430.73 ± 8.71, 8.32 ± 1.14, 0.42 ± 0.04, 13.25 ± 0.24, 2.45 ± 0.06, 1.36 ± 0.07, 157.10 ± 1.11 and 122.81 ± 8.71 $g{\cdot}kg^{-1}$, respectively (Zhou et al., 2017a, 2017b). In total, 540 litterbags (15 plots × 12 sampling time points × 3 bags per sampling time) were placed in the field on November 10, 2013; 36 litterbags were randomly distributed on each plot. Every two months, three bags were collected per plot, i.e., in mid-January, March, May, July, September, and November 2014 to 2015 (twelve times in total). After retrieval, the litter was removed from the litterbag, cleaned from soil and debris, and then oven dried at 65 °C until constant weight was reached. Then, the litter was weighed, milled (< 0.15 mm) and analysed for C, N and P concentrations.

From November 2013 to November 2015, soil temperatures at 10 cm soil depth were measured every month using a 10 cm thermocouple probe of Li-8100 automated soil CO_2 flux system (Li-COR, Inc., Lincoln, NE, USA) (Zhou et al., 2016). Volumetric soil moisture was measured simultaneously by using a time-domain reflectometer (mini Trase 6050X3K1, ICT, USA) with probes (0–10 cm depth) positioned vertically through the forest floor and mineral soil (Zhou et al., 2016).

2.3. Leaf-litter chemical analyses

Total C concentration in the litter was determined using the dichromate oxidation-ferrous sulfate titration method (Lu, 1999). Total N concentration was determined through acid digestion, using the Kjeldahl method (Grimshaw et al., 1989). Total P concentration was analyzed by molybdenum-antimony colorimetric method after the samples had been digested with H_2SO_4 (Anderson and Ingram, 1994). Concentrations were expressed per unit of oven dried sample (65 °C), all analyses were conducted in triplicate.

2.4. Data analysis

Litter decomposition was calculated as cumulative mass loss and by calculating the decomposition constant (k) based on the single exponential and the limit value on the asymptotic model (Berg, 2014, 2018). The decomposition constant (k, $year^{-1}$) was calculated as

$$k = -\frac{\ln(\frac{X_t}{X_0})}{t}$$

with X_0 the initial litter dry mass, X_t the dry mass at sampling time t (year) (Olson, 1963). As litter decomposition may ultimately approach zero and thus leave a recalcitrant or stabilized residue (Berg, 2014, 2018), decomposition may be described by a function which includes an asymptote or limit value (Wider and Lang, 1982; Berg and Ekbohm, 1991; Berg, 2014; Yue et al., 2016). It was calculated as

$$\frac{X_0 - X_t}{X_0} = m(1 - e^{-\frac{tk_{init}}{m}})$$