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Effects of nutrient additions on litter decomposition regulated by phosphorus-induced changes in litter chemistry in a subtropical forest, China

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ABSTRACT

Nutrient additions directly alter exogenous nutrient availability in soil, and then affect endogenous nutrient concentration in litter (i.e., litter chemistry), modifying litter decomposition. However, how nutrient-induced changes in litter chemistry interacting with altered soil nutrients affect litter decomposition remain unclear. In this study, three field experiments with reciprocal transplants using litter bags were conducted in a phosphorous (P) limiting subtropical forest with control, nitrogen addition (+N), P addition (+P), and +NP treatments to examine effects of exogenous and endogenous nutrient availability on litter decomposition. Our results showed that, in Experiment I, decomposition of litter collected from the control plots was significantly inhibited by 16% under both +P and +NP treatments and reversed to become net P accumulation from P release compared to that in the control. In Experiment II, since litter collected from +P and +NP plots had higher litter P, lower C/P and N/P, its decomposition was significantly faster in the control plots by 9% and 26%, respectively, with the faster release of N and P in the litter. The *in situ* Experiment III found that +P and +NP treatments reduced litter decomposition by 6% and 14%, respectively, but +N did not affect it compared to the control. Our results indicate that effects of P addition on litter decomposition were mediated by P-induced changes in litter chemistry, which need to be incorporated into land surface models for predicting effects of nutrient deposition on ecosystem C cycling and assessing the climate-biosphere feedbacks.

Main finding: Effects of nutrient additions on litter decomposition were regulated by P-induced changes in litter chemistry.

1. Introduction

Litter decomposition is critical for nutrients cycles in terrestrial ecosystems, which is an important process to return nutrients to soils (Attiwill and Adams, 1993). Nutrient availability is widely considered as a controlling factor for litter decomposition, especially at the early stages (Swift et al., 1979; Hobbie, 2005; van Huysen et al., 2013). During this period, immobilizations of nitrogen (N) and phosphorus (P) in litter had often been observed, suggesting the low nutrient availability relative to carbon (C) in litter for decomposers (Gosz et al., 1973; Staaf and Berg, 1981). Meanwhile, litter decomposition constants are often positively correlated with initial litter nutrient concentration but negatively with C/N or C/P (Aber and Melillo, 1991; Melillo et al., 1982).

Although it has been well documented that nutrient availability impacted litter decomposition, relative effects of endogenous (i.e., litter chemistry) and exogenous (e. g., fertilization) nutrient availability on litter decomposition are not well known (Prescott, 1995; Hobbie, 2005; Craine et al., 2007; van Huysen et al., 2016). Altered nutrient availability in litter may have different effects on litter decomposition compared to that from exogenous nutrient supply (Prescott, 1995; Hobbie and Vitousek, 2000) due to the difference of the inherent mechanisms (Hobbie, 2005; Craine et al., 2007; Cheever et al., 2013). Litter decomposition rates often positively correlated with endogenous nutrient availability within a specific

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plant or site (Prescott et al., 1992; Hobbie, 2005; Chen et al., 2015), while increased exogenous nutrient availability through N and P fertilization exhibited diverse responses with negative, positive or neutral effects on litter decomposition (Kozovits et al., 2007; Vivanco and Austin, 2011; Chen et al., 2013). A meta-analysis showed that the effect of exogenous N supply on litter decomposition was dependent on site-specific ambient N-deposition level and the amount of N fertilizers as well as soil background levels of nutrient availability (Knorr et al., 2005). Increased endogenous nutrients in litter are preferentially used by decomposers, but exogenous nutrient additions may lead to changes in soil pH and/or decomposer community (Chen et al., 2013; van Huysen et al., 2016), thereby affecting litter decomposition through depressed N or P mining (Craine et al., 2007; Weedon et al., 2009).

Human activity (e.g., fossil fuel burning, deforestation, and fertilizer consumption) had doubled reactive N deposition since the industrial and agricultural revolution (Galloway et al., 2008; Gruber and Galloway, 2008). Such N fertilization led to the direct increase in exogenous nutrient availability, which considerably affected litter decomposition (Fang et al., 2007). On the other hand, N addition can also alter litter chemistry through influencing foliar nutrient stoichiometry and resorption (Kozovits et al., 2007). Nutrient-induced changes in litter chemistry might enhance or alleviate effects of nutrient additions on litter decomposition (van Diepen et al., 2015; Zhang et al., 2016). For example, using the reciprocal litter transplant experiment, van Diepen et al. (2015) found that changes in litter quality induced by a 22-year N deposition reinforced the N-induced suppression of litter decomposition in a mixed hardwood forest. Zhang et al. (2016) found that changes in litter quality could mediate N effect on plant litter decomposition in a subtropical forest. However, how nutrient-induced changes in litter chemistry interacting with altered soil nutrients affect litter decomposition remain unclear (Hobbie and Vitousek, 2000; Finn et al., 2015; Zhang et al., 2016).

Previous studies mainly focused on responses of litter decomposition to N availability in N-limited systems (Aerts and de Caluwe, 1997; Vitousek, 1998; Vestgarden, 2001). However, effects of endogenous or exogenous P availability on litter decomposition in P-limited systems are rare (Hobbie and Vitousek, 2000; Chen et al., 2013; van Huysen et al., 2013). Actually, P availability plays a critical role in the nutrient cycles in terrestrial ecosystems (Kozovits et al., 2007; Chen et al., 2016; van Huysen et al., 2016). For example, Chen et al. (2016) indicated that the woody debris decomposition in their P-limited tropical forest was primarily constrained by P availability. Kozovits et al. (2007) found that litter decomposition rates at the first-year decay responded more strongly to the combined addition of N and P than to fertilization with N or P alone on a dystrophic soil. These results suggested that more attention should be paid on the importance of P availability, especially when P is the limiting resource in terrestrial ecosystems.

In this study, we conducted three field decomposition experiments in a P-limited subtropical forest as suggested by the foliar N/P of 18.77 (Yan et al., 2008). Experiment I was designed to examine direct effects of nutrient additions on litter decomposition by putting the litter collected from the unfertilized plots (control) in N addition (+N), P addition (+P) and +NP plots. Experiment II was to quantify effects of nutrient-induced changes in litter chemistry on its decomposition by putting litter collected from +N, +P and +NP plots in the control. Experiment III was to ascertain the combined effects of nutrient additions and nutrient-induced changes in litter chemistry on litter decomposition by *in situ* decomposition of plant litter under their respective plots. We hypothesized: (1) P addition would stimulate litter decomposition due to the additional P supply to satisfy the microbial P requirement in this P-limited forest; (2) nutrient-induced changes in litter chemistry would enforce the positive effect of P addition on litter decomposition.

2. Materials and methods

2.1. Study site

The study was conducted in Tiantong Forest Ecosystem Observation and Research Station (29°48′N, 121°47′E, 160 m.a.s.l.). This area is characterized by a subtropical monsoon climate, with a mean annual temperature of 16.2 °C and precipitation of 1374 mm. The stand was harvested in the 1960s and has undergone natural reforestation. The soil type is Acrisol, with a medium-heavy loam texture and an organic layer of roughly 5 cm thick (Song and Chen, 2007; Gao et al., 2014).

2.2. Fertilization treatments

Nutrient additions with four treatments (Control: 0 kg N ha^{-1} yr^{-1}; +N: 100 kg N ha^{-1} yr^{-1}, +P: 15 kg P ha^{-1} yr^{-1} and +NP: 100 kg N ha^{-1} yr^{-1} + 15 kg P ha^{-1} yr^{-1}) were conducted in twelve 20 m × 20 m plots in an evergreen broadleaved forest. Each treatment was replicated in triplicate and completely randomly designed. Each plot was enclosed with PVC board inserted into soil at 60 cm depths and separated by at least 10 m from each other. Details of vegetation and soil properties for each treatment are given in Table 1. Since January 2011, fertilizer (NH_4NO_3 or NaH_2PO_3 in 20 L of water) was applied monthly over the litter layer and continued to be applied throughout the whole period in this study. The control plots received 20 L of water to avoid the throughfall differences among different treatments.

2.3. Leaf litter decomposition experiment

The dominant species, *Schima superba*, in fertilization plots was chosen for leaf litter decomposition experiment. Our record showed that *S. superba* had the highest diameter at breast height and richness in the studied forest. Litter was collected in May 2012 (16 months after the first fertilizer application). Only fresh leaf litter on the top litter layer in each plot was collected. The collected litter was cleaned with wet cloth to remove the soil and other possible adhering fertilizer outside of the litter, and then pooled within treatments and air-dried for decomposition.

Experiment I: Litter collected from the control plots was put in +N, +P and +NP plots, respectively, to be decomposed. This experiment was conducted to examine direct effects of nutrient additions on litter decomposition.

Experiment II: Litter collected from the +N, +P and +NP plots was put in the control plots. This experiment was conducted to quantify effects of nutrient-induced changes in litter chemistry on its decomposition.

Experiment III: Litter collected from the control, +N, +P and +NP plots was put under their respective plots. This experiment was conducted to ascertain the combined effects of nutrient additions and nutrient-induced changes in litter chemistry on litter decomposition.

Five collected samples of each plot were oven-dried for 48 h at 65 °C to identify the coefficient between air-dried and oven-dried weight. Another five collected samples of each plot were oven-dried for 48 h at 80 °C to litter chemistry identification. Litter organic C was determined using the oil bath-K_2CrO_4 oxidation method (Nelson and Sommer, 1996). Litter N and P concentrations were determined colorimetrically on the Auto Chemical Analysis Meter (SCHMART, LTC.) after the micro-Kjeldahl digestion.