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Response of carbon and nitrogen release to simulated nitrogen deposition in natural evergreen broad-leaved forests in a rainy area in Western China

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ABSTRACT

Over the last several decades, human activities have increased the nitrogen input in terrestrial ecosystem, and the alteration of the N cycle has profoundly affected the cycles of many other elements, especially carbon (C). Litter decomposition is an important ecosystem process that plays a key role in the balance of global carbon and nitrogen cycles. To investigate the effects of simulated nitrogen (N) deposition on litter decomposition, a one-year field experiment on litter decomposition following N addition treatments was conducted in a natural evergreen broad-leaved forest in a rainy area of Western China. Beginning November 2013, we conducted a field experiment using the litterbag method that included four treatments: 0, 50, 150, and 300 kg N hm^{-2} a^{-1} as the control (CK), low (L), medium (M), and high (H) nitrogen deposition, respectively. Every 15 days, NH_4NO_3 was added to the N-treated plots. The results indicated that after one year of decomposition, the remaining rate in each treatment was between 54.71% and 63.52%, L, M, and H rates were 4.18%, 6.53%, and 8.81% higher, respectively than the CK. N deposition significantly increased the remaining rate and inhibited the decomposition of leaf litter in this ecosystem because of the addition of N. Greater increases in N strengthened the inhibition effect. N addition significantly increased the concentration of carbon and nitrogen in leaf litter. The decomposition coefficient of C and N were in the order k(CK) > k(L) > k(M) > k(H), although N was released faster. The time for 95% C decomposition of foliar litter increased by 0.92–2.20 a from 4.09 a ($T_{95\%}$ of CK) because of N addition, and that for N decomposition increased by 0.64–1.22 a from 3.73 a. After decomposing for 1 a, the C remaining rates for L, M, and H were 6.00%, 9.89%, and 14.11%, respectively, higher than CK, whereas the N remaining rate was 4.13%, 6.75% and 10.08%, respectively. Thus, nitrogen addition significantly increased the C and N remaining rates and significantly inhibited the release of carbon and nitrogen. The L, M, and H treatments increased the C/N ratio of the leaf litter by 3.33%, 5.40% and 6.38%, respectively, suggesting that the M and H treatments significantly increased the C/N ratio. Nitrogen treatments weakened the correlation between the mass remaining and C and N remaining, but strengthened the correlation between mass remaining and the C/N ratio. The correlation coefficient of mass remaining and C and N remaining was reduced by N deposition, whereas the C/N ratio was increased. Under simulated N deposition, C remaining was still a good indicator of litter decomposition relative to the N remaining and C/N ratio.

1. Introduction

In the terrestrial ecosystem, the carbon (C) and nitrogen (N) cycling is an important part for the global biogeochemical cycling [1]. Forests, covering 27% of the land surface of the earth and preserving 60% of the land C storage, are the important C stocks for the terrestrial ecosystem [2]. Litters, besides, are important parts for C and nutrient stocks of the plant ecological system [1], which plays an important role for the nutrient cycling and C flow of the terrestrial ecosystem [3] and is a key link for the global C balance [4–5].

In recent decades, the atmospheric CO_2 concentration increases; the atmospheric reactive nitrogen concentration increases rapidly; such concentrations of CO_2 and reactive nitrogen deposit to the terrestrial and aquatic ecosystems due to human activities such as the burning of fossil fuels, deforestation as well as the production and application of chemical fertilizers [6–7]. It is reported that, China has become one of the three major N deposition concentrated areas (Europe, America and China) globally [8]. And a series of ecological issues due to the excess N deposition has attracted a wide range of attention from domestic and foreign scholars [9–11]. With the Europe and North America N deposition projects in the early 1980s launched, international researches on the decomposition of N deposition to forest litters have been started accordingly [12]. And a series of great achievements have been achieved in aspects of the material cycle of litters, energy flow, information

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transfer, stability of plant community, etc. [13–14]. Researches on influences of the N deposition on the forest ecosystem, however, start relatively late in China. And most of such researches mainly focus on temperate forests [15] of N deficiency and tropical forests [16] of more significant N deposition. Although there are reports for response researches on the decomposition of litters in temperate forests for the atmospheric N deposition, however, relatively-few researches have been conducted for natural evergreen broadleaved forest [17].

The rainy area of west China is an ecotone of large scale and complexity and is the rare climate geographic units mainly featured by dankness in the western China [18]. The area has abundant rainfalls and makes pollutants with a large number of NO_x, etc. from the Chengdu Plain deposit with rainfalls due to its special topography and climate, which has increased the N deposition in the area [19]. Taking natural evergreen broadleaved forests of the area as objects and adopting the litter bag method, therefore, the research aims to study the influence of N deposition for the C and N release during the decomposition of litters in natural evergreen broadleaved forests by simulating the atmospheric N deposition and conducting the field in-situ decomposition test, so as to provide basic data for researching the nutrient cycling of ecosystem in natural evergreen broadleaved forests of the area with the continuous increase of N deposition and global climate change.

2. Materials and methods

2.1. Testing ground before

The research area is located in the Bi Feng Gorge Scenic Spot, Yucheng District, Ya'an City, Sichuan Province (102°90′E, 29°40′N), with the altitude of 977.62 m, ≥ 10 °C annual cumulative temperature of 5231 °C, annual mean temperature of 16.2 °C, the coldest month of January (average temperature: 6.1 °C) and the hottest month of July (average temperature: 25.4 °C). Besides, the area has the duration of day of 1039.6 h, annual total solar radiation amount of 3640.13 MJ/cm^2, average annual precipitation of 1772.2 mm and the annual evaporation of 1011.2 mm. The climate is mild and humid, belonging to the mountain climate of subtropical humid monsoon type. The experimental area has rich species and complex community structure. Major tree species include the *Schima superba*, *Lithocarpus hancei*, *Pittosporum tobira*, *Machilus pingii*, *Symplocos botryantha*, *Eurya japonica*, *Acer davidii*, *Lithocarpus megalophyllus*, *Rhus succedanea*, *Acer sinense*, *Machilus lichuanensis*, *Cinnamomum cassia*, and *Camellia japonica*. And the soil type is mainly the yellow soil with the soil thickness >60 cm and basically the same site conditions [20].

2.2. Experimental design

In October 2013, the representative natural evergreen broadleaved forests in the Bi Feng Gorge, Yucheng District, Ya'an City, Sichuan Province have been selected as the research objects; 12 quadrats of 3 m × 3 m are constructed in these research objects with a buffer strip of >3 m for each quadrat. In the rainy area of west China, the annual total N deposit is 95 kg N hm^{-2} a^{-1}, with the tendency of increase year by year [10]. Therefore, four N deposition levels are set for the test, i.e. levels of the control (CK, 0 kg N hm^{-2} a^{-1}), low-N deposition (L, 50 kg N hm^{-2} a^{-1}), medium-N deposition (M, 150 kg N hm^{-2} a^{-1}) and high-N deposition (H, 300 kg N $hm^{-2}a^{-1}$) with three repetitions for each level. Averagely divide the N application rate into 24 parts, and since November 10, 2013, conduct the simulated N deposition with NH_4NO_3 every 15 d. For the N application, besides, it is to dissolve NH_4NO_3 required by each quadrat into the water of 2 L; use the portable sprayer to evenly spray back and forth at the quadrat height of 50 cm for the forest; for the control quadrat, spray the water of 2 L so as to reduce the influence of external water on the biogeochemical cycling of forests.

In October 2013, collect litters of major trees (*Schima superba*, *Lithocarpus hancei* and *Pittosporum tobira*) in natural broadleaved forests and take such litters back to the laboratory for natural air-drying. Fully mix these litters during the air-drying to ensure the consistent composition and proportion of litters in the litter bag. Weigh 20.0 g of naturally air-dried litters and put them into the prepared nylon-mesh litter bag (with the size of 20 cm × 20 cm and pore size of upper and lower surface of 1 mm × 0.5 mm). Randomly select five bags of litter bags; dry them to the constant weight at 65 °C; determine the water content of litter sample and initial chemical properties (Table 1). In November 2013, evenly arrange litter bags prepared on soil surfaces of 12 quadrats (20 bags for each quadrat). Keep at least the distance of 2 cm among adjacent litters to avoid the mutual effect.

2.3. Sample collection

Collect the litters once every two months since the simulated N deposition, i.e. mid-January, March, May, July, September and November 2014, for six times in total. Randomly collect three bags of litter bags from each quadrat every time (take nine bags for each level). After litter bags are taken back, carefully remove earth, sundries and newly-growing root system. After taking them back to the laboratory and drying to the constant weight at °C; weigh them; calculate the loss of litter quality. Before treating quadrats in the latter part of each month, use the soil thermometer and time domain reflectometry (*miniTrase605OX3KI*, *CT*, *USA*) to measure the soil temperature of 0–10 cm and volumetric water content treated (Fig. 1).

2.4. Index measurement method

After drying and weighing littered took back, use the plant grinding machine (*universal high-speed grinding machine*, *FW-100*, *Beijing Ever Light Medical Equipment Co*., *Ltd*.) grind a part of litters in the litter bag and filter them with the screen of 1 mm; measure the element contents in these litters. Moreover, separately use the externally-heated potassium dichromate oxidation titration method (LY/T1237-1999) and indigo colorimetry (LY/T1271-1999) to measure contents of the organic carbon and total nitrogen. And repeat all chemical analyses for three times.

2.5. Data analysis

Mass remaining rate (MR) = (M_t / M_0) × 100%. Wherein, M_t is the mass (g) of litters at the time *t;* M_0 is the initial dry weight (g) of litters [21].

Element remaining rate (R) = ($C_t \times M_t$) / ($C_0 \times M_0$) × 100%. Wherein, C_t is the element content ($g \cdot kg^{-1}$) of litters at the time t and M_t is the mass (g) of litters at the time *t;* C_0 is the initial element content ($g \cdot kg^{-1}$) of litters and M_0 is the initial dry weight (g) of litters [21].

For the element release of litters, adopt the improved Olson negative-index attenuation model for fitting: $R = a \cdot e^{-kt}$. Wherein, R is the element remaining rate (%) and a is the fitting parameter and k is the annual decomposition coefficient ($kg \cdot kg^{-1} \cdot a^{-1}$); t is the time (a) [22].

Decomposition time: the calculation method for the required time of 95% element decomposition is that: $T_{95\%} = -\text{Ln}\,(1\text{–}0.95) / k$ [22].

Table 1
Initial element concentrations in the broad-leaflitter of the experimental site.

Lignin	Cellulose	Total C	Total N	Total P	Total K	Total Ca	Total Mg
/($g \cdot kg^{-1}$)	/($g \cdot kg^{-1}$)	/($g \cdot kg^{-1}$)	/($g \cdot kg^{-1}$)	/($g \cdot kg^{-1}$)	/($g \cdot kg^{-1}$)	/($g \cdot kg^{-1}$)	/($g \cdot kg^{-1}$)
157.10 ± 1.11	122.81 ± 2.12	430.73 ± 8.71	8.32 ± 1.14	0.42 ± 0.04	13.25 ± 0.24	2.45 ± 0.06	1.36 ± 0.07