Postprint: Responses of Litter Decomposition and Nutrient Release of Dominant Plants to Nitrogen Addition in the Typical Steppe of the Loess Plateau

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Abstract

Using the in situ litterbag method, we studied the response of nutrient release processes in litter of the dominant plants Stipa bungeana and Heteropappus altaicus in the typical steppe of the Loess Plateau to nitrogen addition, with an experimental period of 1 year. Six nitrogen addition levels were established, namely N0 (0), N1 (1.15 g N m ² yr ¹), N2 (2.3 g N m ² yr ¹), N3 (4.6 g N m ² yr ¹), N4 (9.2 g N m ² yr ¹), and N5 (13.8 g N m ² yr ¹), with urea ((NH) CO) as the nitrogen source. The results showed that: (1) Two years of nitrogen addition treatment significantly altered the initial chemical properties of Stipa bungeana and Heteropappus altaicus litter. With increasing nitrogen gradient, litter N (nitrogen) content gradually increased, lignin content first increased then decreased, C/N (carbon-to-nitrogen ratio) and lignin/N decreased, while C (carbon), P (phosphorus), and C/P (carbon-to-phosphorus ratio) showed no significant differences. (2) Nitrogen treatment had no significant effect on the decomposition rate of Stipa bungeana and Heteropappus altaicus litter. The C content of Stipa bungeana and Heteropappus altaicus litter showed an overall decreasing trend with decomposition time, while N and P contents generally showed an increasing trend, and differences in N content among treatments were significant throughout the decomposition process. (3) Nitrogen treatment had essentially no effect on the decomposition of C and P in Stipa bungeana and Heteropappus altaicus litter, with both elements exhibiting a release pattern. Nitrogen treatment had significant effects on the N residual rate of litter; the N residual rate of Stipa bungeana litter under N1-N3 (1.15–4.6 g/m^2) treatments was higher than other treatments and exhibited an enrichment pattern, whereas N in Heteropappus altaicus litter exhibited an enrichment-release pattern. In the typical steppe of the Loess Plateau with nutrient-poor soils, appropriate nitrogen input can promote nitrogen retention in the system.

Full Text

Preamble

Influence of Nitrogen Addition on Litter Decomposition and Nutrient Release of Dominant Plants in a Typical Steppe on the Loess Plateau

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Abstract

This study investigated the response of litter decomposition and nutrient release processes to nitrogen addition for two dominant species—*Stipa bungeana* and *Heteropappus altaicus*—in a typical steppe on the Loess Plateau using the in-situ litterbag method. The experiment comprised six nitrogen addition levels: N0 (0 g N m ^{2}), N1 (1.15 g N m ^{2}), N2 (2.3 g N m ^{2}), N3 (4.6 g N m ^{2}), N4 (9.2 g N m ^{2}), and N5 (13.8 g N m ^{2}), with urea as the nitrogen source. After two years of nitrogen treatment, the initial chemical properties of both litters were significantly altered: N content increased gradually with nitrogen gradient, while C/N and lignin/N ratios declined. Lignin content initially increased then decreased with rising nitrogen levels. However, nitrogen treatments showed no significant effect on the decomposition rates of either litter type after one year of in-situ decomposition. Our results indicated significant correlations between decomposition rates and N content and C/N ratio for *Stipa bungeana* litter. Carbon content decreased over time, whereas N and P contents increased during decomposition. Nitrogen treatments significantly influenced the N content of both litters throughout decomposition and affected the percentage of N remaining. After one year of decomposition, the percentage of N remaining in *Stipa bungeana* litter under N1-N3 treatments (1.15–4.6 g N m ^{2}) was higher than other treatments and showed an enrichment pattern, while *Heteropappus altaicus* litter exhibited N accumulation in early stages and release in later stages. Nitrogen treatments had no significant effects on C and P decomposition, with similar C and P release patterns observed in both litters. Therefore, increased nitrogen deposition could contribute to carbon accumulation in grassland ecosystems.

Keywords: nitrogen addition; steppe; litter; nutrient release; Loess Plateau

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1. Introduction

Since the Industrial Revolution, fossil fuel combustion and fertilizer application have increased nitrogen input to ecosystems by nearly 2- to 5-fold, with this trend continuing to rise globally. Most ecosystems are nitrogen-limited, so nitrogen deposition directly affects the nitrogen cycle in the biosphere and influences plant productivity and ecosystem carbon sequestration capacity, thereby altering ecosystem structure and function. Litter represents a crucial component of decomposer subsystems, linking producers and consumers. Litter dynamics play important roles in plant community structure and succession, ecological environment improvement, soil physicochemical properties, energy flow, and nutrient cycling.

Numerous studies have examined litter decomposition under simulated nitrogen deposition, but the effects of increased nitrogen deposition on plant litter decomposition remain inconsistent. Litter decomposition is an initial process in soil organic matter formation that affects soil respiration, and the nutrients released during decomposition critically regulate plant growth. Therefore, nitrogen deposition effects on decomposition processes will influence soil fertility and ecosystem primary productivity to some extent. Grassland ecosystems are among the most important and widely distributed terrestrial ecosystems, covering 46% of global terrestrial area and significantly impacting global carbon and nutrient cycling and balances. Due to their vulnerability and sensitivity to climate change, grasslands hold a unique position and importance in studies of elemental and energy cycles in terrestrial ecosystems.

While nitrogen deposition research has focused primarily on forest ecosystems in Europe and North America, how increased nitrogen deposition affects litter decomposition in grassland ecosystems remains unclear. This study examined two dominant species—*Stipa bungeana* and *Heteropappus altaicus*—in a typical steppe on the Loess Plateau where simulated nitrogen deposition had been implemented for two years. We investigated litter decomposition rates and element remaining patterns under nitrogen addition gradients to elucidate how nitrogen deposition affects litter decomposition processes in this region, providing a foundation for grassland ecosystem management and further nitrogen deposition research.

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2. Study Site Description

The study site was located in an enclosed grassland at the Lanzhou University Loess Plateau International Ground Climate and Environment Monitoring Station in Yuzhong County, Gansu Province. The region features a loess plateau landscape with residual tablelands, ridges, and gullies. It has a continental semi-arid climate with a mean annual temperature of 6.7°C, mean annual precipitation of 1965.8 mm, mean annual evaporation of 1343 mm, and approximately 2600 hours of sunshine annually. The frost-free period lasts 90–140 days. The soil type is sierozem. The vegetation type is a semi-arid steppe on the Loess Plateau, with dominant species including *Stipa bungeana*, *Heteropappus altaicus*, and *Leymus secalinus*. Species importance values are shown in .

3. Experimental Design

The experiment was established in a flat, topographically uniform area of enclosed grassland (4 m × 5 m) that had been fenced since 2005. A completely randomized block design was used with six nitrogen addition treatments: N0 (0 g N m ^{2}), N1 (1.15 g N m ^{2}), N2 (2.3 g N m ^{2}), N3 (4.6 g N m ^{2}), N4 (9.2 g N m ^{2}), and N5 (13.8 g N m ^{2}). Nitrogen treatments began in 2008. Urea ((NH) CO) was dissolved in water and applied uniformly to each plot during rainfall events to minimize nitrogen loss. The control plots received equal amounts of water without nitrogen.

To ensure experimental material consistency, standing dead material of *Stipa bungeana* and *Heteropappus altaicus* was collected at ground level from each treatment plot in 2010. The litter was air-dried at room temperature to constant weight, cut into 10 cm pieces, and placed in 10 cm × 10 cm nylon mesh bags with 0.5 mm mesh size. Ten grams of litter was placed in each bag. Litter produced under each nitrogen treatment was returned to its original treatment plot and secured with bamboo stakes. Five bags per species were collected from each plot at each sampling time (3, 6, 9, and 12 months). After retrieval, extraneous plant material and small animals were removed by hand. The litter was oven-dried at 65°C for 48 hours to obtain residual dry weight, then ground for chemical analysis.

4. Sample Analysis

Carbon (C) and nitrogen (N) contents were determined using an elemental analyzer (FlashEA1112, USA). Phosphorus (P) content was measured by microwave digestion followed by molybdenum blue colorimetry. Lignin content was analyzed using the detergent method.

5. Data Analysis

Litter dry mass remaining rate was calculated as: (M /M) × 100%, where M is initial dry weight and M is dry weight at time t. The Olson exponential decay model was used to simulate decomposition and calculate the decomposition coefficient (k): M /M = e , where k is the decomposition coefficient and t is decomposition time. Element remaining rate was calculated as: (C × M)/(C × M) × 100%, where C is initial element content and C is element content at time t.

Statistical analysis was performed using SPSS 16.0. One-way ANOVA was used to determine differences in litter traits among nitrogen treatments, with multiple comparisons made using the LSD method at $P < 0.05$ significance level.

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6. Results

6.1 Initial Chemical Properties of Litter

Nitrogen addition treatments significantly altered the initial chemical properties of both *Stipa bungeana* and *Heteropappus altaicus* litters. With increasing nitrogen gradient, N content increased gradually while C/N and lignin/N ratios declined. Lignin content showed a pattern of initial increase followed by decrease. No significant differences were observed in C content among treatments. *Stipa bungeana* litter had lower C/P and lignin content than *Heteropappus altaicus* litter. Initial chemical properties are shown in .

6.2 Effects of Nitrogen Addition on Dry Mass Remaining and Decomposition Rate

Dry mass remaining of both litters decreased gradually with decomposition time, with no significant differences between species [Figure 1: see original paper]. Annual decomposition constants (k) are shown in . The k value indicates decomposition rate, with larger values representing faster decomposition. *Heteropappus altaicus* litter decomposed faster than *Stipa bungeana* litter, with k values ranging from 0.31-0.38 and 0.57-0.68, respectively. No significant differences in k values were found among nitrogen treatments for either species. Both litters were well described by the Olson exponential equation.

Correlations between annual decomposition constants and initial chemical properties are shown in . The decomposition rate of *Stipa bungeana* litter was significantly positively correlated with initial N content ($P < 0.05$) and significantly negatively correlated with C/N ratio ($P < 0.05$). No significant correlations were found between decomposition rate and initial chemical composition of *Heteropappus altaicus* litter.

6.3 Effects of Nitrogen Addition on C, N, and P Content During Decomposition

For *Stipa bungeana* litter, C content decreased overall during decomposition, while N and P contents increased. Significant differences among treatments were observed throughout decomposition. N content showed a sharp decrease in the first 3 months, a slight increase from months 3-6, and a decrease again from months 9-12, with inconsistent changes among treatments in months 9-12 [Figure 2: see original paper].

For *Heteropappus altaicus* litter, C content showed a decreasing trend, while N and P contents increased. Significant differences among treatments were observed only during month 6 of decomposition [Figure 3: see original paper].

6.4 Effects of Nitrogen Addition on Element Remaining Rates

Nitrogen treatments significantly affected N remaining rates in *Stipa bungeana* litter ($P < 0.05$) but had no significant effect on C and P remaining rates. Litter under N1-N3 treatments showed higher N remaining rates than other treatments, exhibiting an enrichment pattern .

Nitrogen treatments had no significant effect on C and P remaining rates in *Heteropappus altaicus* litter. However, N remaining rates under N3-N5 treatments were significantly higher than the control ($P < 0.05$), showing enrichment during months 3-6 .

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7. Discussion

7.1 Response of Initial Litter Chemistry to Nitrogen Addition

Litter initial chemical composition responded differently to nitrogen addition. Our results showed that N content increased significantly with nitrogen gradient ($P < 0.05$), while lignin content initially increased then decreased. Previous studies have found that nitrogen can affect the activity of key enzymes in lignin synthesis. Appropriate nitrogen levels increase lignin content in wheat and rice stems, while excessive nitrogen reduces enzyme activity and lignin content. Major factors affecting litter decomposition include intrinsic factors (physical and chemical properties of litter) and extrinsic factors (external environment of decomposition, including decomposer microorganisms, soil physicochemical properties, and hydrothermal conditions).

7.2 Effects of Nitrogen Treatment on Litter Decomposition

Although nitrogen treatment increased initial N content and altered C/N ratios and lignin content, it only significantly correlated with decomposition rate for *Stipa bungeana* litter, not for *Heteropappus altaicus*. This suggests that relationships between decomposition rate and initial chemistry vary by litter type, and changes in extrinsic factors from nitrogen treatment may alter decomposition patterns.

Our one-year simulated nitrogen deposition experiment on the Loess Plateau steppe showed that nitrogen treatments had no significant effect on decomposition rates of either litter type, though they significantly affected N content and release patterns. Studies on forest and grassland ecosystems have reported inconsistent effects of nitrogen addition on microbial activity, with some showing promotion and others showing inhibition. These discrepancies may result from differences in microbial community composition and enzyme system responses to nitrogen addition.

Nitrogen treatments significantly increased N remaining rates in *Stipa bungeana* litter under N1-N3 treatments. Some researchers suggest that accumulated N in litter is essential for decomposer microorganisms. During substrate degradation, each unit of carbon released requires fixation of additional nitrogen, resulting in continuous nitrogen demand until easily decomposable carbon is fully degraded. Although nutrient immobilization temporarily disrupts mineralization, it provides an important mechanism for nutrient retention in low-nutrient or degraded ecosystems. *Stipa bungeana* is the dominant species in Loess Plateau steppe with an importance value of 0.401, comprising over 40% of total biomass. Therefore, low-concentration nitrogen deposition can increase nitrogen retention in this ecosystem.

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8. Conclusion

Our one-year litter decomposition experiment demonstrated that nitrogen addition had no significant effect on decomposition rates of *Stipa bungeana* and *Heteropappus altaicus* litters. Carbon content decreased over time, while N and P contents increased, with significant differences among treatments throughout decomposition. Nitrogen addition had minimal effect on C and P decomposition, with both elements showing release patterns. However, nitrogen treatments significantly affected N remaining rates in *Stipa bungeana* litter, with N1-N3 treatments showing higher remaining rates than other treatments and exhibiting enrichment patterns.

In the nutrient-poor Loess Plateau steppe, appropriate nitrogen input can promote ecosystem nitrogen retention. However, nitrogen deposition effects on grassland ecosystems are long-term processes. This experiment only analyzed one year of data on litter decomposition responses to nitrogen deposition. Long-term monitoring is needed to fully understand nitrogen deposition effects on litter decomposition in the Loess Plateau steppe.

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Note: Figure translations are in progress. See original paper for figures.