Decomposition Characteristics of Leaf Litter from Two Desert Plant Species Under Natural Light and Shaded Conditions (Postprint)

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Date: 2023-07-19T00:00:00+00:00

Abstract

The southern margin of the Taklamakan Desert is characterized by harsh environmental conditions, deficient soil nutrient content, and relatively simple plant community structure and composition, wherein the influences of various environmental factors on litter decomposition exhibit both complexity and specificity. To investigate litter decomposition characteristics in extremely arid regions, leaf litter of the dominant plant species Alhagi sparsifolia and Karelinia caspia at the southern margin of the Taklamakan Desert was examined using the litterbag method, focusing on mass decomposition and the release characteristics of carbon (C) and nitrogen (N) element content under natural sunlight and shading treatments. The results demonstrated: (1) The mass loss process of leaf litter for both species conformed to an exponential decay model. (2) Following 9 months of decomposition, mass loss rates of Alhagi sparsifolia and Karelinia caspia litter under natural sunlight were 39.81% and 45.43%, respectively; under shading treatment, the corresponding rates were 22.22% and 20.06%, with decomposition rates under light conditions being significantly higher than under shading conditions ($P<0.05$). (3) Throughout the decomposition process, C content in leaf litter of both species exhibited a release pattern, whereas N content displayed distinct patterns: Alhagi sparsifolia leaf litter N content showed an enrichment-release-enrichment pattern, while Karelinia caspia leaf litter N content showed continuous enrichment. In summary, in extremely arid regions, light radiation constitutes the primary driving factor of litter decomposition.

Full Text

Decomposition Characteristics of Leaf Litter from Two Desert Plants under Natural Light and Shade Conditions

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Abstract

The southern edge of the Taklimakan Desert is characterized by harsh environmental conditions, deficient soil nutrient content, and relatively simple plant community structure and composition. The influence of various environmental factors on litter decomposition exhibits both complexity and specificity. To investigate litter decomposition characteristics in extremely arid regions, we conducted a study using the litterbag method to examine leaf litter from two dominant desert plant species—*Alhagi sparsifolia* and *Karelinia caspia*. We analyzed mass loss and carbon (C) and nitrogen (N) release patterns under natural light and shade treatments. The results demonstrated that: (1) The mass loss process for both plant litters followed an exponential decay model. (2) After nine months of decomposition, mass loss rates were 39.81% and 45.43% under natural light, and 22.22% and 20.06% under shade treatment for *A. sparsifolia* and *K. caspia*, respectively. Decomposition rates were significantly faster under light conditions compared to shade ($P < 0.05$). (3) Throughout the decomposition process, C content in both litters showed a release pattern, whereas N content exhibited different release dynamics—*A. sparsifolia* showed an enrichment-release-enrichment pattern, while *K. caspia* displayed consistent enrichment. In conclusion, light radiation represents the primary driving factor affecting litter decomposition in extremely arid regions.

Keywords: extreme drought; mass loss; litter decomposition; photodegradation; nutrient release

1. Materials and Methods

1.1 Study Area Overview

The study was conducted in the desert-oasis ecotone at the periphery of the Qira Oasis in the Hotan region (35.30°–39.50°N, 80.06°–82.18°E). The experimental area experiences a typical continental arid climate with sparse natural vegetation. Summers are extremely hot, with an average annual temperature of 11.9°C, maximum temperature of 41.9°C, and minimum temperature of -23.9°C. The region receives abundant sunshine, with an average annual sunshine duration of 2,697.5 hours. Precipitation is concentrated in summer, with an average annual rainfall of only 35.1 mm, while annual evaporation reaches 2,600 mm. The soil is primarily aeolian sandy soil with poor water retention capacity and severe desertification, with average organic matter content of approximately 3.5 $g \cdot kg^{-1}$ and total nitrogen content of about 0.15 $g \cdot kg^{-1}$. Dominant vegetation includes *Alhagi sparsifolia*, *Calligonum mongolicum*, and *Karelinia caspia*, with low vegetation coverage.

1.2 Litter Collection and Experimental Design

During autumn 2021, 50 cm × 50 cm litter collection baskets were placed beneath the canopies of *K. caspia* and *A. sparsifolia* plants. After collection, impurities other than leaf litter were removed and the samples were thoroughly mixed. The screened litter samples were oven-dried at 65°C to constant weight. Random samples were selected from the dried material to determine initial chemical composition (Table 1). The two species showed significant differences in initial chemical composition: *A. sparsifolia* (a legume) had higher initial C content and cellulose content than *K. caspia* (an asterid), while *K. caspia* had significantly higher initial N, hemicellulose, and lignin contents ($P < 0.05$). Cellulose was the dominant component in both litters.

The decomposition experiment employed the litterbag method using 15 cm × 15 cm nylon mesh bags with 0.5 mm mesh size. Each bag was filled with 10 g of leaf litter and labeled. In March 2022, litterbags containing both plant species were placed on the soil surface under two decomposition conditions: natural light and shade (simulated using shade nets, replaced every two months to prevent aging). For each litter type, 24 bags served as one sampling unit within a 2 m × 2 m plot. A total of 96 bags were deployed per species, placed flat on the ground without overlapping, and secured with ground pegs to prevent wind displacement. Sampling occurred monthly from March to December 2022 (mid-month). Surface soil was removed from collected litter, which was then oven-dried to constant weight and weighed. All samples were analyzed for various indicators after the experiment concluded.

1.3 Index Measurement and Calculation Methods

Total carbon (C) and nitrogen (N) contents in initial litter samples were measured using a total carbon analyzer (Vario micro, Germany) and a Kjeltec-8400 automatic azotometer, respectively. Cellulose, hemicellulose, and lignin contents were determined using a Fibertec 2010 cellulose analyzer (USA), and organic matter content was measured using a muffle furnace.

Litter mass residual rate (M) and nutrient element residual rate (N_c) were calculated using the following formulas:

$$M_r = \frac{M_t}{M_0} \times 100\%$$

$$N_c = \frac{N_t \times M_t}{N_0 \times M_0} \times 100\%$$

where M_0 is the initial dry weight of litter (g), M is the litter mass at decomposition time t (g), N_0 is the initial nutrient element content ($g \cdot kg^{-1}$), and N is the nutrient element content at time t ($g \cdot kg^{-1}$).

A modified Olson exponential model was used to calculate decomposition rate (k) and predict decomposition time:

$$y = a \times e^{-kt}$$

where y is the litter mass residual rate (%), t is decomposition time (years), a is a correction coefficient, and k is the decomposition rate (a^{-1}). The time required for 50% and 95% decomposition was calculated as $T_{50}\%$ = -ln(1 - 0.50)/k and $T_{95}\%$ = -ln(1 - 0.95)/k, respectively.

1.4 Data Processing

Data were organized and calculated using Excel 2019. One-way ANOVA was used to analyze significant differences in litter mass residual rates and nutrient content dynamics under different light treatments. Multi-way ANOVA compared mass residual rate changes between litter types and light treatments. Origin 2022 was used for plotting, with data presented as means ± standard error.

2. Results and Analysis

2.1 Changes in Litter Mass Residual Rate under Different Light Treatments

Both plant species showed similar decomposition trends under natural light and shade conditions (Fig. 1). Throughout the decomposition process, mass loss in both *A. sparsifolia* and *K. caspia* was consistently faster under natural light than under shade. Mass loss was rapid initially, then gradually slowed. After nine months, residual masses were 60.19% and 77.78% for *A. sparsifolia*, and 54.57% and 79.94% for *K. caspia*, under natural light and shade, respectively.

For *A. sparsifolia*, mass residual rates showed no significant difference between treatments in the first four months, but differed significantly thereafter ($P < 0.05$). For *K. caspia*, mass residual rates differed significantly throughout the entire decomposition period ($P < 0.05$). Both species decomposed significantly faster under natural light, indicating that light accelerated decomposition.

2.2 Statistical Analysis of Litter Decomposition Characteristics and Influencing Factors

As shown in Table 2, decomposition rates under natural light exceeded those under shade for both species. Under natural light, *A. sparsifolia* and *K. caspia* had half-decomposition times of 0.94 and 0.85 years, respectively, with *K. caspia* decomposing faster. Under shade, half-decomposition times were 2.23 and 2.54 years, respectively. Multi-way ANOVA revealed extremely significant differences in mass residual rates between species ($P < 0.01$), with rates decreasing significantly over time ($P < 0.01$). The interaction between species and light treatment had an extremely significant effect on mass residual rate ($P < 0.01$), while the three-way interaction was not significant (Table 3). Overall, both litters decomposed fastest under natural light.

2.3 Dynamic Changes in Nutrient Content during Decomposition

Throughout decomposition, C and N content changes showed similar trends between species (Fig. 2). Carbon content exhibited direct release under both light conditions, with final losses of 35.62% and 19.52% for *A. sparsifolia*, and 35.05% and 12.34% for *K. caspia*, under natural light and shade, respectively. Nitrogen content in *A. sparsifolia* showed an enrichment-release-enrichment fluctuation, while *K. caspia* showed consistent enrichment. Final N content increased by 11.26% and 0.42% for *A. sparsifolia*, and by 24.29% and 58.44% for *K. caspia*, under natural light and shade, respectively. Statistical analysis showed significant differences in C content between light treatments for both species ($P < 0.05$), while N content differences were significant only for *A. sparsifolia*.

3. Discussion

3.1 Effects of Light on Litter Decomposition

Litter decomposition is a prolonged process with distinct temporal dynamics. Decomposition rates are typically rapid initially and gradually plateau in later stages. Our findings align with Fan et al.'s research on *K. caspia* and *Populus euphratica* litter decomposition in extremely arid regions. Early-stage decomposition is primarily governed by abiotic factors (physical fragmentation, leaching), with water-soluble compounds decomposing first. As recalcitrant compounds like lignin accumulate, decomposition slows and becomes dominated by biological factors. Studies in arid and semi-arid grasslands show that sunlight-exposed litter generally decomposes faster. Austin and Vivanco found that litter decomposition rates were 35–40% higher under light conditions compared to darkness.

Similarly, our results demonstrate significantly faster decomposition under natural light than shade ($P < 0.05$), with regression analysis showing that shade treatment markedly extended the time required for 50% mass loss. Photodegradation thus plays a crucial role in driving litter decomposition in extremely arid regions.

3.2 Response of Litter Substrate Composition to Light Conditions

Litter substrate composition, particularly C:N ratio, lignin, and cellulose content, is a primary determinant of decomposition rates and can effectively predict decomposition dynamics. Generally, lower N content and higher C:N ratios correspond to slower decomposition, whereas higher N content promotes microbial activity and accelerates decomposition. In our study, *K. caspia* had significantly lower initial N content and higher C:N ratio than *A. sparsifolia*. However, under natural light, *K. caspia* showed greater mass loss, possibly because lignin—highly susceptible to UV degradation—was more abundant in *K. caspia*. Photodegradation preferentially degrades lignin, which absorbs light and enhances mass loss. Under shade, where microbial activity dominates, *A. sparsifolia*'s lower C:N ratio likely stimulated microbial populations, resulting in greater mass loss than *K. caspia*. This suggests that in extremely arid regions with prolonged sun exposure, lignin content may exert stronger influence on mass loss than C:N ratio, warranting further investigation.

3.3 Changes in Nutrient Content under Different Light Conditions

Nutrient release from litter follows three patterns: leaching-release, enrichment-release, and direct-release. Carbon and nitrogen are primary organic components whose release rates affect global ecosystem carbon balance. Nitrogen is not always released during decomposition; its dynamics depend on litter characteristics, environment, and decomposition stage. In our study, both litters showed direct C release under natural light, consistent with Berenstecher et al.'s findings that photodegradation accelerates C loss in dry woodlands. Under shade, both species showed a decline-rise pattern in C content, likely due to initial rapid mass loss via leaching followed by enrichment as leaching diminished. This indicates that photodegradation may be a major contributor to carbon turnover in terrestrial ecosystems, including temperate forests.

Nitrogen dynamics differed between species. *Alhagi sparsifolia* showed enrichment-release-enrichment patterns, while *K. caspia* consistently enriched N. Net N immobilization and release are related to initial N content; when initial N is insufficient for microbial demands, microbes absorb N from the environment, causing enrichment. In photodegradation-dominated systems with low microbial activity, N dynamics may be less influenced by microorganisms. However, the specific causes of N immobilization in extremely arid regions—with their low vegetation cover, simple community structure, intense solar radiation, and low humidity—require deeper investigation.

4. Conclusion

1) Shade treatment resulted in significantly higher mass residual rates for both *A. sparsifolia* and *K. caspia* litter compared to natural light, with faster decomposition occurring under light conditions.

2) Under different light treatments, both litters showed similar trends in C:N ratio dynamics, but N content exhibited distinct release patterns. *Alhagi sparsifolia* litter N showed enrichment-release-enrichment, while *Karelinia caspia* litter N consistently enriched.

3) Natural light created significant differences in mass loss between the two species throughout decomposition, demonstrating that light accelerates decomposition. Therefore, light radiation is the primary factor influencing litter decomposition in extremely arid regions.

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