Effects of Meteorological Factors on Litter Decomposition of Stipa purpurea-Endophyte Symbionts in Alpine Grasslands: Postprint

Authors: Guo Qiang, Wang Yuqin, Song Meiling(2)

Date: 2025-07-14T00:00:00+00:00

Abstract

Litter decomposition plays an important role in carbon and nutrient cycling in terrestrial ecosystems, and climatic conditions are the primary factors determining litter decomposition. Currently, research on litter decomposition in alpine grassland ecosystems is insufficient. To investigate the effects of meteorological factors on the decomposition and nutrient release processes of Stipa purpurea litter under climate change scenarios, this study used alpine grassland S. purpurea plants symbiotic with endophytic fungi as research subjects, employing the litterbag method to analyze the decomposition characteristics and changes in litter components between endophyte-infected (E+) and endophyte-free (E-) S. purpurea litter, and to explore the influence of meteorological factors on litter decomposition in the S. purpurea-endophyte symbiosis. The results showed that the decomposition rate of E+ S. purpurea litter was higher than that of E-, with a shorter decomposition period; with increasing time, the total nitrogen content of both E+ and E- S. purpurea litter showed an upward trend, lignin content changed from being significantly higher in E+ than in E- to showing no significant difference between the two, while cellulose content gradually became significantly lower in E+ than in E- ($P<0.05$). Regardless of E+ or E-, the weight and mass loss rate of S. purpurea litter showed significant correlations with monthly mean air temperature and monthly mean ground temperature ($P<0.05$); the decomposition rate of S. purpurea litter was positively correlated with precipitation, and the total nitrogen content of S. purpurea litter was significantly positively correlated with monthly mean air temperature, monthly mean ground temperature, and precipitation ($P<0.05$); lignin and cellulose contents were negatively correlated with monthly mean air temperature, monthly mean ground temperature, and precipitation. Sunshine duration had a substantial influence on S. purpurea litter decomposition, with lignin, cellulose, and litter weight showing strong correlations with sunshine duration during the decomposition process. Overall, endophytic fungi can accelerate the decomposition

process of S. purpurea litter, and meteorological factors had essentially consistent effects on S. purpurea litter decomposition regardless of whether it was E+ or E-.

Full Text

Effects of Meteorological Factors on Litter Decomposition of the Endophytic Fungal Symbiont *Stipa purpurea* in Alpine Grassland

GUO Qiang[1], **WANG Yuqin**[2], **SONG Meiling**[2]
[1]Xinghai County Meteorological Bureau, Xinghai 813300, Qinghai, China
[2]Academy of Animal and Veterinary Science, Qinghai University, Xining 810016, Qinghai, China

Abstract

Litter decomposition plays a crucial role in carbon and nutrient cycling within terrestrial ecosystems, with climate conditions serving as the primary determinant of decomposition rates. However, research on litter decomposition in alpine grassland ecosystems remains limited. To investigate how meteorological factors influence the decomposition and nutrient release processes of *Stipa purpurea* litter under climate change scenarios, this study examined the endophytic fungal symbiont of *S. purpurea* in alpine grasslands using the litterbag method. We analyzed decomposition characteristics and litter component dynamics in *S. purpurea* with endophytic fungi (E^+) and without endophytic fungi (E^-), and explored the effects of meteorological factors on litter decomposition of the *S. purpurea* endophytic fungal symbiont.

The results demonstrated that E^+ *S. purpurea* litter exhibited a higher decomposition rate and shorter decomposition cycle compared to E^- litter. Over time, the total nitrogen content of *S. purpurea* litter showed an increasing trend, lignin content transitioned from being significantly higher in E^+ to showing no significant difference between treatments, and cellulose content shifted from being significantly lower in E^+ to no significant difference ($P < 0.05$). Regardless of endophytic fungal status, litter weight and mass loss rate were significantly correlated with monthly mean temperature and monthly mean ground temperature ($P < 0.05$). The decomposition rate of *S. purpurea* litter was positively correlated with precipitation, while total nitrogen content showed significant positive correlations with monthly mean temperature, monthly mean ground temperature, and precipitation ($P < 0.05$). Lignin and cellulose contents were negatively correlated with temperature and precipitation. Sunshine duration substantially influenced *S. purpurea* litter decomposition, with lignin, cellulose, and litter weight showing strong correlations with sunshine hours during the decomposition process. Overall, endophytic fungi accelerated the decomposition of *S. purpurea* litter, and meteorological factors affected both E^+ and E^- litter decomposition consistently.

Keywords: *Stipa purpurea*; endophytic fungi; litter decomposition; meteorological factors; alpine grassland

Introduction

Litter constitutes a vital component of grassland ecosystems, connecting producers, decomposers, and consumers through ecological processes such as material cycling, energy flow, and information transfer. Litter also regulates surface microenvironments by forming buffer interfaces. As the core stage of organic matter degradation, litter decomposition represents a critical process for mineral nutrient turnover and cycling in ecosystems. This process enhances soil nutrient input by releasing nutrients such as nitrogen (N), phosphorus (P), and potassium (K), thereby increasing plant-available nutrients and promoting productivity. Decomposition rates result from the combined influence of intrinsic factors —including litter quality parameters such as total nitrogen, lignin, and cellulose contents—and extrinsic factors such as soil microorganisms, soil fauna, and climatic conditions. At global and regional scales, climate factors like temperature and precipitation primarily govern litter decomposition, while at smaller spatial scales or under stable climatic conditions, litter chemical composition and soil organisms become more influential.

Recent research on climate factors and litter decomposition has revealed that decomposition depends not only on plant biological characteristics but also on local climatic conditions. For instance, elevation effects on litter decomposition may be driven by temperature changes, seasonal litter quantity variations may relate to precipitation patterns, and decomposition rates can correlate positively with ultraviolet radiation. Moreover, different litter components exhibit heterogeneous sensitivity to meteorological factors, resulting in differential impacts on various litter constituents. Currently, most litter decomposition research focuses on forest ecosystems, while the unique environmental conditions of alpine grasslands—characterized by high altitude, intense radiation, and aridity—suggest that climate may play a particularly important role in decomposition and nutrient cycling processes. Therefore, analyzing meteorological factor effects on alpine grassland litter decomposition is essential for understanding how future climate change will influence litter dynamics in these ecosystems.

Stipa purpurea, a cold- and drought-resistant species, represents the most widely distributed and characteristic community type in alpine grasslands of the Qinghai-Tibet Plateau. This species plays crucial roles in wind erosion prevention, sand fixation, water conservation, and maintaining environmental stability, while providing essential material foundations for grassland animal husbandry. Recent research on *S. purpurea* has primarily focused on community structure, grazing responses, soil nutrients, and microorganisms, with few studies addressing how meteorological factors affect its litter decomposition. Notably, *S. purpurea* exhibits significant endophytic fungal symbiosis, and endophytes can influence litter decomposition by altering host plant metabolism, while climate factors also regulate decomposition processes. To investigate the roles of meteorological factors and endophytic fungi in *S. purpurea* litter decomposition and identify key meteorological drivers, this study examined the endophytic fungal symbiont of *S. purpurea*. By analyzing decomposition characteristics and chemical component dynamics, we explored meteorological factor effects on the *S. purpurea* endophytic fungal symbiont, providing theoretical insights into how climate influences material cycling in alpine grassland ecosystems.

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1. Materials and Methods

1.1 Litter Collection

Following the methods of Li et al. [20], we detected endophytic fungi in *S. purpurea* inflorescences collected from the field and harvested endophyte-infected seeds. Using high-temperature and high-humidity treatment, we removed endophytes from some seeds to obtain endophyte-free *S. purpurea* seeds. Both endophyte-infected (E^+) and endophyte-free (E^-) seeds were planted in sterilized soil in pots and grown naturally in a greenhouse. To prevent re-infection, pots were spaced at intervals greater than 50 cm. During the late growth stage, we collected aboveground senescent tissues, which were air-dried as litter for the experiment.

1.2 Experimental Design

The experimental site was located in Guinan County, Qinghai Province (35°34 11 N, 100°46 51 E, 3107 m elevation), representing a typical alpine meadow region. Senescent tissues from E^+ and E^- *S. purpurea* plants were cut into 5–10 cm segments. Litter (5.00 g) was placed in 10 cm × 10 cm nylon mesh bags with 0.50 mm mesh size. In mid-September, litterbags were randomly placed at the experimental site after clearing aboveground vegetation to ensure direct contact with soil. Bags were secured with nails, spaced >10 cm apart. At 0, 3, 6, 9, and 12 months after placement, litterbags were randomly collected (five bags per treatment each time), air-dried, and analyzed for litter weight, total nitrogen, lignin, and cellulose contents [21].

1.3 Index Measurement and Calculation

All collected samples were analyzed for total nitrogen, lignin, and cellulose contents. Total nitrogen was determined using an automatic Kjeldahl nitrogen analyzer [22], while lignin and cellulose were measured by the acid detergent fiber method [23]. Meteorological data were obtained from the Guinan National Basic Meteorological Station in Hainan Tibetan Autonomous Prefecture, Qinghai Province (35°35 12 N, 100°44 24 E, 3107 m elevation).

Litter mass loss rate (Mc) was calculated as follows [24]:

$$Mc = \frac{W_0 - W_t}{W_0} \times 100\%$$

where W_0 is the initial litter weight and W_t is the weight at time t.

A modified Olson exponential model was used to calculate decomposition rate (k) [25]:

$$W_t = W_0 \times e^{-kt}$$

The time required for 50% and 95% decomposition was estimated as:

$$T_{50\%} = \frac{-\ln(1 - 0.50)}{k} = \frac{0.693}{k}$$

$$T_{95\%} = \frac{-\ln(1 - 0.95)}{k} = \frac{2.996}{k}$$

1.4 Data Analysis

Data were organized and plotted using Microsoft Excel. SPSS 27.0 software was used for one-way ANOVA to analyze temporal changes in litter indices, independent samples t-tests to examine differences in litter weight, total nitrogen, lignin, and cellulose contents between E^+ and E^- treatments, and Pearson correlation analysis to assess relationships between decomposition characteristics and meteorological factors. Significance was defined as $P < 0.05$. Additionally, redundancy analysis (RDA) was performed to examine relationships between environmental variables (meteorological factors) and *S. purpurea* litter decomposition characteristics.

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2. Results

2.1 Litter Decomposition Characteristics of *S. purpurea*

Changes in litter weight and decomposition rate are shown in [Figure 1: see original paper]. Over time, litter weight decreased substantially in both E^+ and E^- treatments. After March, the weight loss rate began to slow. Litter weight in E^+ was significantly lower than in E^- after 6 months ($P < 0.05$). Mass loss rate increased with decomposition time, being rapid before December and slower thereafter. The mass loss rate of E^+ litter was significantly higher than that of E^- ($P < 0.05$). Fitting exponential regression equations revealed good fit ($R^2 > 0.80$) for both treatments (Table 1). Decomposition rates were higher in E^+ ($k = 1.1024$) than in E^- ($k = 1.09698$), with estimated half-decomposition times of 0.80 years and 1.05 years, and 95% decomposition times of 3.45 years and 4.54 years, respectively.

[Figure 1: see original paper] Change of litter weight and decomposition rate of *Stipa purpurea* with time

2.2 Litter Composition Analysis

Total nitrogen content in *S. purpurea* litter increased gradually over time (Figure 2). Initially, total nitrogen was higher in E^+ than in E^-, with the 12-month nitrogen content being 1.5 times the initial value. Lignin content showed an overall decreasing trend, being significantly higher in E^+ than in E^- at 3 months ($P < 0.05$), with no significant difference at 0 months. After 6 months, lignin content stabilized with minimal change. Cellulose content showed an initial increase followed by a decrease, being significantly higher in E^+ than in E^- at 3 months ($P < 0.05$) with a slight increasing trend, then decreasing significantly over time. After 12 months, cellulose content decline slowed, with E^+ consistently lower than E^- overall.

[Figure 2: see original paper] Changes of total nitrogen, lignin and cellulose contents of *Stipa purpurea* with time

2.3 Meteorological Factor Variations

Monthly mean temperature and precipitation showed distinct seasonal patterns (Figure 3). Temperature peaked in July then gradually declined to approximately -10°C. Precipitation reached maximum values in July and August, exceeding other months, then decreased after August. Mean ground temperature followed a similar trend, peaking in July at 15°C before declining to around -10°C. Sunshine hours showed no clear annual pattern, reaching maximum values in May and minimum values in December and January, then increasing gradually.

[Figure 3: see original paper] Changes of monthly mean temperature, precipitation, monthly mean ground temperature and sunshine hours

2.4 Relationship Between Decomposition Characteristics and Meteorological Factors

Correlation analysis revealed that for E^+ *S. purpurea*, litter weight was significantly negatively correlated with monthly mean temperature and ground temperature ($P < 0.01$), while mass loss rate was significantly positively correlated with these variables ($P < 0.01$). Total nitrogen content was significantly positively correlated with temperature, precipitation, and ground temperature ($P < 0.05$), whereas lignin and cellulose contents were significantly negatively correlated with temperature and ground temperature ($P < 0.01$). Sunshine duration showed no significant correlation with these parameters.

For E^- litter, correlations differed slightly: total nitrogen was extremely significantly positively correlated with monthly mean temperature, while lignin and cellulose were significantly negatively correlated ($P < 0.05$). Litter weight and mass loss rate were significantly correlated with precipitation ($P < 0.05$), but not with sunshine duration.

RDA analysis further clarified relationships between meteorological factors and litter decomposition (Figure 4). For E^+, the first and second axes explained 42.9% and 18.1% of variation, respectively (cumulative 61.0%). For E^-, the first and second axes explained 51.4% and 26.1% of variation (cumulative 77.5%). In both treatments, cellulose, lignin, and litter weight were positively correlated with sunshine duration, while total nitrogen was negatively correlated with meteorological factors. The correlation between meteorological factors and E^+ litter decomposition was more pronounced than for E^-.

[Figure 4: see original paper] RDA analysis of meteorological factors and litter decomposition characteristics of *Stipa purpurea*

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3. Discussion

3.1 Decomposition Rate and Substrate Quality Dynamics of *S. purpurea* Endophytic Fungal Symbiont

Litter decomposition essentially involves the release of mineral elements and nutrients, with substrate quality comprising key parameters such as total nitrogen, lignin, and cellulose contents. Microorganisms serve as the primary drivers of decomposition, critically regulating decomposition rates. Recent studies have documented widespread symbiosis between grasses and endophytic fungi, with endophytes indirectly affecting decomposition rates through antagonistic competition with soil saprotrophs during decomposition. In this study, the mass loss of *S. purpurea* litter occurred primarily during the first 6 months, after which decomposition slowed, consistent with most research findings showing rapid initial decomposition followed by gradual stabilization.

Our results indicate that E^+ *S. purpurea* decomposed approximately 30% faster than E^-, substantially shortening the decomposition cycle. This aligns with Dereske et al. [29], who found that endophyte infection enhanced decomposition of *Ammophila breviligulata* litter. Endophytes may accelerate decomposition by altering soil microbial community structure and abundance. However, this contrasts with Lemons et al. [31], who reported reduced grass decomposition rates with endophytes, likely due to differences in host species and symbiont growth environments.

Changes in plant nutrient content during decomposition directly reflect nutrient transformation processes and influence decomposition rates. Nutrient migration patterns during decomposition include direct release, leaching-immobilization, and immobilization-release. Total nitrogen content serves as an important quality factor regulating decomposition speed, with higher nitrogen indicating faster rates. In this study, total nitrogen in *S. purpurea* litter showed fluctuating patterns of initial decrease followed by increase, similar to leaching-immobilization-release patterns observed in other studies. The overall higher nitrogen content in E^+ litter suggests that endophyte presence may increase nutrient demand during decomposition, while lower nitrogen in E^- may limit microbial activity and reduce decomposition rates.

Lignin and cellulose, as primary litter components, control carbon balance in nature and represent rate-limiting steps in decomposition. We observed significant lignin reduction, with E^+ showing faster degradation than E^-. While some studies report negative correlations between lignin content and decomposition rate, our results differ, possibly due to varying initial lignin concentrations affecting the relationship with decomposition. Cellulose content decreased over time in both treatments, with E^+ showing lower cellulose content than E^-, indicating that endophytes accelerated cellulose degradation. Higher nitrogen content may increase cellulase activity, promoting cellulose breakdown, which our results support. Overall, endophytes accelerated degradation of lignin, cellulose, and nitrogen content, influencing nutrient cycling and energy flow in grassland ecosystems.

3.2 Effects of Meteorological Factors on *S. purpurea* Endophytic Fungal Symbiont Litter Decomposition

Beyond litter quality and soil biota, decomposition is strongly influenced by environmental conditions, with climate (temperature, moisture) considered the most important factor. In this study, regardless of endophytic status, *S. purpurea* litter weight and mass loss rate were significantly correlated with monthly mean temperature and ground temperature, indicating that temperature significantly affected decomposition rates. This aligns with Kravchenko et al. [40], who found decomposition rates increased with ground temperature. Temperature controls microbial activity and metabolism, thereby regulating decomposition. Under climate warming scenarios, increased temperatures accelerate microbial activity and organic matter cycling.

Precipitation also affects decomposition. High-intensity precipitation can accelerate surface litter decomposition and leaching of water-soluble substances, causing rapid mass loss. Our results showed positive correlations between precipitation and *S. purpurea* decomposition rate, consistent with some studies though others found no significant precipitation effects, possibly because precipitation impacts depend on magnitude, surface moisture, and litter quality. Temperature and precipitation influence microbial biomass and activity, which in turn affect litter nutrient concentrations during decomposition. Both E^+ and E^- *S. purpurea* litter showed similar positive correlations between total nitrogen and temperature/precipitation, while lignin and cellulose were negatively correlated with these factors, particularly temperature. Thus, monthly mean temperature, ground temperature, and precipitation emerged as key meteorological drivers of *S. purpurea* litter decomposition.

Sunshine duration also significantly affected decomposition, with lignin, cellulose, and litter weight strongly correlated with sunshine hours. Studies have shown that solar radiation enhances decomposition rates and that ultraviolet radiation can preferentially degrade lignin. Our findings confirm sunshine duration as an important decomposition factor. Given the high radiation, aridity, and altitude of alpine grasslands, where microbial activity is relatively low, meteorological factors showed stronger correlations with E^+ litter, suggesting that climate may promote endophyte-accelerated decomposition. While this study examined overall meteorological effects, future research should simulate different temperature, light, and precipitation conditions to clarify relative contributions and mechanisms, providing scientific basis for understanding litter decomposition responses to climate change.

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4. Conclusion

Based on our analysis of *S. purpurea* endophytic fungal symbiont litter decomposition characteristics and meteorological factor effects, we conclude:

1. Endophytic fungi positively enhanced *S. purpurea* litter decomposition rates and shortened decomposition cycles. Over time, endophytes promoted degradation of nitrogen, lignin, and cellulose to varying degrees.
2. Air temperature, ground temperature, and precipitation were key meteorological factors affecting *S. purpurea* litter decomposition, with sunshine duration also playing a role. Meteorological factors significantly influenced both E^+ and E^- litter decomposition, though correlations were stronger for E^+.

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