

## Leaf Litter Decomposition and Nutrient Release Characteristics of *Karelinia caspia* and *Populus euphratica* in Hyper-arid Regions (Postprint)

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### Abstract

To investigate litter decomposition patterns in extreme arid regions, the litterbag method was employed using leaf litter of the dominant species *Karelinia caspia* and *Populus euphratica* in the Cele Oasis region on the southern margin of the Taklamakan Desert as study subjects. Simulating natural conditions, litter decomposition experiments were conducted across three habitats: soil surface at 0 cm, soil burial depth of 2 cm, and suspension at 1 m height, to explore the characteristics of litter mass decomposition and carbon (C) and nitrogen (N) element release under different decomposition positions. The results demonstrated that mass loss rates of different plants exhibited significant differences among decomposition position treatments, with litter mass loss at the soil surface 0 cm treatment being significantly higher than that at the suspended 1 m and soil burial depth 2 cm treatments. Upon completion of the litter decomposition experiment, the mass loss rates of *Karelinia caspia* followed the order: soil surface 0 cm (19.91%) > suspended 1 m (15.99%) > soil burial depth 2 cm (12.35%). The mass loss rates of *Populus euphratica* followed the order: soil surface 0 cm (24.15%) > suspended 1 m (13.44%) > soil burial depth 2 cm (8.72%). Throughout the decomposition process, N content in leaf litter of both plant species showed an enrichment phenomenon, while C content exhibited a release state. Under different decomposition positions, significant differences were observed in N element enrichment and C element loss; N element enrichment in litter at both soil surface and soil burial depth 2 cm was lower than that in suspended 1 m litter, while C element loss was greater than that in suspended 1 m litter. The Olson exponential decay model was fitted to litter mass remaining rates, and the ranking of decomposition constant  $k$  values for both plant species was: soil surface 0 cm > suspended 1 m > soil burial depth 2 cm. Multi-factor analysis of variance (ANOVA) of leaf litter mass remaining rates indicated that both decomposition time and decomposition position had significant effects on litter mass remaining rate ( $P < 0.01$ ). In extreme arid regions, burial conditions

are not the primary driver of litter decomposition; the main factor influencing litter decomposition is photodegradation.

## Full Text

### Decomposition and Nutrient Release Characteristics of *Karelinia caspia* and *Populus euphratica* Leaf Litters in Extreme Arid Regions

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## Abstract

To investigate litter decomposition patterns in extreme arid regions, we conducted a litter decomposition experiment using the litterbag method. Leaf litters of two dominant species in the Cele Oasis at the southern margin of the Taklamakan Desert—*Karelinia caspia* and *Populus euphratica*—were placed in three different positions to simulate natural conditions: on the soil surface (0 cm), buried at 2 cm depth, and suspended 1 m aboveground. We examined mass loss dynamics and the release characteristics of carbon (C) and nitrogen (N) elements under these different decomposition positions.

The results showed that mass loss rates differed significantly among decomposition positions for both plant species, with surface litters exhibiting significantly greater mass loss than suspended and buried litters. By the end of the experiment, mass loss rates for *K. caspia* followed the order: surface (24.15%) > suspended (15.99%) > buried (8.72%). For *P. euphratica*, the order was: surface (19.91%) > suspended (13.44%) > buried (12.35%). Throughout the decomposition process, N content in both species showed enrichment while C content decreased. The enrichment of N and loss of C varied significantly among positions, with surface and buried litters showing lower N enrichment but greater C loss compared to suspended litters.

Using Olson' s exponential decay model to fit the mass residual rates, the decomposition constant ( $k$ ) values for both species ranked as: surface > suspended > buried. Multivariate analysis of variance revealed that both decomposition time and position had significant effects on litter mass residual rates ( $P < 0.01$ ). In extreme arid regions, burial conditions are not the primary driver of litter decomposition; instead, photodegradation is the main factor influencing the decomposition process.

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

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## 1. Introduction

Litter decomposition is a central component of ecosystem material cycling and plays a crucial role in maintaining soil fertility and regulating energy flow and nutrient balance. Through decomposition and humification, litter promotes soil organic carbon accumulation and improves soil quality. In most ecosystems, litter mass loss and nutrient cycling rates are primarily controlled by climate, litter substrate quality, and decomposer organisms. However, in arid regions, especially extreme arid areas, these factors cannot fully predict litter decomposition rates.

Current research indicates that in most arid regions, litter decomposition proceeds faster than expected due to photodegradation and physical fragmentation. Exposed to sunlight or artificial radiation sources, surface litter can experience mass loss increases of up to 30% from photodegradation. However, changes in litter position also alter the contribution of photodegradation to the decomposition process. At the surface of the litter layer with high light intensity, photodegradation effects are significant, whereas buried litter is less affected by photodegradation.

Some studies have shown that in semi-arid regions, buried litter exhibits greater mass loss than surface litter, possibly because soil moisture conditions under burial are more suitable for microbial growth, enhancing microbial effects on decomposition. However, in extreme arid regions with intense solar radiation and low soil moisture content, microbial reproduction and activity are limited, potentially leading to different decomposition patterns. Therefore, it is necessary to investigate the decomposition processes of litter at different positions in extreme arid areas.

Globally, arid and semi-arid lands account for nearly one-third of the Earth' s land area. Vegetation communities in these regions have simple structures, poor substrate quality, and fragile habitats. Studying litter decomposition patterns in these areas, particularly in the vulnerable sandy extreme arid zones, is essential for accurately assessing material cycling and energy transformation processes.

The Taklamakan Desert, located in the Tarim Basin, is China' s largest desert and the world' s second-largest shifting desert, with an extremely arid climate.

This study focuses on the Cele Oasis at the southern margin of the Taklamakan Desert, examining two dominant species—*Karelinia caspia* and *Populus euphratica*—to analyze the decomposition characteristics, rates, and dynamics of carbon and nitrogen content in leaf litters placed at different positions, thereby exploring litter decomposition patterns in extreme arid regions.

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## 2. Methods

**2.1 Study Area** The experiment was conducted in the desert experimental area of the Cele National Field Science Observation and Research Station, Chinese Academy of Sciences. The study area is located in the oasis-desert transition zone at the southern margin of the Taklamakan Desert (39°30'00" N, 80°03'24" - 82°10'34" E), characterized by a typical continental arid climate with an average annual precipitation of only 35.1 mm. The soil is primarily aeolian sandy soil with poor water retention, severe desertification, and low organic matter content. The average annual temperature is 11.9°C, with extreme maximum and minimum temperatures of 41.9°C and -23.9°C, respectively. The area has abundant heat resources, with annual sunshine duration of 2,697.5 hours and accumulated temperature above 10°C reaching 4,340°C. The annual solar radiation is 604.2 kJ·cm<sup>-2</sup>. The main plant species in the oasis-desert transition zone include *Karelinia caspia*, *Alhagi sparsifolia*, *Tamarix ramosissima*, *Calligonum mongolicum*, and *Populus euphratica*, with low vegetation coverage.

**2.2 Litter Collection** Leaf litters of *K. caspia* and *P. euphratica* were collected as decomposition materials. Collection was conducted in the Cele Oasis transition zone at the southern margin of the Taklamakan Desert on October 15, 2018. Litter collection baskets were placed under the canopies of both species (50 cm × 50 cm for *K. caspia* and 100 cm × 100 cm for *P. euphratica*). Litters were collected daily, and after collection, impurities other than leaves were removed and the samples were mixed uniformly. The samples were stored at 65°C. For each litter type, three mixed samples were selected to determine initial chemical properties. The litters were oven-dried at 65°C for 48 hours before the decomposition experiment.

**2.3 Litter Decomposition Experiment Design and Sampling** The litterbag method was used for the decomposition experiment. Nylon mesh bags (20 cm × 20 cm) served as decomposition bags, with approximately 20 g of leaf litter placed in each bag and weighed. Three treatments were established: (1) Aboveground (0 cm), where litterbags were placed on the soil surface in contact with the soil; (2) Suspended (1 m), where litterbags were tied to iron wires 1 m aboveground; and (3) Belowground (2 cm), where litterbags were buried at 2 cm depth and covered with soil. Each litter type had 5 replicates per treatment. Each plot measured 2 m × 2 m, with 0.5 m spacing between litterbags and 2 m spacing between plots.

On November 1, 2018, decomposition bags for both species were placed in their respective positions. Samples were collected monthly for 6 months. During each collection, litterbags were brought to the laboratory, oven-dried at 65°C, surface sand particles were removed, and the remaining dry mass was recorded. The dried samples were then ground for total carbon (C) and total nitrogen (N) content analysis.

## 2.4 Measurement Methods 2.4.1 Litter Nutrient Determination

Total carbon and nitrogen contents were measured using a C/N elemental analyzer (Vario Max CN, Germany).

### 2.4.2 Litter Mass Residual Rate (MR) and Nutrient Element Residual Rate (NR)

These were calculated using the following formulas:

Mass residual rate:

$$MR(\%) = \frac{M_t}{M_0} \times 100$$

Nutrient element residual rate:

$$NR(\%) = \frac{N_t}{N_0} \times 100$$

where  $M_0$  is the initial litter mass (g),  $M_t$  is the remaining mass at decomposition time  $t$  (g),  $N_0$  is the initial nutrient element content (g), and  $N_t$  is the nutrient element residual amount at time  $t$  (g).

### 2.4.3 Decomposition Rate

The improved Olson exponential decay model was used:

$$MR = ae^{-kt}$$

where  $MR$  is the mass residual rate (%),  $a$  is a fitting parameter,  $k$  is the annual decomposition coefficient ( $\text{year}^{-1}$ ), and  $t$  is decomposition time (years).

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

$$t_{50\%} = -\ln(1 - 0.50)/k$$

$$t_{95\%} = -\ln(1 - 0.95)/k$$

**2.5 Data Processing** Data were analyzed using Excel 2010 and SPSS 21.0 software. One-way ANOVA with least significant difference (LSD) tests were used to compare litter mass residual rates and monthly dynamics among treatments. Multivariate analysis of variance was used to analyze the effects of litter species, decomposition time, and position on mass residual rates. Regression analysis was used to examine relationships between mass residual rates and decomposition time. Figures were created using Origin 2018 software.

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### 3. Results

**3.1 Changes in Leaf Litter Mass Residual Rate** Mass loss rates of *K. caspia* and *P. euphratica* leaf litters differed significantly among treatments (Figure 1). Mass loss was rapid in the early decomposition stage and slowed over time. By the end of the experiment, mass residual rates for *K. caspia* were: surface (75.32%), suspended (83.66%), and buried (91.28%). For *P. euphratica*, the rates were: surface (76.66%), suspended (87.53%), and buried (89.69%). Statistical analysis showed significant differences in mass residual rates among positions for both species ( $P < 0.01$ ), with surface litters showing the greatest mass loss.

**3.2 Dynamics of C, N, and C/N During Litter Decomposition** Throughout the decomposition process, N content in both species showed enrichment while C content decreased (Figures 2 and 3). The dynamics of N and C/N ratio in both species under the three treatments showed two distinct phases: a rapid change phase (0–3 months) and a stable phase (3–6 months). Compared with other treatments, surface litters had the lowest N content and C/N ratio, while suspended litters had the highest. By the end of the experiment, N content in *K. caspia* and *P. euphratica* surface litters increased by 28.66% and 36.98%, respectively, while N content in suspended litters increased by 127.28% and 160.26%, respectively. C content in surface and buried litters showed greater loss than in suspended litters.

**3.3 Litter Decomposition Rate** Olson's exponential decay model was used to fit the mass residual rates and estimate decomposition rates (Table 1). Under different treatments, decomposition rates ranked as: surface > suspended > belowground for both species. *K. caspia* and *P. euphratica* litters on the soil surface had the fastest decomposition rates, with half-life times of 1.71 and 1.39 years, respectively. *P. euphratica* decomposed faster than *K. caspia* under the same conditions.

**Table 1** Olson exponential model and average decomposition rate of leaf litter decomposition of two plants at different decomposition locations

Species	Treatment	Olson Model	k (year <sup>-1</sup> )	t <sub>50</sub> % (year)	t <sub>95</sub> % (year)
K. caspia	Surface	MR = 96.301e <sup>-</sup> (-0.284t)	0.284 ± 0.035	2.44	10.54
K. caspia	Suspended	MR = 98.116e <sup>-</sup> (-0.206t)	0.206 ± 0.046	3.37	14.55
K. caspia	Buried	MR = 98.073e <sup>-</sup> (-0.260t)	0.260 ± 0.032	2.67	11.52
P. euphratica	Surface	MR = 96.247e <sup>-</sup> (-0.405t)	0.405 ± 0.060	1.71	7.39
P. euphratica	Suspended	MR = 97.720e <sup>-</sup> (-0.240t)	0.240 ± 0.032	2.89	12.47
P. euphratica	Buried	MR = 99.537e <sup>-</sup> (-0.498t)	0.498 ± 0.060	1.39	6.02

### 3.4 Statistical Analysis of Factors Affecting Litter Mass Residual Rate

Multivariate analysis of variance showed that decomposition time, litter species, and decomposition position all had significant effects on mass residual rates ( $P < 0.01$ ). The interaction between species and position, as well as between time and position, also significantly affected mass residual rates ( $P < 0.01$ ) (Table 2).

**Table 2** Multivariate analysis of variance of leaf litter species, decomposition time, and different decomposition locations on mass residual rate of leaf litters

Source	df	F-value	P-value
Species (S)	1	0.001	0.981
Time (T)	5	27.876	<0.01
Position (D)	2	10.321	<0.01
S × T	5	0.556	0.733
S × D	2	6.321	<0.01
T × D	10	2.876	<0.01
S × T × D	10	0.876	0.556

*Note: S = Species, T = Time, D = Decomposition position; df = degrees of freedom; F = ratio of mean square of the term to error mean square.*

## 4. Discussion

**4.1 Litter Decomposition Characteristics** Previous studies have shown that in forest ecosystems, buried litter decomposes faster than surface litter. However, in arid regions, high solar radiation and low precipitation reduce microbial activity, potentially limiting microbial decomposition. Research in semi-arid regions has shown that intense sunlight can generate superoxide anion radicals in soils, producing hydrogen peroxide and hydroxyl radicals that oxidize organic matter in litter. In this study, after 6 months of decomposition, both *K. caspia* and *P. euphratica* leaf litters decomposed fastest when placed on the soil surface. The decomposition rate of suspended litters was faster than that of buried litters, suggesting that photodegradation directly contributes to litter decomposition. However, the specific mechanisms by which photodegradation promotes decomposition require further investigation.

Litter decomposition involves both physical and biochemical processes, typically completed through the combined effects of leaching, fragmentation, and metabolism. Previous studies have shown two distinct phases of litter decomposition: rapid initial decomposition followed by slower rates. In this study, rapid decomposition occurred during the first 3 months, after which the process stabilized. Regression analysis showed that the time required for 95% decomposition was approximately 3–4 times longer than that for 50% decomposition, reflecting the pattern of rapid early decomposition followed by slower later stages.

In the early stage, water-soluble substances and easily decomposable compounds are primarily broken down through abiotic factors (physical fragmentation, leaching degradation). As decomposition progresses, recalcitrant substances such as lignin accumulate, and the process shifts to biologically-dominated decomposition. Our multivariate analysis confirmed that decomposition time and position significantly affect mass residual rates.

**4.2 Changes in Litter Nutrient Content** In desert ecosystems with nutrient-poor soils, litter decomposition and nutrient release are crucial for plant growth and soil nutrient cycling. N accumulation during decomposition is a notable characteristic. Studies have shown that N immobilization occurs during litter decomposition. For example, research on *P. euphratica* litter in the Tarim Basin showed N immobilization under the canopy. This N enrichment may occur because the initial N content cannot meet microbial demands, requiring microbes to absorb additional N from the environment to build microbial biomass or extracellular enzymes.

However, in extreme arid regions with limited microbial biomass, litter decomposition is primarily driven by photodegradation rather than microbial activity, and N dynamics may be less related to microbial decomposition. In this study, both *K. caspia* and *P. euphratica* leaf litters showed N enrichment during decomposition. The observed N dynamics in extreme arid regions may be caused by other abiotic factors. Litter decomposition in these regions is N-limited, and

after easily decomposable substances are lost through weathering, leaching, and photodegradation, the remaining recalcitrant material has higher N content.

Carbon is the main element composing organic matter and provides energy for decomposers. However, nutrient release during decomposition varies with litter type, environment, decomposition time, and nutrient characteristics. In this study, C content showed a pattern of initial decrease followed by increase. For fresh litter, initial mass loss is primarily due to leaching of soluble elements. As leaching weakens, C content increases, showing some enrichment. Under suspended treatment, litter decomposition rate was faster than nutrient loss, resulting in lower C loss. This suggests that litter decomposition in extreme arid regions differs significantly from that in humid regions and requires further investigation.

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## 5. Conclusion

This study on leaf litter decomposition and nutrient dynamics of *K. caspia* and *P. euphratica* in the Cele Oasis at the southern margin of the Taklamakan Desert demonstrates that both decomposition time and position significantly affect decomposition rates, with aboveground litter decomposing faster than belowground litter. The N release patterns of both species were consistent across different positions, though N release amounts differed significantly among treatments. In extreme arid regions with abundant heat resources, photodegradation directly promotes litter decomposition and is the primary driver of the decomposition process.

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