

## Effects of Exposure and Sand Burial on Litter Decomposition and Nutrient Release in Extreme Arid Regions: Postprint

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### Abstract

To evaluate the characteristics of litter decomposition and nutrient dynamics under exposed and sand burial treatments in desert highway shelterbelt forest belts, a decomposition experiment was conducted using the litterbag method with assimilating branches of *Haloxylon ammodendron* and *Calligonum arborescens*, and leaf litter of *Tamarix ramosissima* as study materials. The results showed that: (1) Significant differences in mass loss among the three litter types existed under both treatments, with mass loss under sand burial being greater than under exposed conditions. By the end of the experiment, weight loss rates under exposed treatment were 7%, 6.8%, and 18.1% for *Haloxylon ammodendron*, *Calligonum arborescens*, and *Tamarix ramosissima*, respectively; corresponding values under sand burial were 23.7%, 9.7%, and 21.9%; (2) During decomposition, changes in C, N, and P contents were not consistent across treatments. N and P contents in assimilating branches of *Haloxylon ammodendron* and *Calligonum arborescens* showed net enrichment, while C content exhibited net release. For *Tamarix ramosissima* leaves, N content showed net enrichment and P content net release, while C content displayed an enrichment-release pattern; (3) Analysis of decomposition rate constant  $k$  and related factors indicated that initial litter N, P, C:N, and C:P contents significantly affected decomposition rate ( $P < 0.01$ ). These results demonstrate that sand burial exerts a significant positive effect on litter decomposition processes in extremely arid regions.

### Full Text

### Preamble

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Effects of Bare Surface and Sand Burial on Litter Decomposition and Nutrient Release in Extremely Arid Regions

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**Abstract:** To evaluate the decomposition dynamics and nutrient release characteristics of litter under bare versus sand burial conditions in desert highway shelterbelt forests, we conducted a 510-day decomposition experiment using litterbag methods with assimilative branches of *Haloxylon ammodendron* and *Calligonum arborescens*, and leaves of *Tamarix ramosissima*. The results demonstrated: (1) Significant differences in mass loss occurred among the three litter types under both treatments, with substantially greater mass loss under sand burial. By the experiment's conclusion, weight loss rates under bare conditions were 18.1% for *H. ammodendron*, 6.8% for *C. arborescens*, and 18.1% for *T. ramosissima*; corresponding values under sand burial were 23.7%, 9.7%, and 21.9%, respectively. (2) Changes in carbon (C), nitrogen (N), and phosphorus (P) contents during decomposition showed inconsistent patterns between treatments. N and P contents in *H. ammodendron* and *C. arborescens* assimilative branches exhibited net enrichment, while C content showed net release. For *T. ramosissima* leaves, N and P displayed net enrichment and net release patterns, respectively, while C showed an enriched-released state. (3) Olson's negative exponential decay model revealed decomposition coefficients (k) consistently ranked as sand burial > bare surface across all species. (4) Correlation analysis indicated that initial N, P, C:N, and C:P ratios significantly influenced decomposition rates ( $P < 0.01$ ). These findings demonstrate that sand burial exerts a significant positive effect on litter decomposition processes in extremely arid desert protection forests.

**Keywords:** extremely arid region; litter decomposition; sand burial; mass residue rate

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## Introduction

Litter serves as a critical link between plants and soil, playing a vital role in maintaining ecosystem functions, material cycling, and energy flow. Its primary significance lies in the decomposition process, which releases nutrients and energy stored in plant tissues back into the soil, thereby providing essential resources for plant growth and microbial metabolism while promoting ecosystem structural stability and soil fertility maintenance. Globally, litter decomposition releases approximately 68 Gt of carbon dioxide annually, making it a

crucial component of the global carbon cycle. However, in arid and extremely arid regions, where soils are typically nutrient-poor and low in organic matter, litter decomposition and nutrient release assume even greater importance for improving soil texture and sustaining vegetation stability.

These regions are characterized by dry climates and frequent dust storm activity, with strong winds providing the driving force for both horizontal sand movement and litter burial. Sand burial consequently represents a common natural phenomenon that profoundly alters soil temperature, moisture, and light intensity. Compared to surface soils, buried soils experience reduced light penetration, resulting in lower temperatures but higher moisture retention. These microenvironmental modifications significantly influence litter mass loss, though the effects remain complex and context-dependent. Some studies in arid ecosystems have found that the moderate temperature and moisture conditions created by sand burial enhance microbial activity, leading to significantly faster decomposition of buried litter compared to surface litter. Conversely, other research suggests that surface litter decomposition may proceed more rapidly or show no significant difference from buried litter. These contradictory findings indicate that the effects and mechanisms of sand burial on decomposition remain unclear and warrant further investigation.

The Taklamakan Desert, the world's second-largest shifting sand desert, provides an ideal setting to explore these processes. In the desert highway shelterbelt forests of this region, frequent aeolian sand activity regularly buries litter, creating decomposition environments distinct from surface conditions and potentially altering biogeochemical cycling in this extremely arid ecosystem. To investigate these effects, we conducted a study in the hinterland of the Taklamakan Desert focusing on three dominant shelterbelt species: *Haloxylon ammodendron*, *Calligonum arborescens*, and *Tamarix ramosissima*. Our objectives were to characterize decomposition patterns and nutrient release dynamics under both bare and sand burial conditions, thereby elucidating the material cycling characteristics of shelterbelt litter in this extreme environment.

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## 1. Materials and Methods

### 1.1 Study Area Description

The experimental site was located at the Taklamakan Desert Research Station of the Chinese Academy of Sciences (38°58' 13.56" N, 83°39' 36.48" E, elevation 1100 m). Situated in the central Tarim Basin of southern Xinjiang, this represents China's largest shifting sand desert. The region experiences a typical warm temperate continental arid climate, with an average annual precipitation of 24.6 mm, mean annual temperature of 12.8°C, maximum temperature of 45.7°C, minimum temperature of -22.3°C, and annual sunshine duration of 2854.2 hours. The area exhibits large annual and diurnal temperature variations, with frequent wind-sand activity and widespread shifting sand phenomena. The soil type is

mobile aeolian sandy soil, and the vegetation consists primarily of highly stress-resistant shrubs and small trees including *Calligonum* spp., *Haloxylon* spp., and *Tamarix* spp.

## 1.2 Experimental Design and Sample Analysis

Within the experimental area of the research station, we selected three uniformly growing individuals each of *H. ammodendron*, *C. arborescens*, and *T. ramosissima*. For each species, three trees were randomly assigned to sand burial treatment (litter buried at 10 cm depth to simulate wind-blown sand burial), while three trees received surface bare treatment (litter placed on the soil surface to simulate exposed conditions). In October 2021, we deployed litter collection frames (50 cm × 50 cm) in shelterbelt forests established in the same year along the desert highway. We collected assimilative branches of *H. ammodendron* and *C. arborescens* and leaves of *T. ramosissima*, removing impurities before oven-drying at 65°C to constant weight.

Each litter sample (15.00 g) was placed in decomposition mesh bags (25 cm × 15 cm). Concurrently, three replicate samples of each litter type were weighed, oven-dried, and ground to determine initial chemical composition. On November 1, 2021, the prepared litterbags were positioned beneath the respective trees. For bare treatment, surface litter and herbaceous plants were removed, and bags were secured with wire to prevent wind displacement. For sand burial treatment, litterbags were buried at 10 cm depth. Soil temperature was continuously monitored throughout the experiment using soil thermometers.

Sampling occurred after 3, 6, 9, 12, and 18 months of decomposition. At each sampling, three mesh bags per treatment per species were randomly retrieved and returned to the laboratory. Retrieved litter was cleaned, oven-dried at 65°C to constant weight, and weighed to determine remaining dry mass. The dried samples were then ground and sieved (1 mm) for chemical analysis. Soil samples (0–5 cm) were also collected beneath each bag, with one portion used for moisture determination and another air-dried, ground, and sieved for organic carbon and nutrient analysis.

Total carbon (C) and nitrogen (N) contents were determined using the potassium dichromate oxidation-sulfuric acid heating method and continuous flow analysis following sulfuric acid-hydrogen peroxide digestion, respectively. Total phosphorus (P) was measured by continuous flow analysis after sulfuric acid-perchloric acid digestion. Soil moisture content was determined by the oven-drying method.

## 1.3 Data Processing

Litter mass residue rate was calculated as:

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

where  $Y$  is the mass residue rate (%),  $M_t$  is the litter mass at decomposition time  $t$ , and  $M_0$  is the initial litter mass.

We fitted the decomposition process using Olson's negative exponential decay model to calculate decomposition rate constants ( $k$ ) and estimate half-life ( $t_{0.5}$ ) and 95% decomposition time ( $t_{0.95}$ ):

$$Y = \alpha e^{-kt}$$

where  $Y$  and  $M_t$  are as defined above,  $\alpha$  is a correction coefficient, and  $t$  is decomposition time (years). The half-life and 95% decomposition time were calculated as  $t_{0.5} = \ln(0.5)/(-k)$  and  $t_{0.95} = \ln(0.05)/(-k)$ , respectively. Larger  $k$  values indicate faster decomposition.

Nutrient residue rate (NR, %) was calculated as:

$$\text{NR} = \frac{M_t X_t}{M_0 X_0} \times 100\%$$

where  $X_0$  is the initial nutrient concentration ( $\text{g} \cdot \text{kg}^{-1}$ ) and  $X_t$  is the nutrient concentration at time  $t$ . When  $\text{NR} < 100\%$ , net nutrient release occurred; when  $\text{NR} > 100\%$ , net nutrient immobilization occurred.

Data were processed using Excel 2016 and Origin 2018 for visualization. One-way ANOVA was used to test differences in initial chemical composition and decomposition rates among litter types. Repeated measures ANOVA examined the effects of decomposition time, treatment, species, and their interactions on mass and nutrient residue rates. Pearson correlation analysis assessed relationships between initial litter properties, soil microenvironment, and decomposition rates. Exponential regression equations were fitted between mass residue rates and decomposition time. All data are presented as means  $\pm$  standard error.

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## 2. Results

### 2.1 Changes in Litter Mass Residue Rate and Decomposition Rate Under Bare and Sand Burial Treatments

Mass loss in *H. ammodendron* and *C. arborescens* assimilative branches occurred primarily during the first 6 months, whereas *T. ramosissima* leaf decomposition continued until 12 months before stabilizing. By the experiment's conclusion, mass residue rates under bare treatment were 81.9% for *H. ammodendron*, 93.2% for *C. arborescens*, and 81.9% for *T. ramosissima*; corresponding values under sand burial were 76.3%, 90.3%, and 78.1%, respectively [Figure 1: see original paper].

Repeated measures ANOVA revealed that decomposition time, treatment, and species all significantly affected litter mass residue rates ( $P < 0.05$ ), though interactions among these factors were non-significant. We fitted mass residue data to Olson's negative exponential decay model to estimate decomposition coefficients ( $k$ ). Decomposition rates under sand burial consistently exceeded those under bare conditions across all species, with significant differences among the three litter types ( $P < 0.05$ ). *Tamarix ramosissima* leaves decomposed fastest, while *C. arborescens* assimilative branches decomposed slowest.

## 2.2 Dynamics of C, N, and P Residue Rates Under Bare and Sand Burial Treatments

Throughout the decomposition period, C residue rates in all three litter types showed net release patterns under both treatments. However, N and P dynamics varied among species [Figure 2: see original paper]. For *H. ammodendron* and *C. arborescens* assimilative branches, N and P residue rates exhibited net enrichment, while *T. ramosissima* leaves showed net enrichment for N but net release for P. Repeated measures ANOVA indicated that C residue rates were significantly influenced by decomposition time and species ( $P < 0.01$ ), but not by treatment or interactions. In contrast, N and P residue rates were significantly affected by decomposition time, species, and treatment ( $P < 0.01$ ).

## 2.3 Factors Influencing Decomposition Rate Constants

Correlation analysis between decomposition rate constants ( $k$ ) and various factors revealed that  $k$  values were significantly positively correlated with initial N and P contents, and significantly negatively correlated with initial C:N and C:P ratios ( $P < 0.01$ ). These relationships held true for both bare and sand burial treatments, indicating that initial litter chemistry strongly regulates decomposition rates in this system.

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## 3. Discussion

### 3.1 Effects of Bare Surface and Sand Burial on Litter Decomposition

Our results demonstrate that sand burial significantly accelerated litter mass loss in all three species. Regression analysis showed that decomposition proceeded significantly faster under sand burial than bare conditions, likely due to differences in microenvironmental conditions. During the experiment, average annual temperatures were approximately 16.1°C for bare surface and 13.8°C for sand burial, while soil moisture under sand burial was 1.3 times higher than under bare conditions. Sand burial reduces evaporative water loss and maintains higher moisture levels for longer periods, creating favorable conditions for microbial activity and accelerating decomposition. This pattern aligns with

previous studies in arid and semi-arid ecosystems showing faster decomposition under sand burial.

The initial rapid mass loss observed during the first 6 months can be attributed to leaching of soluble compounds and microbial processing of labile substrates. Additionally, large diurnal temperature variations and freeze-thaw cycles during early decomposition stages may have further accelerated breakdown. The subsequent slower decomposition phase reflects the recalcitrant nature of remaining lignified tissues.

### 3.2 Effects of Bare Surface and Sand Burial on Nutrient Release

Nutrient release patterns varied among elements and species. Throughout decomposition, nutrient residue rates were consistently lower under sand burial, indicating enhanced nutrient release compared to bare conditions. The net release of C observed in all litter types reflects the mineralization of organic compounds. In contrast, the net enrichment of N and P in *H. ammodendron* and *C. arborescens* assimilative branches suggests microbial immobilization of these limiting nutrients during decomposition.

For *T. ramosissima* leaves, N showed net enrichment while P exhibited net release. This divergence may reflect the extremely low initial P content in these leaves ( $1.24 \text{ g} \cdot \text{kg}^{-1}$ ), which likely failed to meet microbial demand, resulting in net release. Conversely, N immobilization may occur when environmental N availability is insufficient for microbial requirements. Previous studies in desert ecosystems have reported similar nutrient accumulation patterns, particularly for N-limited systems. Our findings indicate that while sand burial generally promotes nutrient release, the complete decomposition trajectory requires longer-term studies to fully resolve.

### 3.3 Influence of Initial Litter Properties on Decomposition

Initial litter chemistry is a robust predictor of decomposition rates. Our results show that higher initial N and P contents and lower C:N and C:P ratios significantly enhanced decomposition rates ( $P < 0.01$ ). *Tamarix ramosissima* leaves, with the highest N content ( $11.05 \text{ g} \cdot \text{kg}^{-1}$ ) and lowest C:N ratio (24.13), decomposed fastest, while *C. arborescens* assimilative branches, with the lowest N content ( $5.20 \text{ g} \cdot \text{kg}^{-1}$ ) and highest C:N ratio (60.47), decomposed slowest. This pattern supports the nutrient limitation hypothesis, where high-quality litter with lower recalcitrance and higher nutrient content promotes microbial activity and accelerates decomposition.

The significant correlations between initial chemical properties and  $k$  values underscore the importance of substrate quality in regulating decomposition, even under the harsh environmental conditions of extremely arid regions. Sand burial may moderate temperature fluctuations and reduce photodegradation, but substrate quality remains the primary driver of decomposition dynamics.

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## 4. Conclusion

In the desert highway shelterbelt forests of the extremely arid Taklamakan Desert, sand burial treatment resulted in lower litter mass residue rates compared to bare surface treatment, significantly accelerating mass loss. Sand burial also reduced nutrient residue rates, promoting faster nutrient release. Initial litter properties, particularly N content and C:N ratio, significantly influenced decomposition rates. These results demonstrate that sand burial exerts a significant positive effect on both decomposition rates and nutrient release patterns, though the magnitude of these effects varies among litter types. These findings provide theoretical insights into litter decomposition processes and contribute to understanding biogeochemical cycling in extremely arid regions.

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