Response of Surface and Aboveground Litter Decomposition in a Temperate Desert to Ultraviolet Radiation

He Ziwei, Li Yongping, Shen Xiaohan, Kou Tianle, Hu Yutong, Cheng Junhui, Zhao Hongmei

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Abstract

This study examined the litter of three common plant species in the Gurbantunggut Desert, Haloxylon ammodendron, Nitraria sibirica, and Ceratocarpus arenarius. A split-plot experimental design was adopted, with two radiation treatments, ultraviolet exclusion (UV-) and ultraviolet transmission (UV+), combined with two litter positions, on the soil surface and above the ground. Through a 357 d field decomposition experiment, the effects of ultraviolet radiation on litter decomposition and N and P nutrient release at different positions were investigated. The results showed that ultraviolet radiation promoted mass loss of desert plant litter to varying degrees. After 357 d of decomposition, compared with ultraviolet exclusion, the decomposition rates of aboveground Haloxylon ammodendron litter, surface Nitraria sibirica litter, and aboveground and surface Ceratocarpus arenarius litter under the ultraviolet transmission treatment increased significantly by 49.12%, 23.72%, 30.10%, and 17.84%, respectively. Under the same ultraviolet radiation treatment, surface litter of all three species decomposed significantly faster than aboveground litter. During the entire experiment, the decomposition processes of Haloxylon ammodendron and Nitraria sibirica litter placed on the soil surface and above the ground showed net release of N and P nutrients, whereas P nutrients in Ceratocarpus arenarius showed varying degrees of immobilization. Compared with ultraviolet exclusion, ultraviolet transmission promoted nutrient release during litter decomposition of the three species to some extent, but the magnitude and direction of its effects varied with litter placement position and decomposition time. After 357 d of decomposition, N and P release from aboveground Nitraria sibirica litter and surface Ceratocarpus arenarius litter increased significantly by 21.5% and 11.1%, and 21.9% and 8.1%, respectively. These results indicate that ultraviolet radiation is a key environmental factor affecting litter decomposition and nutrient release in arid regions and plays an important role in accurately predicting nutrient cycling in arid ecosystems.

Full Text

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He Ziwei, Li Yongping, Shen Xiaohan, Kou Tianle, Hu Yutong, Cheng Junhui, Zhao Hongmei

(College of Resources and Environment, Xinjiang Agricultural University; Xinjiang Key Laboratory of Soil and Plant Ecological Processes, Urumqi, Xinjiang

830052, China)

Abstract: In this study, litter from three common plant species in the Gurbantunggut Desert—*Haloxylon ammodendron*, *Nitraria sibirica*, and *Ceratocarpus arenarius*—was used as the research material. A split-plot experimental design was adopted, with two radiation treatments, ultraviolet exclusion (UV−) and ultraviolet transmission (UV+), combined with two litter placement positions, on the soil surface and aboveground. Through a 357-day field decomposition experiment, the effects of ultraviolet radiation on litter decomposition and N and P nutrient release at different positions were investigated. The results showed that ultraviolet radiation promoted mass loss of desert plant litter to varying degrees. After 357 days of decomposition, compared with ultraviolet exclusion, the decomposition rates under ultraviolet transmission significantly increased by 49.12%, 23.72%, 30.10%, and 17.84% for aboveground *H. ammodendron* litter, surface *N. sibirica* litter, and aboveground and surface *C. arenarius* litter, respectively. Under the same ultraviolet-radiation treatment, surface litter of all three species decomposed significantly faster than aboveground litter. Throughout the experimental period, decomposition of *H. ammodendron* and *N. sibirica* placed on the surface and aboveground showed net release of N and P nutrients, whereas P in *C. arenarius* exhibited immobilization to varying degrees. Compared with ultraviolet exclusion, ultraviolet transmission promoted nutrient release during decomposition of the three species to some extent, but the magnitude and direction of its effect varied with litter placement position and decomposition time. After 357 days of decomposition, N and P release from aboveground *N. sibirica* litter and surface *C. arenarius* litter increased significantly by 21.5% and 11.1%, and by 21.9% and 8.1%, respectively. The results of this study indicate that ultraviolet radiation is a key environmental factor affecting litter decomposition and nutrient release in arid regions and plays an important role in accurately predicting nutrient cycling in arid-region ecosystems.

Keywords: desert ecosystem; litter decomposition; decomposition rate; nutrient release; ultraviolet radiation

Arid and semiarid regions are important components of terrestrial ecosystems, accounting for approximately 40% of the global land area. Because they are constrained by water availability, their vegetation is sparse, their ecological environments are fragile, and they are highly sensitive to global climate change[1]. In arid regions, litter decomposition, as a key process in ecosystem C and N cycling, has decomposition dynamics that influence the stability of the structure and function of arid-region ecosystems[2–3]. However, traditional models that use climate and litter quality to predict decomposition often underestimate the decomposition rate of litter in arid-region ecosystems, posing a major challenge for accurately estimating the carbon budget of terrestrial ecosystems and its feedback to climate change[2]. In arid regions, vegetation cover is low, litter is exposed to strong light for long periods, and microbial activity is relatively weak; abiotic factors such as photodegradation may therefore become key drivers of litter decomposition in arid-region ecosystems[4]. Accordingly, in-depth analysis of the role of ultraviolet radiation in litter decomposition in arid regions is of great significance for accurately predicting carbon turnover and nutrient cycling in arid-region ecosystems.

In recent years, many scholars have studied the effects of ultraviolet radiation on the decomposition of surface litter in arid-region ecosystems. In extremely arid regions, Li Meiqi et al.[5] showed that, compared with ultraviolet shielding, natural light significantly promoted the decomposition of litter from *Karelinia caspia*, *Alhagi sparsifolia*, and *Populus euphratica*. Other studies have shown that ultraviolet radiation significantly promotes C loss from *Proustia pungens* litter and accelerates its decomposition[6]. A recent meta-analysis indicated that, owing to differences in microclimate, species traits, decomposition time, and other factors, ultraviolet radiation may promote surface-litter decomposition, inhibit mass loss, or have no effect[7]. In arid regions, some plants do not fall to the ground immediately after death but persist as standing dead material for several months or even multiple seasons[8]. As an important stage in the decomposition of plant residues, the decomposition of standing dead plants also has a non-negligible influence on ecosystem C and N cycling[9]. Some researchers have found that ultraviolet radiation accelerates mass loss of surface litter but has no significant effect on decomposition of aboveground litter[9]. In contrast, Erdenebileg et al.[10] showed that ultraviolet radiation significantly promoted mass loss only in aboveground litter of two perennial grasses and one annual herb, while having no significant effect on the decomposition of most surface litter. Thus, changes in the microenvironment caused by different spatial positions may also alter the effect of photodegradation on litter decomposition.

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Author profile: He Ziwei (1998-), female, master’ s student, engaged in research on decomposition of desert plant litter. E-mail: 15199376536@163.com
Corresponding author: Zhao Hongmei. E-mail: zhaohongmeidu@163.com

Therefore, to accurately evaluate the photodegradation effect on litter decomposition in arid ecosystems, further study of the decomposition processes of surface litter and standing dead plants is still needed; this is of important theoretical and practical significance for comprehensively revealing the ecological effects of photodegradation.

The Gurbantünggüt Desert is the largest fixed and semi-fixed desert in China. It is rich in light and heat resources and has scarce precipitation. Its distinctive climatic conditions have fostered dominant plant communities that differ markedly from those in other deserts, such as *Haloxylon ammodendron*, *Nitraria sibirica*, and *Ceratocarpus arenarius*. Vegetation coverage is as high as 40%-55%, making it the main contributor to the soil carbon pool[^11-12]. Field observations indicate that vegetation senescence and litterfall in the Gurbantünggüt Desert occur synchronously with strong summer solar radiation, suggesting that photodegradation may be a key factor driving litter decomposition in this desert region[^3]. However, the limited existing studies have mostly focused on the effects of ultraviolet radiation on surface litter decomposition and nutrient release[^3,^13], while neglecting the role of standing dead plants in litter photodegradation. This omission prevents accurate assessment of the role of ultraviolet radiation in carbon turnover in arid ecosystems. Accordingly, this study, conducted on the southern margin of the Gurbantünggüt Desert, used *Haloxylon ammodendron*, *Nitraria sibirica*, and *Ceratocarpus arenarius* as study objects to investigate the effects of ultraviolet radiation on litter decomposition and nutrient release at different placement positions, to reveal the role of photodegradation in litter decomposition in arid ecosystems, and to provide a theoretical basis for constructing more accurate arid-region biogeochemical models and for assessing material cycling and energy transformation in arid ecosystems under future global change.

1 Materials and Methods

1.1 Overview of the Study Area

The study area is located in the Beishawo region on the southern margin of the Gurbantünggüt Desert (44°22$ ‘36’ ‘*N*, 87°55’ 26” $E). It has a typical temperate continental arid climate, with hot, dry summers and cold winters[^14]. The annual accumulated temperature is 3000–3500 °C, and annual precipitation is 70–150 mm, mainly concentrated from April to September, accounting for 60%–70% of the annual total. Potential annual evaporation exceeds 2000 mm. The soil type is desert solonchak, and the tops of dunes are aeolian sandy soil[^15]. The dominant vegetation species are *Haloxylon ammodendron*, *Artemisia ordosica*, *Ceratocarpus arenarius*, *Erodium oxyrrhinchum*, and *Centaurea pulchella*[^16].

1.2 Experimental Design

To examine the role of ultraviolet radiation (280–400 nm) in the decomposition of desert plant litter, a split-plot experimental design was adopted in an open, flat interdune lowland on the southern margin of the Gurbantünggüt Desert. Two main-plot treatments were established: ultraviolet exclusion (UV−) and ultraviolet transmission (UV+). Within each main plot, two subplots were established, corresponding respectively to two litter placement treatments: surface and aboveground. In each plot receiving ultraviolet-radiation treatment, ultraviolet-radiation devices carrying removable plastic templates (100 cm × 6.5 cm × 2 mm) were installed following the method of Brandt et al.[^17]. In the ultraviolet-exclusion treatment (UV−), polycarbonate shading panels were used; these filtered out 87% of UV-A and UV-B (280–400 nm) while transmitting 85% of photosynthetically active radiation (400–700 nm). To ensure consistency in climatic conditions other than ultraviolet radiation, acrylic shading panels were used in the ultraviolet-transmission treatment (UV+); these allowed 87% of UV-A and UV-B (280–400 nm) to pass through and transmitted 85% of photosynthetically active radiation (400–700 nm). Under the ultraviolet-radiation devices, litterbags were placed either on the soil surface (surface litter) or suspended on wire mesh 15 cm above the ground (aboveground litter), thereby simulating the decomposition of surface litter and standing dead plants under natural conditions, respectively. A total of 20 subplots were established in this experiment (4 treatments × 5 replicates), each with an area of 1.5 m^2 (1.5 m × 1.0 m) (Fig. 1). Within each main plot, a 1 m buffer zone was set between subplots to reduce mutual interference among quadrats. Meanwhile, to accurately assess changes in radiation under the ultraviolet-radiation devices, photosynthetically active radiation in each quadrat was measured monthly during the experiment using a light meter (Li-250A), and ultraviolet radiation (280–400 nm) in each quadrat was measured using a Spectrum 3415FX light sensor (Fig. 2).

In September 2023, at or near the end of the plant growing season, assimilating branches of *Haloxylon ammodendron* and litter leaves of *Nitraria sibirica* and *Ceratocarpus arenarius* were collected. After impurities were removed from the collected litter, the litter was placed in a 65 °C drying oven and dried to constant weight for later use. For each litter type, 6 g was weighed and placed into a 10 cm × 15 cm litter decomposition mesh bag. The decomposition bags were made of nylon, with a top mesh aperture of 2 mm and a bottom mesh aperture of 0.1 mm, to ensure a relatively large area exposed to solar radiation, allow microorganisms to pass through normally, and prevent litter fragments from being lost through the bottom mesh because of disturbance by small invertebrates[^18-19]. During sample loading, a plastic label was also placed in each bag to indicate the sample number, name, and deployment time. At the same time, five sets of samples of each litter type were weighed, ground using a mixed oscillatory grinder (Retsch-MM400), and analyzed for the initial chemical composition of the litter, including total C, total N, total P, total K, hemicellulose, cellulose, lignin, and ash. In October 2023, the weighed and labeled litter decomposition bags were deployed in the corresponding field quadrats. Twelve litterbags were randomly placed in each quadrat (3 litter types × 4 sampling times), for a total of 240 litterbags. Litter samples were collected after 38 d, 171 d, 262 d, and 357 d of decomposition. The retrieved samples were brought back to the laboratory; after adhering soil and other impurities on the litter surface were washed off, the samples were placed in a 65 °C drying oven and dried to constant weight, weighed, and then ground to determine the samples collected at each sampling time

Fig. 1. Schematic diagram of experimental plot layout

Text in figure: aboveground; surface; UV removal; UV transmission; replicate 1; replicate 2; replicate 3; replicate 4; replicate 5; 1.5 m; 1 m; 1 m.

Fig. 2. Changes in ultraviolet radiation and photosynthetically active radiation

under different treatments during the experiment period

Legend: surface UV removal; surface UV transmission; aboveground UV removal; aboveground UV transmission.
Panel (a): ultraviolet radiation / (μmol $\cdot$ m^{-2} $\cdot$ s^{-1}); time / year-month.
Panel (b): photosynthetically active radiation / (μmol $\cdot$ m^{-2} $\cdot$ s^{-1}); time / year-month.

the total N, total P, and ash contents of the samples.

1.3 Measurement Indices and Methods

Litter ash content was determined by the ashing method; total C was determined by the potassium dichromate volumetric method with external heating; total N was determined by the Kjeldahl nitrogen method after $H_2SO_4 - H_2O_2$ digestion; total P was determined by molybdenum-antimony colorimetry after $H_2SO_4 - H_2O_2$ digestion; and total K was determined by flame photometry after $H_2SO_4 - H_2O_2$ digestion [20]. Cellulose, hemicellulose, and lignin contents were measured using an ANKOM A200i semi-automatic fiber analyzer (ANKOM Technology Corp., Macedon, NY, USA) [21].

1.4 Data Processing and Analysis

During litter decomposition, the mass remaining rate, nutrient remaining rate, and changes in each chemical component were all expressed as relative ratios after ash removal. The mass remaining rate (M_r) and nutrient remaining rate (N_r) of litter [15] were calculated as follows:

$$M_r = M_t/M_0 \times 100\% \tag{1}$$

$$N_r = (M_t \times N_t)/(M_0 \times N_0) \times 100\% \tag{2}$$

where M_0 is the initial litter mass (g); M_t is the residual mass after litter decomposition for t days (g); N_0 is the initial concentration of nutrient elements in the litter (%); and N_t is the concentration of nutrient elements in the litter after decomposition for t days (%).

The Olson [22] negative exponential decay equation was used to fit the litter decomposition process and calculate the litter decomposition rate k, expressed as:

$$M_t/M_0 = e^{-kt} \tag{3}$$

where M_0 and M_t are as above; t is decomposition time (a); and k is the decomposition rate (g $\cdot$ g^{-1} $\cdot$ a^{-1}).

The relative contribution rate of ultraviolet radiation [23] was calculated as:

$$\text{Relative contribution rate of ultraviolet radiation (\%)} = \frac{k_{\text{UV transmission}} - k_{\text{UV removal}}}{k_{\text{UV transmission}}} \times 100\% \quad (4)$$

where $k_{\text{UV transmission}}$ is the litter decomposition rate under the UV-transmission treatment, and $k_{\text{UV removal}}$ is the litter decomposition rate under the UV-removal treatment.

Data processing and statistical analysis were performed with R software (4.2.3), and plotting was conducted with Origin 2024 and R (4.2.3); among these, R (4.2.3) was used only to draw the correlation heat map. One-way ANOVA was used to test differences in the initial chemical composition of litter among species; repeated-measures ANOVA was used to test the effects of decomposition time, ultraviolet radiation, and their interaction on litter mass remaining and nutrient remaining percentages; two-way ANOVA was used to test the effects of ultraviolet radiation, litter placement position, and their interaction on decomposition rate; a one-sample T-test was used to analyze the contribution of ultraviolet radiation to litter decomposition; and Pearson tests were used to analyze correlations between initial chemical composition and decomposition rate. Data in the figures and tables are means ± standard errors.

2 Results and Analysis

2.1 Initial chemical composition of litter

As shown in Table 1, the initial chemical composition of the litter components differed significantly ($P < 0.05$). In comparison, walnut litter had the highest initial P and K contents and the lowest initial C content; *Nitraria sibirica* litter had the lowest initial K content, lignin content, hemicellulose content, and lignin:N, and the highest initial N:P; whereas *Ceratocarpus arenarius* had initial C content, hemicellulose content, cellulose content, C:N, and lignin:N that were significantly higher than those of the other two species.

Table 1. Initial chemical composition of litters ($n = 5$)

<table>
<tr><th>Initial chemical component</th><th>Walnut</th><th>Nitraria sibirica</th><th>Ceratocarpus arenarius</th></tr>
<tr><td>C/%</td><td colspan="3">39.68$±0.42c|41.53±0.39b|45.06±0.50a||N/±0.27a|3.38±0.13a|2.00±0.01b||P/±0.003a|0.17±[illegible] N|11.46±0.48b|12.37±0.55b|22.48±0.23a||lignin : N|1.09±0.43b|0.68±0.04c|1.86±0.10a||N : P|18.43±0.40b|20.34±0.84a|12.45±$0.17c</td></tr>
</table>

Note: Different lowercase letters within the same row indicate significant differences among species ($P < 0.05$); data are means ± standard errors; n is the sample size.

2.2 Effects of ultraviolet radiation on litter mass remaining percentage and decomposition rate

Throughout the experimental period, the mass remaining percentages of the three litter species all showed a downward trend, and mass loss was mainly concentrated during 0–171 d of decomposition. After 357 d of decomposition, under the UV-transmitting treatment, the mass remaining percentages of above-ground and surface litter of walnut, *Nitraria sibirica*, and *Ceratocarpus arenarius* were 69.3% and 55.0%, 48.4% and 45.6%, and 75.4% and 45.8%, respectively; under the UV-exclusion treatment, their mass remaining percentages were 82.2% and 56.7%, 63.4% and 45.6%, and 85.5% and 55.1%, respectively. Comparative analysis of the effects of ultraviolet radiation on the decomposition of the three litter species showed that decomposition time significantly affected the mass remaining percentage of all three species ($P < 0.05$), whereas the effect of ultraviolet radiation on their decomposition varied with species and decomposition time. At 38 d and 171 d of decomposition, UV transmission significantly increased mass loss from above-ground walnut litter, surface *Nitraria sibirica* litter, and surface *Ceratocarpus arenarius* litter ($P < 0.05$). At 262 d of decomposition, compared with UV transmission, UV exclusion significantly reduced the mass loss of surface *Nitraria sibirica* litter by 13.4%. At 357 d of decomposition, under UV exclusion, mass loss from above-ground walnut litter, above-ground *Nitraria sibirica* litter, and above-ground and surface *Ceratocarpus arenarius* litter was significantly reduced by 12.9%, 15.0%, 10.1%, and 9.3%, respectively (Fig. 3).

The Olson negative-exponential decay model fitted the decomposition process of each litter component well ($R^2 = 0.64 \sim 0.98$, $P < 0.05$), and ultraviolet radiation and litter placement position significantly affected the decomposition rate of each litter component ($P < 0.05$). Under the same ultraviolet-radiation treatment, the decomposition rates of surface litter of the three species were all significantly higher than those of above-ground litter ($P < 0.05$) (Fig. 4a). Compared with UV exclusion, UV transmission significantly increased the decomposition rates of above-ground walnut litter, surface *Nitraria sibirica* litter, and above-ground and surface *Ceratocarpus arenarius* litter by 49.12%, 23.72%, 30.10%, and 17.84%, respectively (Fig. 4b). Pearson correlation analysis of the relationship between initial chemical composition and decomposition rate further showed that, under different ultraviolet-radiation treatments, the decomposition rates of surface and above-ground litter were significantly negatively correlated with initial K content, lignin content, hemicellulose content, and lignin:N; initial N:P was significantly positively correlated only with the decomposition rates of above-ground litter ($K1$ and $K2$), and initial N content was significantly positively correlated with the decomposition rate of above-ground litter under UV transmission ($K2$) (Fig. 4c).

2.3 Effects of ultraviolet radiation on nutrient remaining percentage during decomposition

2.3.1 Effects of ultraviolet radiation on N remaining percentage during decomposition During the entire experimental period, the N remaining percentages of the litter of all three species indicated net release. For aboveground litter, N release from the three species was mainly concentrated during 0–262 d of decomposition, whereas the N remaining percentage of surface litter decreased rapidly during 0–38 d of decomposition, after which the N remaining curve gradually tended to level off (Fig. 5). The results of repeated-measures ANOVA showed that decomposition time, ultraviolet radiation, and the interaction between decomposition time and ultraviolet radiation (except for aboveground walnut litter) had significant effects on the N remaining percentage of each litter component ($P < 0.05$), whereas the effect of ultraviolet radiation on N remaining percentage varied with species and decomposition time. At 38 d of decomposition, compared with ultraviolet

Visible figure text

Legend: UV exclusion; UV transmission

Column headings: **Aboveground**; **Surface**

- **(a) Saxaul** –mass remaining/%; UV **; Time *; T×UV ns
- **(b) Saxaul** –mass remaining/%; UV ns; Time ***; T×UV ns
- **(c) Small-fruited nitraria** –mass remaining/%; UV ns; Time ***; T×UV*
- **(d) Small-fruited nitraria** –mass remaining/%; UV *; Time* **; T×UV ns
- **(e) Horn-fruited chenopod** –mass remaining/%; UV ns; Time **; T×UV** ; decomposition time/d
- **(f) Horn-fruited chenopod** –mass remaining/%; UV *; Time* **; T×UV ns; decomposition time/d

Note: UV indicates ultraviolet-radiation treatment; Time indicates decomposition time; T×UV indicates the interaction between ultraviolet radiation and decomposition time; ns indicates not significant; * indicates $P < 0.05$, ** indicates $P < 0.01$, and *** indicates $P < 0.001$. The same applies below.

Fig. 3 Effects of ultraviolet radiation on mass remaining of aboveground and surface litter

exclusion, under the UV-transmission treatment, N release from saxaul aboveground and surface litter significantly increased by 6.0% and 9.5%, respectively; at 171 d of decomposition, under UV transmission, N release from small-fruited nitraria surface litter and horn-fruited chenopod surface litter significantly increased by 10.9% and 9.8%, respectively; at 262 d of decomposition, under UV transmission, N release from small-fruited nitraria surface litter significantly increased by 22.8%, whereas N release from horn-fruited chenopod aboveground litter significantly decreased by 17.9%; at 357 d of decomposition, under UV transmission, N loss from small-fruited nitraria aboveground litter and horn-fruited chenopod surface litter significantly increased by 21.5% and 11.1%, respectively.

2.3.2 Effects of ultraviolet-radiation treatment on P remaining percentage during decomposition

During decomposition, the aboveground and surface litter of the three species showed different P-release dynamics. Among them, P in the aboveground and surface litter of saxaul and small-fruited nitraria showed net release, whereas the P remaining percentage in the aboveground and surface litter of horn-fruited chenopod showed varying degrees of immobilization during decomposition (Fig. 6).

After 357 d of decomposition, under the UV-transmission treatment, the P remaining percentages of saxaul, small-fruited nitraria, and horn-fruited chenopod aboveground and surface litter were 34.3% and 45.7%, 24.2% and 50.7%, and 83.9% and 49.6%, respectively; under the UV-exclusion treatment, their P remaining percentages were 44.8% and 31.7%, 46.1% and 49.9%, and 83.9% and 57.7%, respectively. Decomposition time had a highly significant effect on the P remaining percentage of litter from the three species ($P < 0.001$), whereas the effect of ultraviolet radiation on P remaining percentage differed with species, decomposition time, and litter placement position. For aboveground litter, UV transmission significantly promoted P release from saxaul litter except at 262 d of decomposition, but significantly inhibited P release from horn-fruited chenopod litter at 171 d and 262 d of decomposition. For surface litter, UV transmission significantly promoted P release from small-fruited nitraria except at 357 d of decomposition and from horn-fruited chenopod except at 262 d of decomposition, but at 171 d and 357 d of decomposition, saxaul P release

Fig. 4 (visible figure text).
Panel (a): legend—UV removed; UV transmitted. Y-axis: decomposition rate. X-axis: aboveground and soil surface placements for saxaul, small-fruited *Nitraria*, and *Ceratocarpus*. ANOVA labels shown above the bars: for saxaul, UV*, Position***, UV×P ns; for small-fruited *Nitraria*, UV**, Position***, UV×P ns; for *Ceratocarpus*, UV***, Position***, UV×P ns.
Panel (b): Y-axis: contribution rate of ultraviolet radiation/%; X-axis: aboveground and soil surface placements for saxaul, small-fruited *Nitraria*, and *Ceratocarpus*.

Panel (c): color legend—correlation coefficient. Columns: K1, K2, K3, K4. Rows and visible coefficients: C: −0.24, −0.52*, −0.22, −0.05; N: 0.50, 0.59*, 0.42, 0.30; P: −0.20, 0.12, 0.06, −0.32; K: −0.86***, −0.61*, −0.61*, −0.84***; lignin: −0.85***, −0.63*, −0.59*, −0.70**; hemicellulose: −0.68**, −0.76**, −0.60*, −0.53*; cellulose: −0.51, −0.69**, −0.51, −0.35; C:N: −0.48, −0.63*, −0.44, −0.30; lignin:N: −0.75**, −0.74**, −0.60*, −0.55*; N:P: 0.69**, 0.68*, 0.49, 0.50.

Note: Different lowercase letters indicate significant differences in decomposition rate between different ultraviolet-radiation treatments for the same species at the same placement position ($P<0.05$); * indicates a significant difference in decomposition rate between placement positions for the same species under the same ultraviolet-radiation treatment; * indicates $P<0.05$; ** indicates $P<0.01$; *** indicates $P<0.001$. Position refers to litter placement position, and UV×P indicates the interaction between ultraviolet radiation and litter placement position. K1 and K2 represent the decomposition rates of aboveground litter under the UV-removal and UV-transmission treatments, respectively; K3 and K4 represent the decomposition rates of soil-surface litter under the UV-removal and UV-transmission treatments, respectively.

Figure 4 Contribution of ultraviolet radiation to the decomposition rate of litter and its relationship with initial chemical composition

Fig. 4 Contribution of ultraviolet radiation to the decomposition rate of litter and its relationship with initial chemical composition

were significantly reduced by 17.2% and 14.0%, respectively. After 357 d of decomposition, compared with UV removal, UV transmission significantly increased P release from aboveground saxaul litter, aboveground small-fruited *Nitraria* litter, and soil-surface *Ceratocarpus* litter by 10.5%, 21.9%, and 8.1%, respectively.

3 Discussion

3.1 Effects of ultraviolet radiation on the decomposition of soil-surface and aboveground litter

In arid and semi-arid regions, ultraviolet radiation is a key environmental factor driving litter decomposition[24–25]. Most studies have shown that ultraviolet radiation can accelerate litter mass loss and promote decomposition[2,9,13,26]. In desert regions with different precipitation levels, Huang et al.[13] found that, compared with UV exclusion, UV transmission significantly promoted the mass loss of saxaul, reed, and wheat litter at three sites, increasing their decomposition rates by 23%–70%. In different grassland ecosystems, Yang et al.[27] found that ultraviolet radiation promoted the decomposition of rough cleistogenes litter. In the present study, ultraviolet radiation promoted the mass loss of saxaul, small-fruited *Nitraria*, and *Ceratocarpus* litter to varying degrees, significantly increasing their decomposition rates by 17.84%–49.12%, which supports previous studies. Conversely, some studies have shown that ultraviolet radiation has no effect on litter decomposition or even inhibits it[9-10,28]. For example, Gallo et al.[29] showed that ultraviolet radiation had no significant effect on the decomposition of juniper and dwarf pine litter. Rozema et al.[30] found that enhanced UV-B radiation could increase the lignin content of *Calamagrostis epigeios* litter, thereby reducing the decomposition rate. Differences among studies indicate that environmental characteristics of the study area, species traits, and decomposition stage are very likely to affect the sensitivity of litter to photodegradation, leading to differences in results among studies[17,31].

Previous studies have found that ultraviolet radiation promotes litter mass loss to a certain extent, but its photodegradation effect strengthens as radiation dose, environmental aridity, and drought duration increase[26,32-33]. In arid and semi-arid regions rich in light and heat resources, vegetation cover is low and the amount of radiation reaching the ground surface is relatively large; ultraviolet radiation therefore usually promotes litter decomposition. In warm and humid climatic regions, however, biological factors may dominate the litter decomposition process, resulting in a relatively small influence of ultraviolet radiation on decomposition[27]. In a shortgrass prairie ecosystem, Brandt et al.[17] showed that under drought conditions, compared with UV removal, the decomposition rate of litter under UV transmission increased by 25%, whereas under humid conditions ultraviolet radiation had no significant effect on decomposition. Even within the same climatic region, the effect of ultraviolet radiation on decomposition may vary with litter quality. Some studies have found that UV transmission significantly promotes the decomposition of litter with high C:N, but has no significant effect on litter with low C:N[17]. Other studies have shown that, because of high light absorptivity, the higher the lignin:N of litter, the stronger the effect of ultraviolet radiation on its decomposition[27]. For the litter placed on the soil surface in the present study, after 357 d of decomposition, ultraviolet radiation did not significantly affect the mass remaining of saxaul litter, but significantly promoted the decomposition of small-fruited *Nitraria* and *Ceratocarpus*. This indicates that differences in the initial chemical composition of species largely interfered with the photodegradation effect during litter decomposition, leading to differences among species in the response of litter decomposition to ultraviolet radiation. It can therefore be seen that species chemi-

Legend: ultraviolet removed; ultraviolet transmitted; ultraviolet removed; gray bar ultraviolet transmitted

Aboveground Surface

(a) Saxaul
Left y-axis: nitrogen remaining/%; right y-axis: nitrogen release/%
UV **
Time ***
T×UV ns

(b) Saxaul
Left y-axis: nitrogen remaining/%; right y-axis: nitrogen release/%
UV **
Time *
T×UV **

(c) Small-fruited *Nitraria*
Left y-axis: nitrogen remaining/%; right y-axis: nitrogen release/%
UV ns
Time ***
T×UV **

(d) Small-fruited *Nitraria*
Left y-axis: nitrogen remaining/%; right y-axis: nitrogen release/%
UV ns
Time ***
T×UV ***

(e) Horn-fruited goosefoot
Left y-axis: nitrogen remaining/%; right y-axis: nitrogen release/%
UV ns
Time ***
T×UV ***

(f) Horn-fruited goosefoot
Left y-axis: nitrogen remaining/%; right y-axis: nitrogen release/%
UV ns
Time ***
T×UV **

x-axis: decomposition time/d

Fig. 5 Effects of ultraviolet radiation on nitrogen remaining in aboveground and surface litter

Litter chemical characteristics are key factors influencing photodegradation effects. Under future climate-change scenarios, it will still be necessary to pay attention to the combined effects of ultraviolet radiation and factors such as litter quality, so as to comprehensively understand the potential influence of photodegradation on material cycling in arid-zone ecosystems.

Microclimatic changes caused by litter placement position may also affect the decomposition process of litter. Almagro et al. [31] found that, across different habitats and litter types, mass loss of surface litter was faster than that of aboveground litter, and that photodegradation contributed more to the decomposition of surface litter. In the present study, under the same ultraviolet-radiation treatment, the decomposition rates of surface litter from all three species were significantly faster than those of aboveground litter, supporting previous studies. The reasons may be as follows. On the one hand, surface litter is in direct contact with the soil, and abiotic processes such as physical fragmentation and abrasion caused by wind-blown sand burial may accelerate mass loss of surface litter and promote its rapid decomposition [34]. In contrast, aboveground litter is directly exposed to the atmosphere, where microbial activity is relatively low and colonization pathways are fewer; at the same time, it lacks processes such as animal activity and the physical fragmentation of litter by wind-blown sand movement, thereby resulting in a relatively lower decomposition rate of aboveground litter [35-36]. On the other hand, compared with surface litter, aboveground litter is directly exposed to ultraviolet radiation; ultraviolet light may directly damage microbial DNA and proteins, reduce fungal abundance, inhibit metabolic activity, and lower the decomposition rate [37]. Thus, litter placement position also affected the litter decomposition process to a certain extent, altering the relative contributions of photodegradation and microbial decomposition to litter decomposition [10]. However, this study did not simultaneously measure microbial [[unclear: text continues on next page]]

Visible labels in Fig. 6. Legend: UV excluded; UV transmitted. Columns: Aboveground; Surface. Left y-axis: P remaining rate/%; right y-axis: P release/%; x-axis: Decomposition time/d. Panels: (a) *Haloxylon ammodendron*; (b) *Haloxylon ammodendron*; (c) *Nitraria sibirica*; (d) *Nitraria sibirica*; (e) *Ceratocarpus arenarius*; (f) *Ceratocarpus arenarius.* Significance annotations: (a) UV *, Time* **, T×UV ns; (b) UV ns, Time** *, T×UV* **; (c) UV ns, Time** *, T×UV* **; (d) UV *, Time*** , T×UV **; (e) UV ns, Time** *, T×UV ns; (f) UV* ***, Time*** , T×UV ns.

Fig. 6. Effects of ultraviolet radiation on the P remaining rate of aboveground and surface litter

···microbial activity and community structure. In future research, changes in microbial community structure should also be incorporated to further analyze the role of photodegradation in litter decomposition. This will help reveal the decomposition mechanisms of litter in desert ecosystems and enable more accurate prediction of carbon budgets in arid-region ecosystems.

3.2 Effects of ultraviolet radiation on nutrient release from surface and aboveground litter

Litter decomposition is accompanied by nutrient immobilization and release. Throughout the entire experimental period, under all ultraviolet-radiation treatments, the decomposition of surface and aboveground litter of *Haloxylon ammodendron* and *Nitraria sibirica* showed net release of N and P nutrients, supporting previous studies. In the same study area, Zhang Caiyun et al.[15] found that, under natural light conditions, the decomposition of litter from *Tamarix ramosissima*, *Salicornia europaea*, and their mixtures all exhibited net release of N and P nutrients, with relatively rapid release during the early stage of decomposition. In a semiarid grassland, Wang et al.[38] showed that *Artemisia frigida* litter exhibited net release of P and K nutrients. The reason may be that *Haloxylon ammodendron* and *Nitraria sibirica* had relatively high initial

N contents and low initial C:N ratios ($ $20), so their decomposition processes may have met the nutrient demands of microbial decomposers, thereby directly releasing nutrients[10,39-40]. However, this study also found that the P remaining rate of surface and aboveground litter of *Ceratocarpus arenarius* followed a release-immobilization-release pattern. The enrichment of P during decomposition may be because, as decomposition proceeded, the P nutrients in *Ceratocarpus arenarius* itself could not meet the demands of microbial decomposers; microbes therefore immobilized P from the surrounding environment, resulting in an increase in the P remaining rate. This finding is also consistent with the conclusions of Song Xinzhang et al.[41].

Differences in litter placement position and decomposition stage may also alter the response of nutrient dynamics during litter decomposition to ultraviolet radiation[39-40,42-43].

Erdenebileg et al. [10] found that ultraviolet (UV) radiation promoted N loss in most surface litter, but its effect on N loss in standing litter varied among species: it significantly promoted N release from standing litter of *Agriophyllum squarrosum*, while inhibiting N loss from standing litter of *Calamagrostis pseudophragmites*. Other studies have shown that UV radiation significantly promoted only N and P nutrient release from *Castanopsis eyrei* litter and P release from *Cyclobalanopsis glauca* litter, while slowing P release from *Cinnamomum camphora* litter and having no significant effect on N or P release from other species [44]. Consistently, this study found that UV radiation affected the release of N and P nutrients during litter decomposition, and that the magnitude and direction of the effect varied with litter placement position and species. At 357 d of decomposition, compared with the UV-exclusion treatment, the UV-transmission treatment promoted, to varying degrees, nutrient release from the surface litter of *Haloxylon ammodendron*, *Nitraria sibirica*, and *Ceratocarpus arenarius*—except for P release from surface litter of *H. ammodendron*—as well as from the standing litter of *H. ammodendron* and *N. sibirica*, supporting previous studies. The reasons may be as follows. On the one hand, UV radiation may reduce nutrient immobilization by microbial decomposers, so that the decomposition process is directly manifested as the release of N and P nutrients [11]. On the other hand, when litter is placed on the soil surface, it can, to a certain extent, promote the formation of soil aggregates, improve soil structure, enhance microbial activity, or optimize microbial community structure, thereby promoting rapid mass loss and nutrient release from surface litter [45]. It is worth noting, however, that at 171 d or 262 d of decomposition, UV transmission significantly inhibited N and P release from standing litter of *C. arenarius*, as well as P release from surface litter of *H. ammodendron*. This suggests that the mechanisms by which UV radiation affects nutrient release during litter decomposition are complex, and that differences among decomposition stages or microenvironmental changes caused by litter placement may influence the role of UV radiation in litter decomposition [10,44]. At the same time, it also indicates that, owing to differences in species traits, the balance between biological and abiotic processes during the decomposition of litter components may also affect the differing responses of nutrient dynamics to UV radiation [29]. Given the complexity of the factors and mechanisms influencing litter decomposition, long-term fixed-site studies are still needed to clarify the long-term effects of UV radiation on nutrient dynamics during litter decomposition, so as to predict nutrient cycling in arid ecosystems under future climate change.

4 Conclusion

By examining the responses of decomposition and nutrient release of surface and standing litter in a temperate desert to UV radiation, this study found that, over the entire experimental period, UV radiation generally promoted, to a certain extent, the mass loss and nutrient release of litter from *H. ammodendron*, *N. sibirica*, and *C. arenarius*, thereby accelerating their decomposition. However, the magnitude and direction of this effect varied with litter placement position, species, and decomposition time. Under the same UV-radiation treatment, significant differences existed between surface and standing litter decomposition among the three species: decomposition and N and P nutrient release were faster in surface litter than in standing litter. This indicates that, in desert ecosystems, standing dead plants constitute an important stage in the process from senescence to death and decomposition of desert vegetation.

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Response of surface and aboveground litter decomposition

to ultraviolet radiation in temperate deserts

HE Ziwei, LI Yongping, SHEN Xiaohan, KOU Tianle, HU Yutong, CHENG Junhui, ZHAO Hongmei

(College of Resources and Environment, Xinjiang Agricultural University, Key Laboratory of Soil and Plant Ecological Processes in Xinjiang, Urumqi 830052, Xinjiang, China)

Abstract: A split-plot experimental design was used to investigate the litter decomposition of three common plant species (*Haloxylon ammodendron*, *Nitraria sibirica*, and *Ceratocarpus arenarius*) in the Gurbantunggut Desert. The experiment included two UV treatments (UV block and UV pass) and two placement positions (surface and aboveground) conducted over a 357 day period. The results show that UV radiation promoted mass loss of desert plant litter to different extents. After 357 days, compared with UV block, UV pass increased the decomposition rates of aboveground litter of *H. ammodendron*, surface litter of *N. sibirica*, aboveground litter of *C. arenarius*, and surface litter of *C. arenarius* by 49.12%, 23.72%, 30.10%, and 17.84%, respectively. Under the same UV treatment, surface litter decomposed significantly faster than aboveground litter across all three species. Throughout the experiment, both surface and aboveground litter of *H. ammodendron* and *N. sibirica* showed net releases of N and P, whereas *C. arenarius* exhibited varying degrees of P immobilization. Compared with UV block, UV pass generally facilitated nutrient release during litter decomposition of the three species, although the magnitude and direction of these effects depended on both litter placement position and decomposition time. After 357 days, UV pass significantly increased the N and P release from the aboveground litter of *N. sibirica* by 21.5% and 11.1%, respectively; and from surface litter of *C. arenarius* by and 21.9% and 8.1%, respectively. These findings demonstrate that UV radiation is a key environmental factor regulating litter decomposition and nutrient release in arid regions, and it plays a critical role in accurately predicting nutrient cycling in dryland ecosystems.

Keywords: desert ecosystem; litter decomposition; decomposition rate; nutrient release; ultraviolet radiation

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