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Positive and negative effects of UV irradiance explain interaction of litter position and UV exposure on litter decomposition and nutrient dynamics in a semi-arid dune ecosystem

Enkhmaa Erdenebileg[a,b], Xuehua Ye[a], Congwen Wang[a,b], Zhenying Huang[a,*], Guofang Liu[a,**], Johannes H.C. Cornelissen[c]

[a] State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences, Beijing 100093, PR China
[b] University of Chinese Academy of Sciences, Beijing 100049, PR China
[c] Systems Ecology, Department of Ecological Science, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam, the Netherlands

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ABSTRACT

Solar radiation mediated photodegradation of leaf litter has been studied substantially as it plays important roles in the cycling of carbon (C) and nutrients in dryland ecosystems. However, the mechanism by which ultraviolet (UV) radiation and its interaction with litter quality and microbial degradation affect dryland litter decomposition is still uncertain. A field experiment was carried out in semiarid *Mu Us* inland dunes of Inner Mongolia, China to investigate the effects of UV radiation and litter position on leaf litter decomposition of eight contrasting species (three perennial grasses, three shrubs, two annual forbs) representing different litter qualities over a whole year of incubation. The results showed that UV radiation increased mass loss of suspended litters for two perennial grasses and two annual forbs, but had no significant effect on the other four species considered; across species the percentage increase in mass loss ranged from 4.5 to 27.3% with an average of 13.7%. C release from suspended litters in response to UV radiation showed similar patterns with mass loss. Nitrogen (N) release from litters on the soil surface was lower than in suspended position because the former was involved in N immobilization driven by microbial decomposition. There were no net effects of UV radiation on decomposition rates of surface litters possibly due to the positive effects of photochemical process offsetting negative effects on microbes. Multiple linear regressions showed that the C:N ratio of initial leaf litter and leaf dry matter content (LDMC) could predict the rate of litter decomposition, in which litter C:N ratio had stronger influence. The findings, based on multiple species, highlight the importance of photodegradation on litter nitrogen and/or carbon mineralization in drylands as mediated by different abiotic and biotic drivers.

1. Introduction

Decomposition of plant litter plays a crucial role in the cycling of carbon (C) and nutrients (Berg and McClaugherty, 2008; Swift et al., 1979). In and across most terrestrial ecosystems and climatic regions, litter decomposition is controlled by three main factors: incubation environment, litter quality and decomposer community composition (Coûteaux et al., 1995). These three factors modulate the fluxes of carbon and nutrients with different relative contributions in different ecosystem types or regions (Bradford et al., 2014; Cornwell et al., 2008; Gholz et al., 2000; Liu et al., 2015a, 2018; Swift et al., 1979). Drylands comprise approximately 40% of global land cover and account for roughly 20% of the soil organic carbon pool (Lal, 2004; Reynolds et al., 2007). In contrast with biotically driven litter decomposition in mesic ecosystems (Bradford et al., 2014; Liu et al., 2015a), abiotic photodegradation is a predominant control on the cycling of C and nutrients in dryland ecosystems (Austin, 2011; Austin and Vivanco, 2006). The different contributions of these competing pathways between mesic and xeric ecosystems have challenged accurate predictions of global litter decomposition rates and associated nutrient fluxes (Parton et al., 2007; Throop and Archer, 2009).

One of the most documented effects of human activity on the environment is the reduction of stratospheric ozone resulting in an increase of biologically harmful ultraviolet (UV) radiation, especially UV-

* Corresponding author.
** Corresponding author.
E-mail addresses: enkhmaa@ibcas.ac.cn (E. Erdenebileg), yexuehua@ibcas.ac.cn (X. Ye), wangcw@ibcas.ac.cn (C. Wang), zhenying@ibcas.ac.cn (Z. Huang), liugf@ibcas.ac.cn (G. Liu), j.h.c.cornelissen@vu.nl (J.H.C. Cornelissen).

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B (Bornman et al., 2015). Many researchers have investigated direct and indirect effects of UV, particularly UV-B effects on plant growth, litter decomposition (Pancotto et al., 2003; Rozema et al., 1997) and terrestrial carbon and nutrient cycling (Smith et al., 2009). In contrast with microbial decomposition, UV radiation affects litter decomposition by direct photochemical degradation of the litter (Brandt et al., 2007). Photodegradation is the photochemical mineralization of photo-reactive compounds such as lignin or cellulose (Bornman et al., 2015; King et al., 2012). Generally, UV radiation has been demonstrated to stimulate litter decomposition in arid and semi-arid terrestrial ecosystems (Austin and Ballaré, 2010; Austin and Vivanco, 2006; Brandt et al., 2010; Day et al., 2007, 2015; Gaxiola and Armesto, 2015; Lin and King, 2014). However, direct exposure to UV-B radiation can also reduce microbial decomposition by inhibiting microbial activity or altering microbial community composition (Johnson, 2003; Robson et al., 2005). Additionally, some studies reported that photodegradation by UV radiation could increase subsequent microbial decomposition, which is called the photopriming effect (Gaxiola and Armesto, 2015; Huang et al., 2017; Lin et al., 2017). However, Kirschbaum et al. (2011) did not find such an effect of UV radiation on subsequent microbial decomposition. The net effect of UV radiation on the litter decomposition rates thus largely depends on the balance between the positive effect on abiotic photodegradation or subsequent microbial decomposition and the negative effect on microbial activity and composition (Smith et al., 2010; Wang et al., 2015, 2017b).

The impact of UV radiation on leaf litter decomposition also depends on litter chemistry (Brandt et al., 2007; King et al., 2012; Uselman et al., 2011). However, the effects of UV radiation on litter decomposition as dependent on litter quality are inconsistent (Brandt et al., 2007; King et al., 2012; Liu et al., 2018; Uselman et al., 2011). Litter position, either falling onto the surface versus intercepted or standing above the surface, can also affect decomposition rates and could possibly modify the relative contribution of photodegradation and microbial decomposition to the cycling of C and nutrients. In semiarid and arid ecosystems, most litter, particularly that of grasses and forbs, can remain standing for several months or seasons (Wang et al., 2017a). Thus standing litter decomposition also plays important roles in C and nutrient cycling of drylands. Most studies have found that suspended litters were decomposed more slowly than litters placed on the soil surface (Almagro et al., 2017; Dukes and Field, 2000; Thurow, 1989). It was thought that the proximity of litter to the soil surface increased litter decomposition mostly due to effects of the microbial activity. However, faster litter decomposition above the surface than on the soil surface has been found too and attributed to a stronger effect of wind abrasion (Lin and King, 2014).

Up to now, the interactive effects of UV radiation, litter position, and species (with different litter qualities) on dryland litter decomposition are unclear. To answer this question, leaf litters of eight contrasting species were exposed in a semiarid ecosystem to experimentally manipulated UV radiation using specially designed screens (UV pass versus UV block), in positions both at the surface and suspended above the surface, for one year. Due to distinct abiotic and biotic environmental conditions between surface and suspended locations, there should be strong interaction between litter position and UV exposure on litter decomposition across eight species with different litter qualities. Thus, the hypothesis is that UV radiation would increase litter decomposition rates and C and nitrogen (N) mineralization of suspended leaf litters compared with UV block treatment, but it would decrease decomposition rates and C mineralization and microbial N immobilization of surface litters due to a negative effect on microbial composition and activity for most species.

2. Materials and methods

2.1. Study site

The field work was conducted at the Ordos Sandland Ecological Research Station (OSERS) in *Mu Us* inland dune, Institute of Botany, Chinese Academy of Sciences (Inner Mongolia, China, 39°29′37.6″N, 110°11′29.4″E, 1290 m a.s.l.). This site experiences a continental climate with extreme seasonal and diurnal temperature variation and low annual rainfall amount. Mean annual temperature is 6.2 °C and mean annual precipitation is 369 mm, 80% of which falls during the growing season from April to August (Liu et al., 2010). The soil in this area is sandy texture that the percentage of sand is over 90% (see Gao et al., 2016). Soil N fertility is low (N concentration 0.081 ± 0.009 g N kg^{-1} versus 0.405 ± 0.031–0.491 ± 0.028 g N kg^{-1} for other vegetation types such as desert, desert steppe and typical steppe across Ordos Plateau; authors' unpublished data). Since strong winds occur in winter and early spring, both wind erosion and sand burial are common processes in this area. Nowadays the landscape in this region is characterized by mobile, semi-fixed and fixed inland dunes, where vegetation comprises perennial shrubs (dominated by *Artemisia ordosica* Krasch., *Hedysarum mongolicum* Turcz., *Salix psammophila* C. Wang et Ch. Y. Yang, *Caragana korshinskii* Kom.) and annual herbs (dominated by *Agriophyllum pungens* (Vahl) Link ex A. Dietr, *Corispermum chinganicum* Iljin) together accounting for 30–50% coverage (authors' unpublished data).

2.2. Litter collection and quality

For the vegetation described above, recently senesced leaf litters of eight species had been collected from the plants or the soil surface from the beginning of October through mid-November 2015. Leaf litters sampled from the soil surface could be recognized as recently senesced based on leaf color and texture. The species used were three shrubs *Salix psammophila* C. Wang et Ch. Y. Yang, *Caragana korshinskii* Kom., *Atraphaxis bracteata* A. Los., three perennial grasses *Psammochloa villosa* (Trin.) Bor, *Calamagrostis pseudophragmites* (Hall. f.) Koel., *Pennisetum centrasiaticum* Tzvel., two annual forbs *Corispermum chinganicum* Iljin and *Agriophyllum pungens* (Vahl) Link ex A. Dietr.

For measurements of functional traits that may correlate with litter decomposition rates across species, green leaves of the eight species were sampled at the end of August 2015 within an area of about 5 ha around OSERS. These samples were put into nylon bags and immersed into water to be rehydrated. They were fully saturated for one night, then wiped gently with filter paper, weighed and scanned with a resolution of 300 dpi using a plane scanner (UNIS Uniscan D6810, Tsinghua Unisplendour Co., Ltd.); their leaf areas were measured using ImageJ software (https://imagej.nih.gov/ij/index.html). They were then oven-dried at 65 °C for 48 h to obtain the dry weights. Leaf dry matter content (LDMC, g g^{-1}) was determined as green leaf dry mass divided by its saturated mass and specific leaf area (SLA, cm^2 g^{-1}) as green leaf area divided by its dry mass (Cornelissen et al., 2003). LDMC and SLA (or its inverse, leaf mass per area) are now commonly used as negative and positive indicators of litter decomposability, respectively (Cornwell et al., 2008; Fortunel et al., 2009).

2.3. Decomposition experiment

In order to assess the influences of UV radiation and litter position (soil surface versus suspended above the surface) on litter decomposition, a plot at OSERS with a size of 20 × 23 m was established near the meteorological station to host 10 subplots with a size of 2.4 × 4.4 m each. The standing plants and litters were removed by hand (Fig. S1). In this study, four subplots (two UV treatments × two litter positions) were used to examine responses of leaf litter decomposition. A UV screen treatment design was adopted based on the method reported by