Science of the Total Environment 601–602 (2017) 784–792

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Litter decomposition in hyper-arid deserts: Photodegradation is still important

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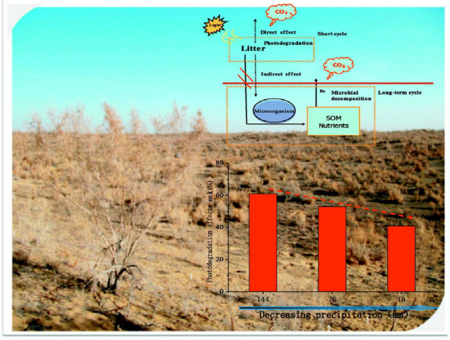
HIGHLIGHTS

- UV radiation increased litter decomposition in hyper-arid regions.
- Photodegradation effects were not strongest at the driest region.
- Photodegradation effects on N loss dynamic depended on litter quality.
- Lignin loss did not account for the increased mass loss under UV radiation.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 8 March 2017
Received in revised form 22 May 2017
Accepted 23 May 2017
Available online xxxx

Editor: Simon Pollard

Keywords:
C:N ratio
Cell solubles
Hyper-arid regions
Nitrogen dynamics
Photodegradation
UV radiation

ABSTRACT

Photodegradation due to litter exposure to solar UV radiation is presumed to contribute to the surprisingly fast decomposition in some arid and semi-arid regions; however, few studies have directly examined photodegradation effects in hyper-arid regions (annual precipitation <150 mm) and its dependence on precipitation. Three litters with different initial qualities (low vs high C:N) were decomposed under full spectrum sunlight (UV radiation) and UV filtering from solar radiation at three sites with contrasting precipitation amounts (144 mm, 76 mm and 16 mm) for 2.5 years. UV radiation increased mass loss and litter decomposition rates by 23–70%. UV photodegradation effects (UVE) on litter decomposition rate differed among experimental sites, with significantly stronger effects in less arid sites (144 mm and 76 mm) than more arid site (16 mm). High-quality litter (low C:N ratio) showed the fastest decomposition rate, and UVE was also affected by litter quality, but no consistent trend was observed. Litter N loss was greatest in full sunlight and the linear relationships between C and N contents was not changed by UV filtering over time. UV radiation increased C loss of all fractions, and hemicellulose and cell solubles showed significant contributions to litter mass loss. Our findings suggest that UV photodegradation can increase mass loss and nutrient release by the positive priming effects on microbial decomposition in hyper-arid regions, although UVE differed among three sites with contrasting precipitation amounts.

1. Introduction

Litter decomposition is one of the most important processes in carbon (C) and nutrient cycling in terrestrial ecosystems (Berg and Mc-Claugherty, 2008; Campos et al., 2017). Traditional decomposition

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http://dx.doi.org/10.1016/j.scitotenv.2017.05.213
0048-9697/

models combining climate parameters (precipitation and temperature) with litter chemical traits (C:N, lignin:N) can only predict litter mass loss dynamics in mesic ecosystems (Meentemeyer, 1978; Moorhead et al., 1996; Gholz et al., 2000; Parton et al., 2007). However, litter decomposition in arid ecosystems exhibits more rapid rates than models have predicted, despite the inhibited local microbial decomposition under low water availability (Whitford et al., 1981; Moorhead et al., 1996; Gholz et al., 2000). Scientists have proposed that a series of abiotic factors, including photodegradation, leaching, physical fragmentation and sand burial, may have contributed to the rapid litter decomposition (Austin and Vivanco, 2006; Brandt et al., 2007; Day et al., 2007; Epp et al., 2007; Austin and Ballare, 2010).

It is worth noting that positive roles of photodegradation in litter decomposition have often been observed in areas with an annual precipitation ranging 152–726 mm (Pancotto et al., 2003, 2005; Austin and Vivanco, 2006; Day et al., 2007; Brandt et al., 2009; Austin and Ballare, 2010; King et al., 2012; Almagro et al., 2015; Day et al., 2015), and empirical studies in hyper-arid regions with an annual precipitation <150 mm are very scarce. In hyper-arid regions, low precipitation makes photodegradation more possible since plant litters can receive more solar radiation due to the low vegetation cover (Austin and Vivanco, 2006), while inhibiting microbial decomposition, although photodegradation supplies easily decomposable substrates to microbes (Pancotto et al., 2003; Austin and Vivanco, 2006; Brandt et al., 2007, 2009, 2010; Smith et al., 2010). Therefore, litter decomposition in hyper-arid regions is dependent on the balance between positive abiotic degradation and the negative effects of low water available on microbial decomposition. Empirical studies in hyper-arid regions can help us understand the photodegradation role in a wider precipitation gradient in arid and semiarid regions (Duguay and Klironomos, 2000; Pancotto et al., 2003; Belnap et al., 2008).

Litter decomposition is closely associated with nitrogen (N) dynamics, and microbial N mineralization or immobilization is determined by the stoichiometric balance between soil microbes and litters (Manzoni et al., 2010). N immobilization is common during decomposition in humid regions because of the higher ratios of litter C:N (Parton et al., 2007; Manzoni et al., 2008, 2010; Gallo et al., 2009; Keuskamp et al., 2015), and higher initial N concentrations can promote litter decomposition rates (Michopoulos et al., 2004; Vanderbilt et al., 2008). N immobilization seldom occurs in arid regions due to the high photodegradation and low microbial activity and carbon-use efficiency (Brandt et al., 2007; Parton et al., 2007; Rustad, 2008; Lin et al., 2015b; Wang et al., 2015; Yanni et al., 2015). Thus, N release pattern reflects photodegradation role in litter decomposition and its photo-priming effects on microbial decomposition.

Carbon fractions (including cell solubles, lignin, cellulose and hemicellulose) differ in bonding energy, UV absorption coefficient and resistance to microbial decomposition (Austin and Vivanco, 2006). Lignin is identified as a photosensitive compound (George et al., 2005), and photodegradation effects are stronger for litters with a higher lignin concentration (Moorhead and Callaghan, 1994; Austin and Ballare, 2010). However, a recent meta-analysis study showed a negative relationship between photodegradation effect and initial lignin content, and the narrow range of lignin content was ascribed to the negative lignin role in photodegradation (King et al., 2012). Despite the disputed roles of lignin in photodegradation, lignin loss is identified as a critical part of mass loss in some empirical (Day et al., 2007; Austin and Ballare, 2010) and modeling (Moorhead and Callaghan, 1994) studies. More studies including litter C fraction loss dynamics can help to know the role of lignin in photodegradation.

Temperate deserts in Central Asia account for 90% area of the world's temperate desert, where vegetation coverage can reach up to 40%, and substantial litter production overlaps with the strong UV radiation in summer, implying the possibility of strong photodegradation. In this study, three litters with different initial qualities (low C:N vs high C:N) subjected to full sunlight and UV radiation filtering treatments were decomposed at three sites with contrasting annual precipitation amounts of 144 mm, 76 mm and 16 mm for 2.5 years. Our main aim was to assess the photodegradation effects in hyper-arid regions and its dependence on litter quality. Two hypotheses were proposed: first, the relative contribution of photodegradation would be stronger in more hyper-arid site due to the decreasing microbial decomposition with decreasing moisture; second, UV radiation filtering would decrease litter N immobilization and increase lignin loss due to photo-priming effects on microbial decomposition. This study can help us further understand the photodegradation effects and underlying mechanisms in hyper-arid regions; moreover, it would help to extend litter decomposition models from humid to a wide spectrum of dry climates.

2. Materials and methods

2.1. Site description

The study was simultaneously conducted at three sites, the margin (44°22′N, 87°55′E, 460 m a.s.l.) and the center (45°15′N, 87°36′E, 507 m a.s.l.) of the Gurbantunggut Desert, and the margin of the Turpan Desert (40°51′N, 98°11′E, - 86 m a.s.l.) (Fig. S1). At the margin of the Gurbantunggut Desert, the annual mean precipitation is 144 mm, of which 60% to 70% is distributed in the plant growth season from late April to early September, and the annual mean temperature is 6.6 °C. Soils are desert solonetz, with aeolian sandy soil at the top (0–100 cm). The shrubs are primarily *Haloxylon ammodendron*, *Haloxylon persicum*, and *Tamarix ramosissima*, with coverage of ca. 30%. The herbaceous layer is composed of *Erodium oxyrrhynchum*, *Alyssum linifolium*, *Schismus arabicus*, *Lactuca undulate*, *Salsola subcrassa*, *Ceratocarpus arenarius*, *Seriphidiam santolinum*, and *Agriophyllum squarrosum*, with a coverage reaching 40% at growth peak. At the center of the Gurbantunggut Desert, the multiyear precipitation is 76 mm, predominantly occurring in spring. The average annual temperature is 7.3 °C. *Ephedra distachya* is the dominant semi-shrub, and annuals are composed of *E. oxyrrhynchum*, *A. linifolium* and *A. squarrosum*, with a cover reaching 20% at the growth peak. The interspaces between shrubs and semishrubs are covered with cyanobacterial-lichen crusts at the margin and central of the Gurbantunggut Desert (Su et al., 2013), which is very common in desert ecosystems in northern China (Su et al., 2007; Li, 2012). At the margin of the Turpan Desert, the average annual rainfall is 16 mm, and the average annual temperature is 13.9 °C, with the minimum and maximum temperatures of −28 °C and 49 °C, respectively. Soils are Aeolian desert soil, with sand particles >0.3 mm at surface soils. The shrubs are *Ammopiptanthus mongolicus*, *Alhagi sparsifolia* and *Nitraria tangutorum*, with a coverage <3%. Annual precipitation in 2011, 2012 and 2013 was 167.4 mm, 102 mm and 142.7 mm at the margin of the Gurbantunggut Desert, 105.9 mm, 89.2 mm and 81.4 mm at the center of the Gurbantunggut Desert, and 9.3 mm, 21.6 mm and 8.7 mm at the margin of the Turpan Desert. Annual average temperature in 2011, 2012 and 2013 was 6.5 °C, 6.9 °C and 8.0 °C at the margin of the Gurbantunggut Desert, 9.1 °C, 12.4 °C, and 10.0 °C at the center of the Gurbantunggut Desert, and 15.8 °C, 15.5 °C, and 16.1 °C at the margin of the Turpan Desert (Fig. S2). The seasonal variation of ultraviolet radiation has the similar one-peak pattern in three decomposition sites, with the annual ultraviolet radiation of 238.3 MJ m^{-2} a^{-1}, 238.8 MJ m^{-2} a^{-1} and 272.9 MJ m^{-2} a^{-1} at the margin of the Gurbantunggut Desert, at the center of the Gurbantunggut Desert, and at the margin of the Turpan Desert, respectively (Fig. S3).

2.2. Experimental design

To assess the effect of UV radiation (280–380 nm) on litter decomposition, six paired UV-filtering and sunlight (UV-passing) treatments representing six replicates were manipulated by deploying litters under frames with special films (1.5 × 2.0 m) in each site. The full-spectrum sunlight treatment was carried out using UV-transparent aclar