A UV dosimeter for estimating the influence of soil deposition and other factors on solar UV exposure of decomposing leaf litter in dryland ecosystems

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Abstract

Exposure to solar UV radiation is known to accelerate the decomposition of leaf litter in dryland ecosystems via photodegradation. However, under field conditions UV exposure of ground-level leaf litter is influenced by numerous factors including time of year, clouds, shading by overstory plants, and coverage by soil. Quantification of the temporal and spatial variation in UV exposure of litter is thus challenging but necessary to estimate and model the role of photodegradation as a driver of litter decomposition in these systems. In this study, we tested whether polysulphone film, a plastic polymer, could be used to reliably measure plant-effective UV doses under different UV and soil cover conditions. Small dosimeters were constructed of different polysulphone film thicknesses and changes in optical absorbance at 330 nm were related to varying plant-effective UV doses under field and greenhouse conditions. These dosimeters were then dusted with different levels of native desert mineral soil and exposed to UV in a greenhouse. Calibrations against broad-band UV sensors indicated that ΔA_{330} of the polysulphone film was related in a non-linear fashion to plant-effective UV doses, though saturation occurred after only ca. 4-6 h of full sun UV exposure. Different calibration relationships existed for the different film thicknesses as well as for ambient solar and greenhouse UV lamp conditions. After 1 h of exposure in a greenhouse, mean UV doses declined linearly with increasing soil coverage. These findings indicate, 1) that these inexpensive dosimeters may be of value in characterizing cumulative UV exposures of leaf litter occurring in various habitats at least over periods < 1 day, and 2) these dosimeters can detect attenuation effects of UV by soil, at least under greenhouse conditions.

Introduction

- Under field conditions UV exposure of ground-level leaf litter is influenced by numerous factors including time of year, clouds, shading by overstory plants, and coverage by soil (Figs. 3, 4).
- Quantification of the temporal and spatial variation in UV exposure of litter is thus necessary to estimate and model the role of photodegradation and soil coverage as drivers of litter decomposition in these systems (Austin & Vivanco 2006; Throop & Archer 2007).
- Previous studies have shown that polysulphone film, a plastic polymer, can be reliably used as human UV dosimeters (Davis et al. 1976; Diffey 1989), and some recent work has explored their utility in measuring plant-effective UV doses under different UV environments (Parisi et al. 2003;Turner et al. 2009).
- Polysulphone films have greater thermal stability than traditional UV measurement methods (Kollias et al. 2003), an important factor when considering their effectiveness in dryland ecosystem experiments. In addition, these films are highly cost effective and portable, making them ideal for use in the field (Dunne 1999, Webb 1995).
- However, the effectiveness/accuracy of the film may be influenced by variables such as the thickness of the film, duration and intensity of exposure and degree of soil cover (Parisi & Wong 1994).

Objectives

In this study we wished to 1) test the effectiveness of different thicknesses of polysulphone films as dosimeters of plant effective UV and 2) explore the utility of these dosimeters in measuring solar UV doses in the context of research examining the roles of UV and soil deposition on litter decomposition in dryland ecosystems.

Methods

- Small UV dosimeters were constructed using polysulphone film of 3 different thicknesses (0.025, 0.076, or 0.127 mm; K-Mac Plastics, Wyoming, MI, USA) inserted into plastic 35-mm slide holders (window size = 2.3 x 3.5 cm; Fig. 1).

Fig. 1. Broadband sensors and polysulphone dosimeters in field test.

- Dosimeters were exposed to ambient solar conditions for different time intervals and on different days over a range of sky conditions and temperatures during June and July in New Orleans, LA (30° N latitude).
- Companion measurements of ambient solar UV were made using broadband UV sensors (Skye UV-B and UV-Index) that had previously been calibrated against a scanning UV spectroradiometer (Optronic Labs Model 754; Fig. 2) under both the solar spectrum and UV lamps in a greenhouse.

Fig. 2. Calibrating the broadband UV sensors using a spectroradiometer.

- At selected times, the dosimeters were collected and placed in the dark for 24 h. After this incubation period, the film was removed, cut into 3 equal strips and placed in a spectrophotometer for measurement of optical absorbance at 330 nm (A_{330}). These three values were averaged for each dosimeter. Control dosimeters were kept in the dark over the exposure and incubation time period. The difference in A_{330} between the control and treatment dosimeters is here referred to as ΔA_{330}.
- Changes in A_{330} (ΔA_{330}) were related to plant-effective UV doses as calculated using two weighting functions—the Caldwell (1971) generalized UV-B plant action spectrum and the Flint & Caldwell (2003) action spectrum, which has an extended response to include part of the UV-A as well as the UV-B.
- Individual dosimeters were then dusted with different levels of mineral soil (0, 0.32 and 0.64 g; simulating 0, 50 and 100% relative cover) collected from the Santa Rita Experimental Range (SRER), a desert grassland/shrubland in SE Arizona, USA, and exposed to UV in a greenhouse environment.

Results

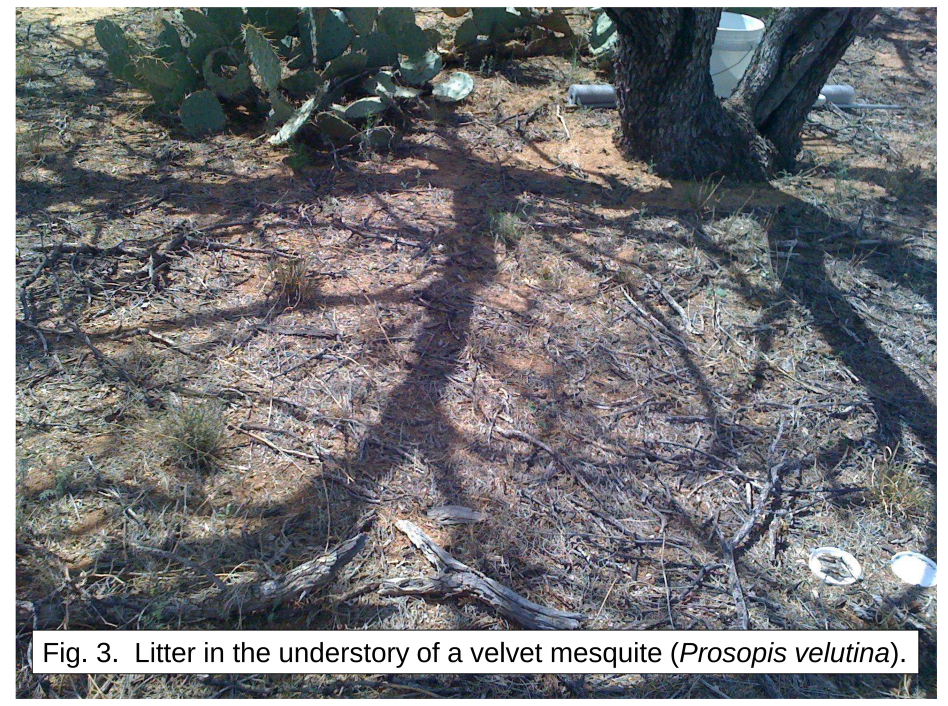

Fig. 3. Litter in the understory of a velvet mesquite (*Prosopis velutina*).

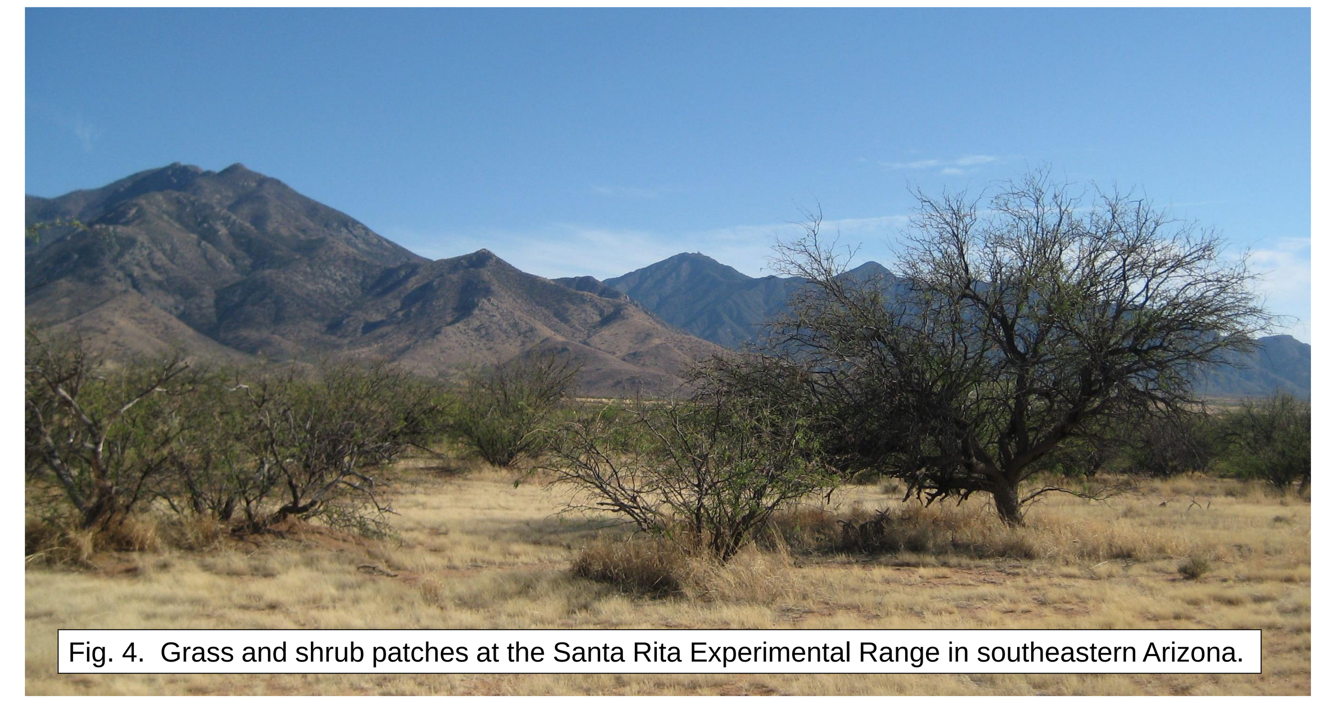

Fig. 4. Grass and shrub patches at the Santa Rita Experimental Range in southeastern Arizona.

- Calibrations against broadband UV sensors indicated that ΔA_{330} of the polysulphone film was related in a non-linear fashion to plant-effective UV doses when calculated using either the Caldwell (1971) or the Flint & Caldwell (2003) weighting functions (R^2 = 0.90-0.95 for exponential regression models) (Figs. 5, 6).
- Under ambient summer conditions, saturation occurred after about 4-6 h of UV exposure, which was the time required to achieve a total effective UV dose of 3 kJ/m² (Caldwell; Fig. 6) or 12 kJ/m² (Flint & Caldwell; Fig. 5).
- Different calibration relationships existed for the different film thicknesses (Figs. 5, 6) with the differences being the greatest between the thinnest film (0.025 mm) and the other two thicknesses.
- Different calibration relationships also existed for ambient solar and greenhouse UV lamp conditions (data not shown).
- After 1 h of exposure in a greenhouse, mean UV doses (Caldwell plant effective UV-B) declined linearly with soil coverage (Fig. 7), however even the treatment simulating 100% soil coverage still registered some UV exposure.

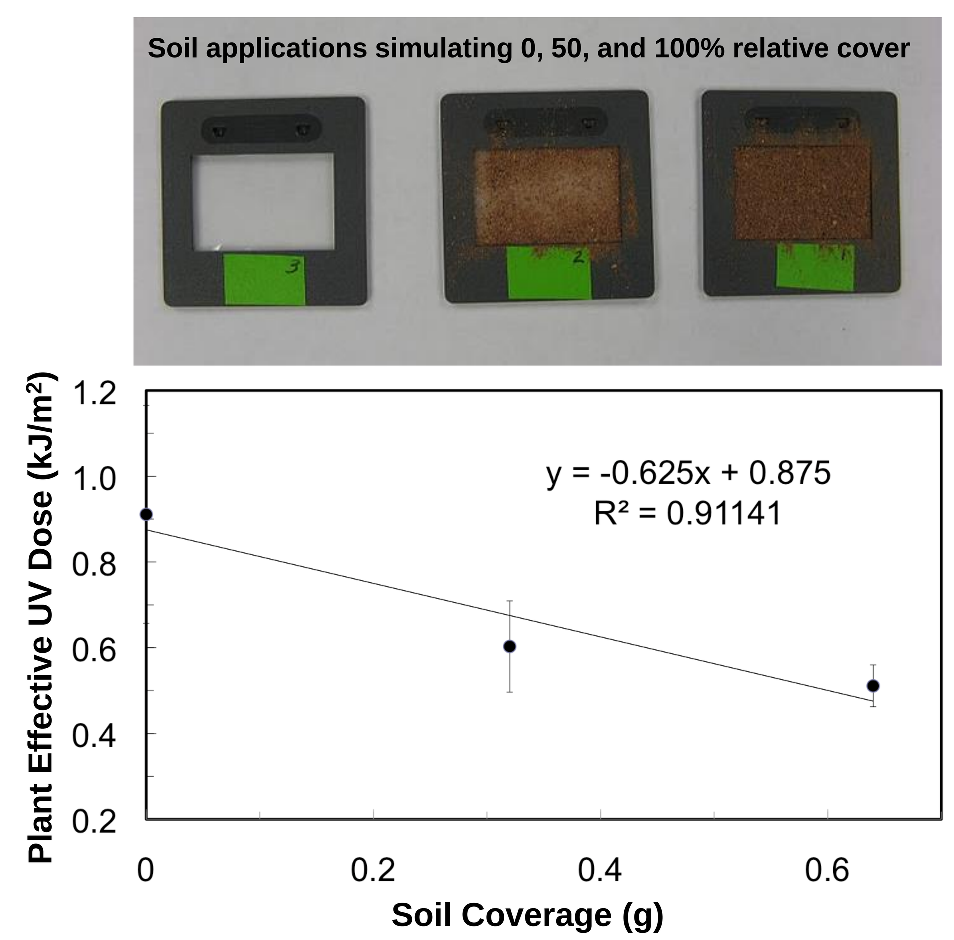

Fig. 7. The relationship between plant effective UV dose (Caldwell) and soil coverage after one hour of UV exposure in a greenhouse (UV-B313 fluorescent bulbs filtered with cellulose diacetate film). Data are means ± SE (n=3).

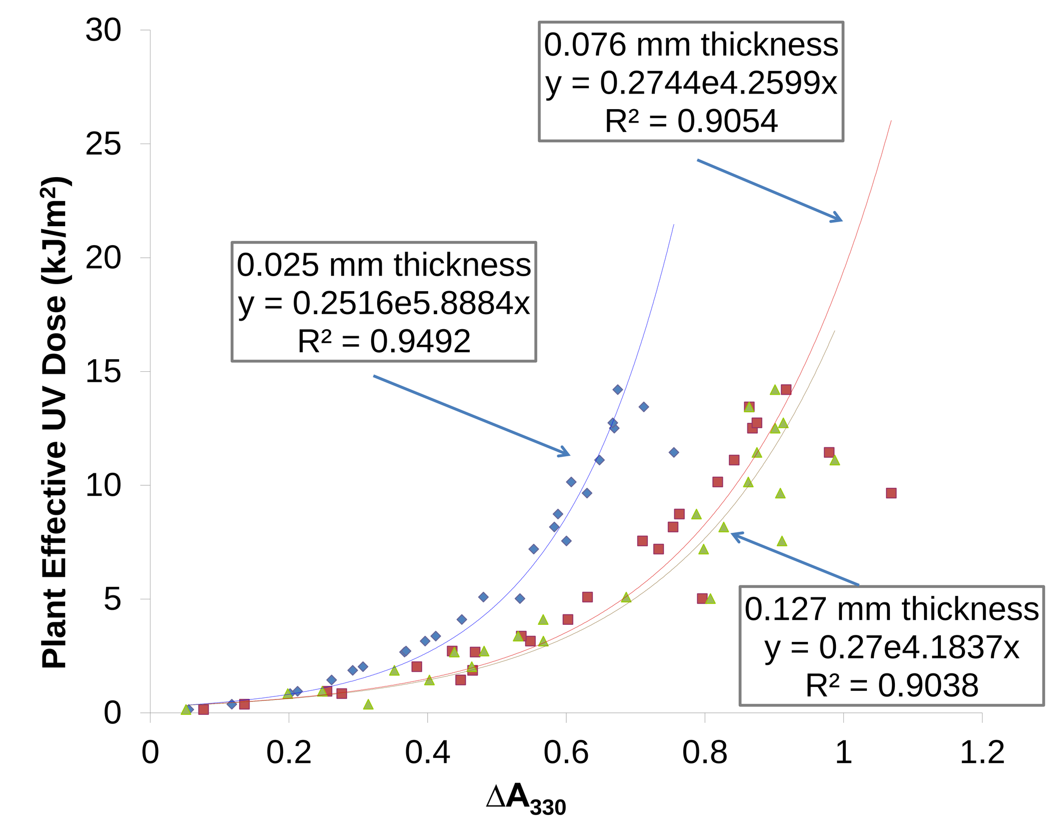

Fig. 5. Exponential regression calibration models relating plant effective UV dose (Flint & Caldwell action spectrum) and changes in optical absorbance at 330 nm ($\Delta A_{330\ nm}$) for three thicknesses of polysulphone film exposed to ambient solar UV radiation at Loyola University – New Orleans.

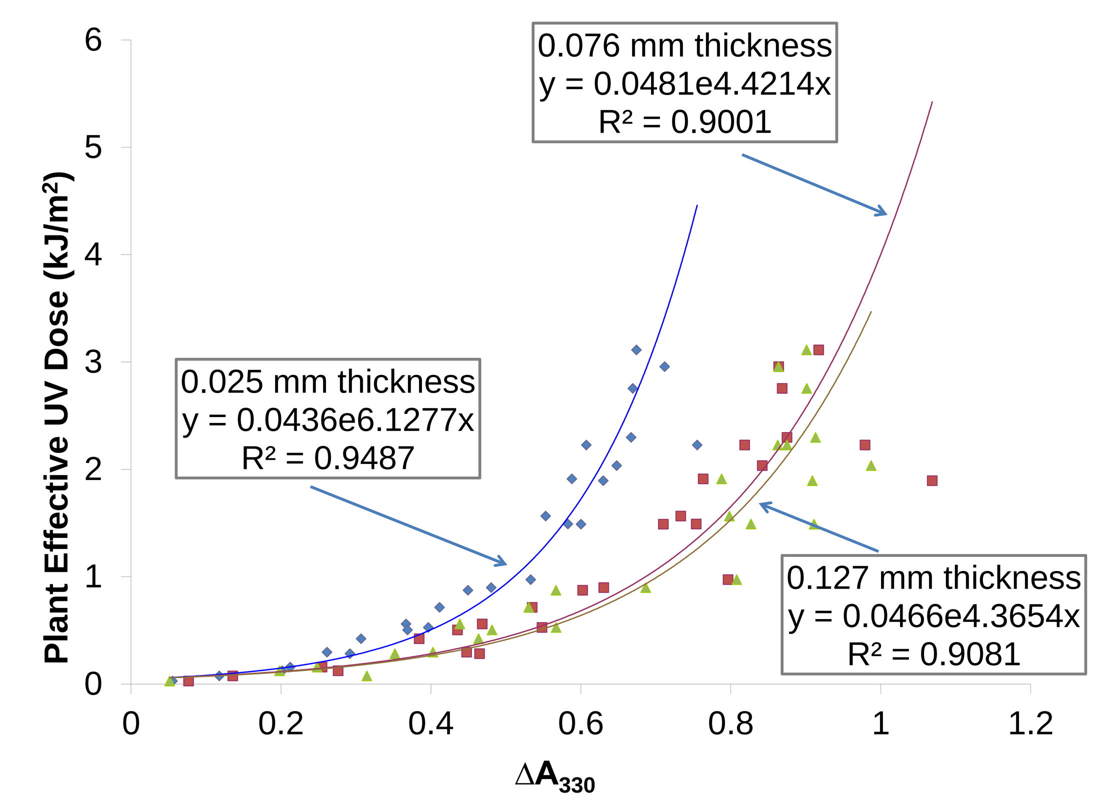

Fig. 6. Exponential regression calibration models relating plant effective UV dose (Caldwell action spectrum) and changes in optical absorbance at 330 nm ($\Delta A_{330\ nm}$) for three thicknesses of polysulphone film exposed to ambient solar UV radiation at Loyola University – New Orleans.

Summary & Conclusions

- Under both ambient field and greenhouse conditions, changes in the optical absorbance (ΔA_{330}) of polysulphone film was found to be closely correlated with plant effective UV dose. These findings are consistent with work by others that have shown this film to reliably measure human erythemal UV doses.
- However, saturation of the film occurred within several hours of exposure. Thus, these dosimeters can only effectively measure UV doses for periods less than one day.
- Additionally, the action spectrum of UV exposure to plants (and plant materials) may be different than that which affects polysulphone absorbance (280-330nm) (Flint et al. 2004).
- There may be ways to expand the effective range and duration of polysulphone dosimeters by using it in conjunction with other materials to capture information about expanded UV spectrum exposure (Parisi & Kimlin 2004).
- Under greenhouse conditions, these dosimeters appear to be able to detect attenuation effects of UV by soil, but how they respond to dust in the field has yet to be explored.
- Future studies are aimed at extending the duration of these dosimeters and deploying them in the field to quantify how soil coverage influences UV exposure and photodegradation of leaf litter.

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