Techniques for Solar Dosimetry in Different Ecosystems

A.V. Parisi[1], D.J. Turnbull[1], P. Schouten[1], N.J. Downs[1] and J. Turner[1]
[1]Faculty of Sciences, University of Southern Queensland, Toowoomba, Australia.

Paper presented at 18th International Congress of Biometeorology
22-26 September 2008, Tokyo, Japan

1. INTRODUCTION

Over exposure to UV radiation can cause serious damage to the human body resulting in skin cancer and sun-related eye disorders. Furthermore, agricultural production can be influenced by higher levels of solar UV (Flint et al., 2003) and changes in visible radiation due to atmospheric change, for example cloud cover resulting from climate change. Research into the effects of solar radiation on different ecosystems is of particular significance in order to determine any associated consequences that changes in solar radiation levels may cause. In order to optimise the solar radiation exposure of different ecosystems such as, agricultural crops, a complete understanding of the solar radiation environment is necessary. The UV radiation environment during greenhouse, growth chamber and field studies on the effects of supplemental UV radiation on plants is generally measured with spectroradiometers and radiometers on a horizontal plane (for example Sullivan et al., 2003; Antonelli et al., 1997).

To a much lesser extent, the UVB (280-320 nm) exposures to a plant canopy during various times of year have been measured with polysulphone dosimeters (Parisi et al., 1996; 1998) and the photosynthetically active radiation (PAR) to a plant canopy has been measured with a dosimeter responsive to the visible wavelengths (Parisi et al., 2003). The size of the polysulphone dosimeters including the holder is approximately 3 cm x 3 cm. This is acceptable for larger plants, however it is too large for attachment to the leaves of smaller plants as it may interfere with the UV and PAR to the leaf and it may alter the inclination of the leaf due to its weight. Additionally, the dynamic range of polysulphone at a sub-tropical site is approximately one day in summer. For periods of exposure longer than this, the polysulphone dosimeters have to be replaced on a daily basis.

This paper describes miniaturized polysulphone dosimeters to allow measurement of the UVB exposures to the leaves of smaller plants in order to characterise the solar UVB environment to the leaves of plants. Miniaturized polysulphone dosimeters have been applied to measure erythemal UV exposure to humans (Downs and Parisi, 2008) and in this paper, the method is extended to measure UVB exposures to plant leaves. Additionally, for larger plants a dosimeter based on polyphenylene oxide (PPO) (Davis et al., 1976; Lester et al., 2003; Schouten et al., 2007; 2008) with a dynamic range that is approximately four to five times longer than that of polysulphone is described for the dosimetric measurement of solar UVB exposures to the leaves of plants over an extended time period.

2. METHODS

2.1 MINIATURISED DOSIMETER UVB MEASUREMENTS ON PLANT LEAVES

Dosimeters fabricated from polysulphone film have been made smaller in order to be lighter and attached to more complex surface topography not readily accessible to conventionally sized dosimeters (Downs and Parisi, 2008). Polysulphone film produced at the University of Southern Queensland was adhered to flexible cardboard frames measuring approximately 1.5 cm x 1 cm having a clear circular aperture of 6 mm. The weight of each dosimeter is on average 0.031 g compared to 0.71 g for a conventionally sized dosimeter. Four dosimeters were attached with tape to the upper side of each of the leaves of a small plant (Fig. 1a) at Toowoomba, Australia (27.5^o S, $151.9\ ^o$ E, 693 m altitude). In addition, dosimeters were attached to the underside of each leaf and two dosimeters were attached on a horizontal plane. The exposure time was on 13 May between 8.00 am and 5.00 pm when the solar zenith angle (SZA) ranged from 46^o to 88^o.

The change in optical absorbance caused by UV exposure to the dosimeters was measured at 330 nm in a spectrophotometer (model 1601, Shimadzu Co., Kyoto, Japan). The dosimeters were calibrated by exposing a series of dosimeters for different periods of time while concurrently measuring the UVB exposures with a calibrated scanning spectroradiometer (Bentham Instruments, Ltd, Reading, UK).

2.2 LONG TERM UVB MEASUREMENTS ON PLANT LEAVES

The dosimeters were fabricated at the University of Southern Queensland from PPO cast in thin film form at a thickness of approximately 40 µm and attached to a 3 cm x 3 cm holder. The film was secured to the holder with tape. The change in optical absorbance caused by UV exposure to the PPO was measured at 320 nm in the spectrophotometer. This wavelength was employed as this is the wavelength where a measurably significant change in optical absorbance occurs.

The long term dosimeters were calibrated on a horizontal plane to solar UV over the time period of seven days outdoors for the UVB waveband. The calibrations took place in Toowoomba, Australia over the SZA range of 38^o to 58^o during autumn. The dosimeters were exposed for different periods of time while concurrently measuring the UVB exposures with the spectroradiometer. The dosimeters were attached with tape to the upper side of each leaf of a plant with six leaves (Fig. 1b) at 9.30 am 12 May 2008 and removed at 10:50 am on 16 May. The minimum SZA over this period was 38^o. Additionally, a dosimeter was attached to the underside of each of two leaves and two were attached to an unshaded horizontal plane. The dosimeters were fabricated from light weight holders, which had no effect on the inclination of each leaf of the plant.

Fig. 1. (a) The miniaturised dosimeters attached to each leaf of a small plant in the field and (b) the long term dosimeters attached to a larger plant in the field. The dosimeters that are visible are marked with an arrow.

3. RESULTS AND DISCUSSION

The UVB exposures over a day, as measured with the miniaturised dosimeter are shown in Fig. 2(a) for each of the dosimeter locations on each of the four leaves on the small plant. Dosimeter locations 1 to 4 represent the dosimeters on the upper sides of the leaves. Dosimeters 5 to 8 are on the under sides of the leaves and dosimeter 9 is the dosimeter on an unshaded horizontal plane. The percentages of the exposures for each dosimeter location relative to the UVB exposure to a horizontal plane are provided in Fig. 2(b).The UVB intercepted by the leaves is influenced by the inclination, azimuth and shading of each leaf.

The average of the percentages to the upper sides of the leaves is 47% with the range of 14 to 78%. Similarly, for the under side of the leaves, the average is 6.6% with a range of 0.2% to 20%. The value of 20% was for a leaf inclined at 85^o to the horizontal and it was consequently exposed to a large amount of sky compared to the leaves with the small inclination, allowing interception of a higher amount of solar radiation. These leaves with the smaller inclinations have percentage exposures of 5% or less. The exposures to the under sides of the leaves are influenced to a certain extent by the albedo of the ground cover.

The percentage of the UVB exposures relative to a horizontal plane measured over five days with the long term dosimeters at each dosimeter location are provided in Fig 3. Dosimeter locations 1 to 7 are on the upper side of the leaves. Dosimeter locations 8 and 9 are on the under side of the leaves with locations 1 and 2. The average for the upper side of the leaves is 70% with a range of 26 to 84% and the average for the under side of the leaves is 2.9% with a range of 0.4 to 5.4%. The percentage exposures to dosimeter locations 6 and 7 illustrate the influence of the leaf azimuth on the UVB exposure. The leaves at locations 6 and 7 have inclinations of 80^o and 85^o respectively with azimuths of 180^o and 260^o. The leaf at location 6 has a higher exposure as the leaf is facing towards the north. At the Southern Hemisphere location of this research, this leaf is in sun throughout the day provided there is no shading by other leaves. In comparison, the leaf at location 7 is facing towards the east and the upper side of the leaf would be in shade for the afternoon.

The UVB exposures across each of the leaves of both the small and large plants varied for each of the leaves due to the inclination and azimuth of each leaf and the variable shading of individual leaves by other leaves through the daily exposure cycle. Furthermore, the average of the percentage of the UVB exposures to each leaf compared to the UVB exposure to a horizontal plane was different for each of the two plants due to the differences in their plant structure and positioning.

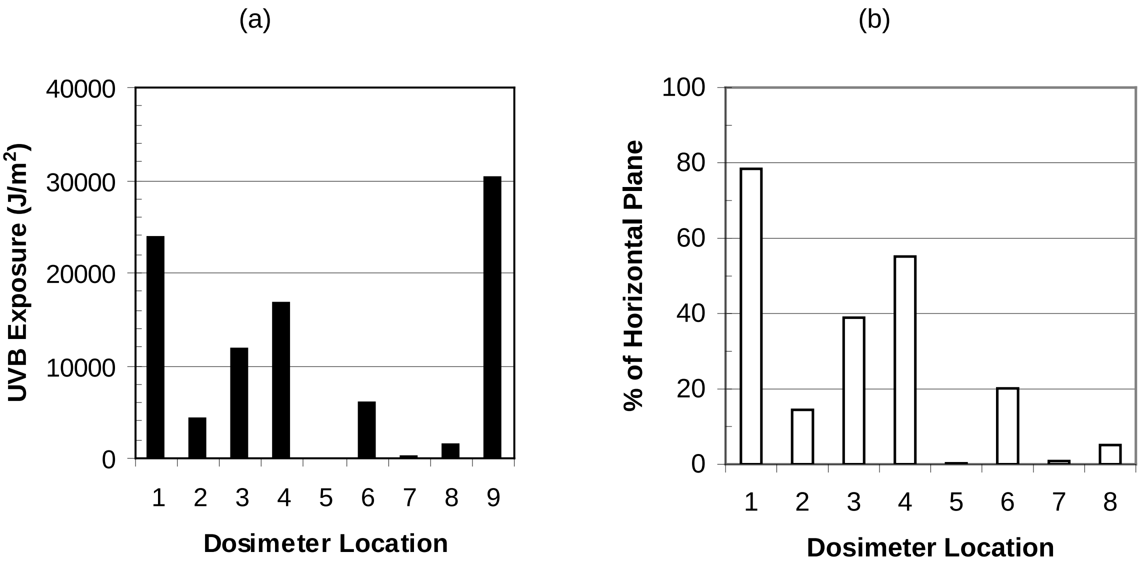

Fig. 2. (a) The UVB exposures over a day measured with the miniaturised dosimeters at each dosimeter location where location 9 is an unshaded horizontal plane and (b) the percentage of the exposures relative to a horizontal plane.

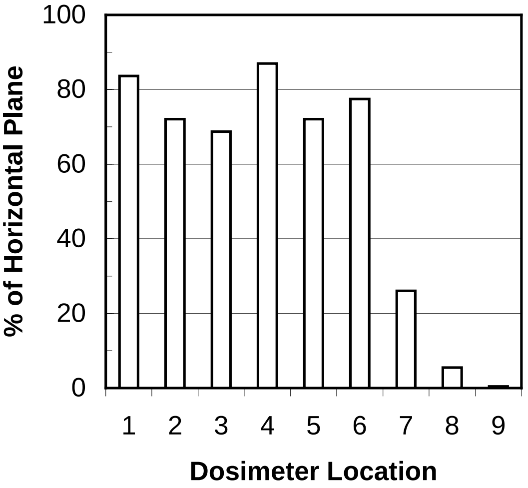

Fig. 3. The percentage of the UVB exposures relative to a horizontal plane measured over five days with the long term dosimeters at each dosimeter location.

4. CONCLUSION

This research has characterised the UVB environment to the leaves of plants in the field through the use of miniaturised polysulphone dosimeters. The miniaturisation of the dosimeters has allowed the deployment of dosimeters to the leaves of small plants. Furthermore, the use of dosimeters, based on PPO, with a larger dynamic range has allowed the characterisation of the UVB environment to the leaves of a plant over an extended period of time without the need for daily replacement, which would be required if polysulphone was employed for the same task. The miniaturised dosimeters and the long term dosimeters as described in this paper for use on the leaves of plants has increased the number of ecosystems in which the UVB can be characterised in a non invasive manner. These will form an important tool in studies in understanding the UV environment in studies on the effects of changes in the UV environment to plants. The implications of which include improving the characterisation of the UV exposures to agricultural and native plant species within a changing global climate.

REFERENCES

Antonelli, F., Grifoni, D., Sabatini, F. & Zipoli, G., 1997: Morphological and physiological responses of bean plants to supplemental UV radiation in a Mediterranean climate. Plant Ecol. 128: 127-136.

Davis, A., Deane, G. H. W., Gordon, D., Howell G. V. & Ledbury K. J., 1976: A world – wide program for the continuous monitoring of solar UV radiation using poly (phenylene oxide) film, and consideration of the results. J. Appl. Poly. Sci. 20: 1165–1174.

Downs, N. & Parisi, A.V., 2008: Patterns in the Received Facial Ultraviolet Exposure of School Children Measured at a Sub-tropical Latitude. Photochem. Photobiol. 84: 90-100.

Flint, S.D., Ryel, R.J. & Caldwell, M.M., 2003: Ecosystem UV-B experiments in terrestrial communities: a review of recent findings and methodologies. Agric. For. Meteorol. 120: 177-189.

Lester, R.A., Parisi, A.V., Kimlin, M.G. & Sabburg, J., 2003: Optical properties of poly(2,6-dimethyl-1,4-phenylene oxide) film and its potential for a long term solar ultraviolet dosimeter. Phys. Med. Biol. 48: 3685-3698.

Parisi, A.V., Galea, V.J. & Randall, C., 2003: Dosimetric measurements of the visible and UV exposures on field grown soybean plants. Agric. For. Meteorol. 120: 153-160.

Parisi, A.V., Wong, C.F. & Galea, V., 1998: A study of the total ultraviolet exposure to all the leaves for small plant growth. J. Photochem. Photobiol. B: Biol. 45: 36-42.

Parisi, A.V., Wong, C.F. & Galea, V., 1996: A method for evaluation of UV and biologically effective exposures to plants. Photochem. Photobiol. 64: 326-333.

Schouten, P., Parisi, A.V. & Turnbull, D.J., 2007: Evaluation of a high exposure solar UV dosimeter for underwater use. Photochem. Photobiol. 83: 931-937.

Schouten, P.W., Parisi, A.V. & Turnbull D.J., 2008: Field calibrations of a long term UV dosimeter for aquatic UVB exposures. J. Photochem. Photobiol. B: Biol. doi:10.1016/j.jphotobiol.2008.02.004

Sullivan, J.H., Gitz, D.C., Peek, M.S. & McElrone, A.J., 2003: Response of three eastern tree species to supplemental UV-B radiation: leaf chemistry and gas exchange. Agric. For. Meteorol. 120: 219-228.