S39-74

N96- 18162

SHORT REPORT

UV FILTERS FOR LIGHTING OF PLANTS

T. Döhring, M. Köfferlein, S. Thiel, H.K. Seidlitz, and H.D. Payer

GSF-Forschungszentrum für Umwelt und Gesundheit GmbH, Expositionskammern, D-85758 Oberschleissheim, FRG

INTRODUCTION

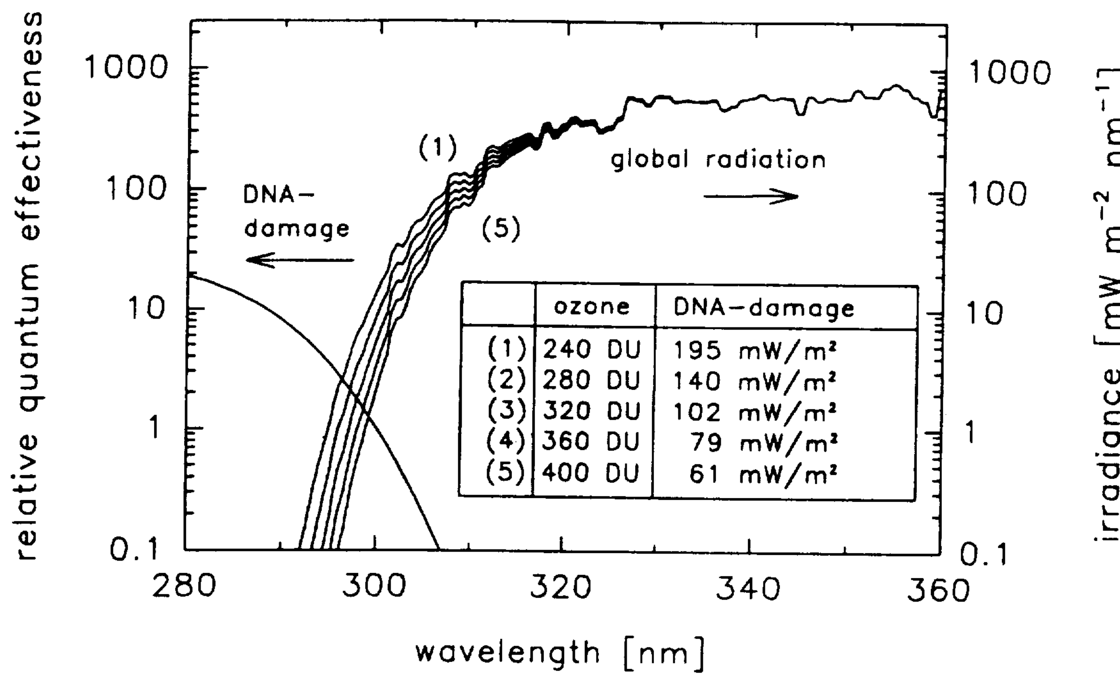
Plants as result of biological evolution exhibit a complex system of pigments and photoreceptors and respond very sensitively to changes of the spectral irradiation. Lighting for ecological plant research, therefore, requires an engineering which provides a spectral irradiance close to natural conditions. (Kofferlein et al. 1994) Terrestrial global radiation is characterized by a cut-off between 280 and 320 nm by several orders of magnitude due to the filtering effect of stratospheric ozone (Bener 1972). A reduction of the ozone layer will cause a shift of the UV absorption edge to shorter wavelengths thereby increasing the integral UV irradiation (Fig. 1).

The wavelength dependent interaction of biological systems with radiation is commonly described by appropriate action spectra (Caldwell et al. 1986). Particularly effective plant responses are obtained for UV radiation. Excess shortwave UV-B radiation will induce genetic defects and plant damage. As an example the action spectrum of DNA damage is plotted in Figure 1. Due to the strong wavelength dependence of this action spectrum, a shift of the UV absorption edge of the radiation spectrum towards shorter wavelengths will effect a significant increase of DNA damage. A 13% decrease of the ozone column from 320 DU to 280 DU, for instance, will result in a 36% increase of DNA damaging irradiation.

Besides the ecological discussion of the deleterious effects of the excess UV radiation there is increasing interest in horticultural applications of this spectral region. Several metabolic pathways leading to valuable secondary plant products like colors, odors, taste, or resulting in mechanical strength and vitality are triggered by UV radiation. Thus, in ecologically as well as in economically oriented experiments the exact generation and knowledge of the spectral irradiance, particularly near the UV absorption edge, is essential.

The ideal filter 'material' to control the UV absorption edge would be ozone itself. However, due to problems in controlling the toxic and chemically aggressive, instable gas, only rather 'small ozone filters' have been realized so far (Tevini et al. 1989). In artificial plant lighting conventional solid filter materials such as glass sheets and plastic foils (celluloseacetate or cellulosetriacetate) which can be easily handled have been used to absorb the UV-C and the excess shortwave UV-B radiation of the lamp emissions.

The artificial generation of spectral UV irradiances for plant research requires more than appropriate combinations of lamp systems. Reliable filter systems are also necessary to cut the UV irradiance within defined spectral ranges.



	ozone	DNA-damage
(1)	240 DU	195 mW/m²
(2)	280 DU	140 mW/m²
(3)	320 DU	102 mW/m²
(4)	360 DU	79 mW/m²
(5)	400 DU	61 mW/m²

Fig. 1. Spectra of terrestrial global radiation (sun elevation 60°) for different values of the stratospheric ozone column. The spectra were calculated using a radiation transfer model based on Green (1983). The DNA action spectrum (Caldwell et al. 1986), normalized to 1 at 300 nm, is also plotted. The insert gives the resulting integral radiation dose of these spectra weighted for DNA damage.

Lighting set-up at the GSF Phytotron

The phytotron uses a combination of quartz halogen lamps (Osram, Halostar), metal halide lamps (Osram HQI D), blue light lamps (Philips TL18), and UV-B lamps (Philips TL12) in order to obtain a good match to the solar spectrum (Seckmeyer and Payer 1993, Payer et al. 1993). Four walk-in-chambers and a smaller solar simulator are in operation, furthermore two new solar simulators are under construction. Different glass filter systems applied to artificial lighting and monitored by appropriate spectroradiometric instruments are used at the GSF phytotron at Munich.

The standard UV filtering in these chambers is performed by layers of borosilicate glass (Tempax, and Pyran,) which exhibits a steep absorption edge near 300 nm. The respective UV monitoring and spectral measurements have to be performed with high precision and accuracy. This spectral measurement can only be achieved by a double monochromator providing the required wavelength resolution with a maximum of straylight rejection and with dynamics of about 6 decades.

The spectral irradiances at plant level were measured in the chambers by a double monochromator system (Bentham, U.K.) as described by Seckmeyer (1989). The results of these measurements are compared to a model of global radiation (60° sun elevation and 320 DU based on Green 1983) as shown in Figure 2. The spectral distribution of UV irradiation demonstrates the close approximation to natural global radiation. The integral irradiance (Table 1) within the solar simulator reaches values comparable to those referring to a sun elevation of 60°. Within the large walk-in-chambers approximately 60% of this irradiance data are achieved.

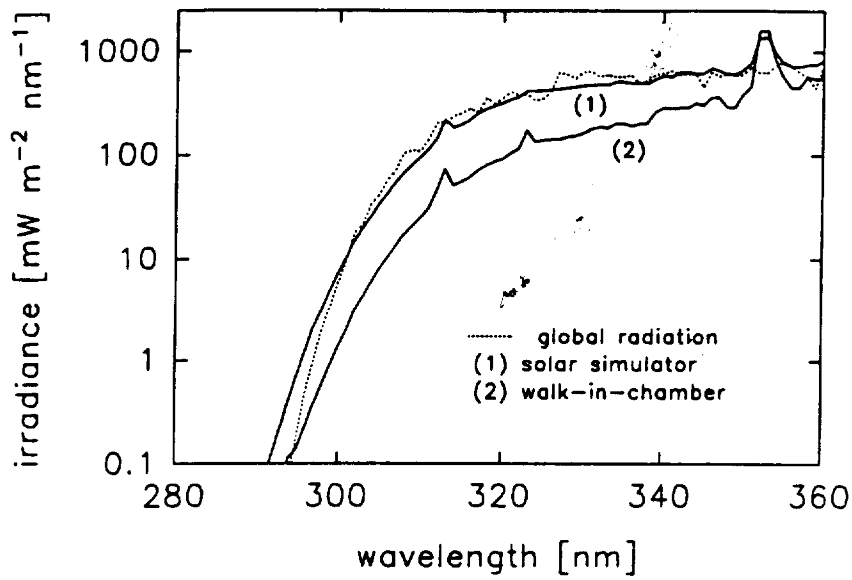


Fig. 2. UV spectra of the small solar simulators and the walk-in-chambers of the GSF phytotron (Seckmeyer and Payer 1993, Payer et al. 1993), compared to a model of global radiation (60° sun elevation, 320 DU) based on Green 1983. The superposed spectra of different lamps are filtered by borosilicate glass.

TABLE 1 Integral parameters of walk-in-chambers, solar simulators and model of global radiation calculated according to Green (1983).

		Solar Simulator	Walk-in Chamber	Global Radiation (60°, 320 DU)	Unit
UV-C	(200 - 280 nm)	$< 10^{-7}$	$< 10^{-7}$	$< 10^{-7}$	W/m^2
UV-B	(280 - 320 nm)	2.4	0.67	2.8	W/m^2
UV-A	(320 - 400 nm)	53.5	36.6	53.3	W/m^2
VIS	(400 - 800 nm)	571	343	532	W/m^2
IR	(800nm - 2500nm)	410	290	292	W/m^2
Total irradiance		1038	670	880	W/m^2
PAR	(400 - 700 nm)	2100	1260	1940	$\mu mol/m^2s$
Erythemal dose		3	0.9	3.4	MED/h
Illuminance		126	72	107	klx

Closed chambers are particularly suited for reproducible dose response studies under simultaneous variation of other environmental parameters. Interactive effects as well as action spectra will be obtained under these controlled conditions. In order to perform experiments on possible biological consequences of the predicted depletion of the stratospheric ozone column, the UV absorption edge has to be varied. UV absorption edges can be varied to some degree by use of cut-off filters, for instance WG-filters (Schott Glaswerke, Mainz, FRG). However, to cover an experimental area of several squaremeters with this type of filter would not be an economical approach. The variation of UV absorption edges is also limited by the restricted graduation of filters with different cut-off wavelengths.

Commercial borosilicate and other glasses are used at the GSF research center in order to simulate different UV spectra corresponding to those resulting from a proposed depletion of the natural ozone layer. Glass sheets from different production batches and of different thickness are carefully selected to shift the UV absorption edge over a wide spectral range (Fig. 3). For a quantitative comparison with natural UV irradiation the spectra have been weighted by appropriate action spectra (Table 2). These calculations provide insight into the biological effectiveness of changing UV spectra. As seen from Figure 3 glass can only approximate the sharp absorption edge of ozone. The differences between natural and experimental effects have to be considered in the evaluation of such experiments.

Ageing of filter materials

Inside the UV compartment of the lamphouse a harsh, almost 'extraterrestrial' radiation environment is encountered. Materials are exposed to high levels of UV-B radiation (approximately 30 Wm-2) and even UV-C radiation (about 0.1 Wm-2). Filters are, therefore, subject to enhanced ageing processes. The effect of such ageing is demonstrated in Figure 4, showing the results of UV-B monitoring by a Robertson-Berger-meter (Solar Light, USA) obtained during a long-term experiment in the walk-in-chambers of the GSF phytotron. The continuous decrease of erythemal weighted UV-B irradiation at the plant level amounted to approximately 25% after 250 hours of UV-B lamp operation.

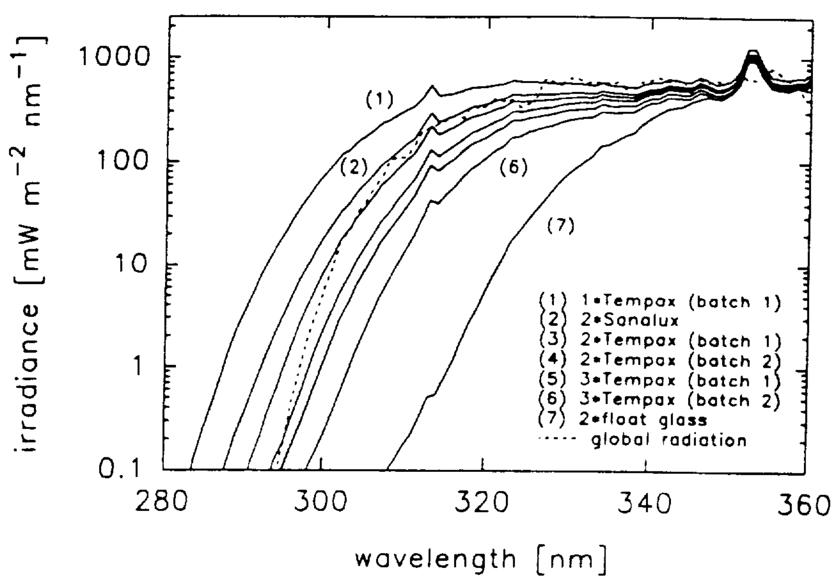


Fig. 3. Spectra of the solar simulator for different filter combinations of 5 mm Tempax®, 4 mm Sanalux®, 4 mm float glass.The dotted line represents the model of global radiation based on Green 1983 (sun elevation 60°, 320 DU).

TABLE 2 Integral values for weighted spectra with different filter combinations as plotted in Figure 3 (action spectra according to Caldwell et al. 1986).

Spectrum	UV-B (W/m^2)	DNA-damage (mW/m^2)	Plant damage (mW/m^2)
(1)	5.1	751	1000
(2)	3.5	248	427
(3)	2.4	123	246
(4)	1.6	45	103
(5)	1.2	27	64
(6)	0.6	10	20
(7)	0.02	1.4	0.3
Global radiation	2.8	102	264

The corresponding changes of the spectral transmittance of borosilicate glass during a period of 100h UV irradiation are plotted in Figure 5(a). The absorption edge was red shifted during this period by about 3 nm and the slope is somewhat flatter. The detailed analysis (Figure 5(b)) revealed the transmittance decrease to be exponential with rates depending on the wavelength. A fast 'decay' of UV-B transmittance was obtained, particularly in the first few hours. A slower decrease in the UV-A range and nearly no change in the region of visible light was observed. These wavelength dependent transmittance changes are supposed to be caused by photochemical reactions within the glass and seem to be correlated to a contamination of the glass by metal ions, most probably iron ions. The iron content of the investigated glasses differed from batch to batch within a range of a few hundred mg/kg.

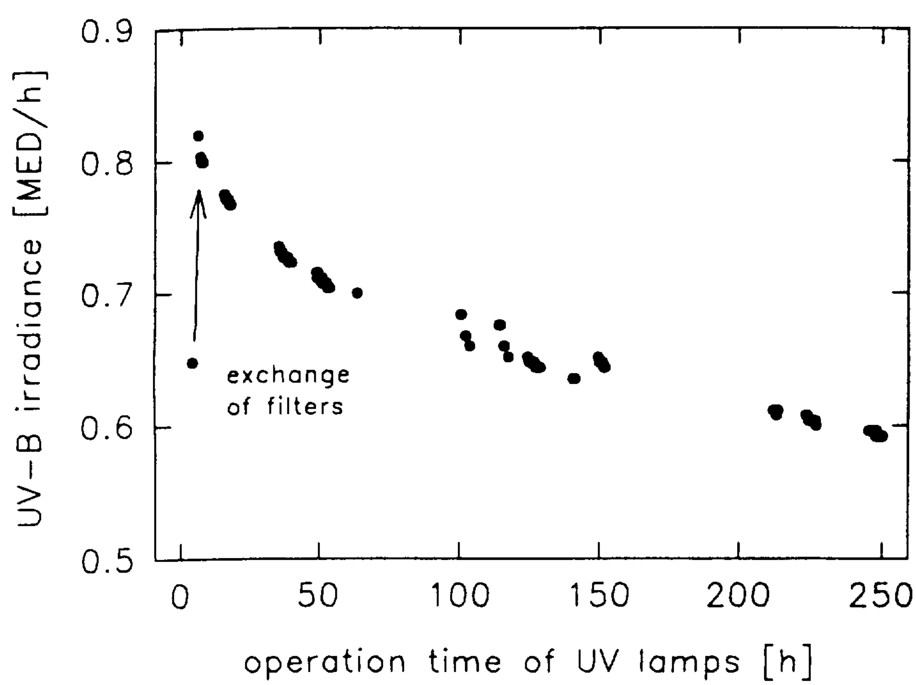


Fig. 4. Decrease of UV-B during 250h of filter ageing, measured with a Robertson-Berger-meter (erythemal weighting of the irradiance).

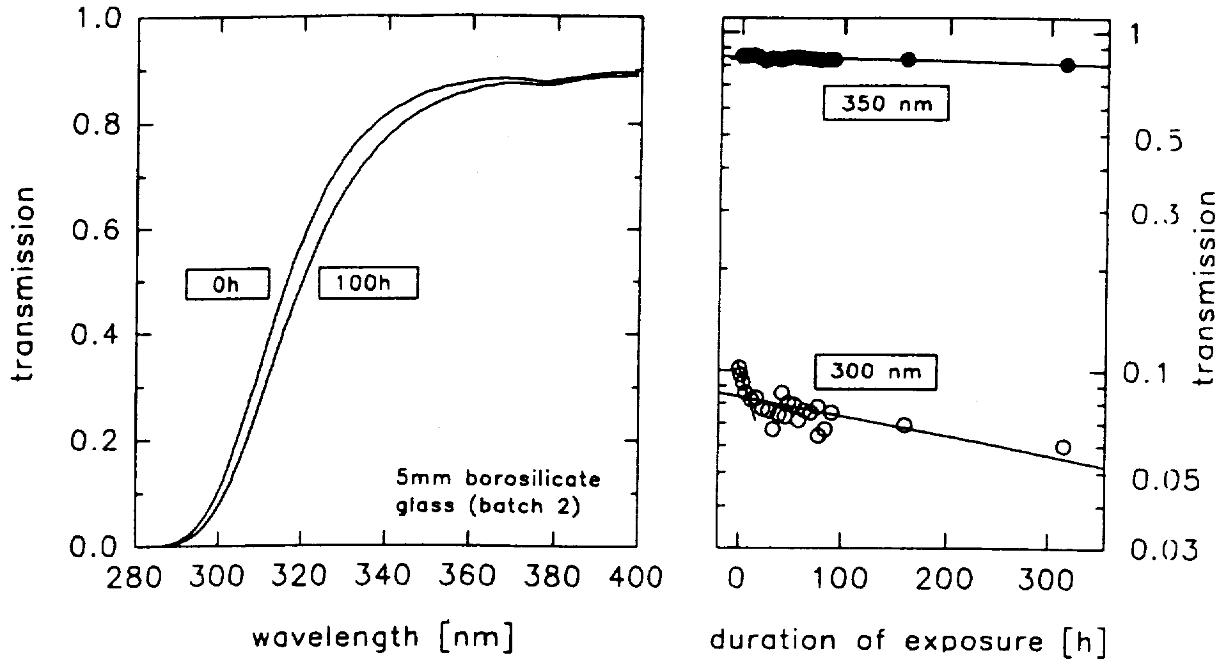


Fig. 5. Behaviour of borosilicate glass filters (batch 2 of Figure 3) during ageing with UV-B radiation of approximately 32 Wm-2.
(a): Change of spectral transmission
(b): Decrease of transmission vs. exposure time

The described degradation of borosilicate filters imposes problems and limitations particularly for investigations using artificial irradiation in the UV-B range. Plastic materials are even less resistant to the extreme radiation in the phytotron lamp house and deteriorate more rapidly than glasses. At present there is no other choice than the periodical exchange of the whole filter set.

CONCLUSIONS

Different filter glasses are available which provide absorption properties suitable for gradual changes of the spectral UV-B illumination of artificial lighting. Using a distinct set of lamps and filter glasses an acceptable simulation of the UV-B part of natural global radiation can be achieved. The ageing of these and other filter materials under the extreme UV radiation in the lamphouse of a solar simulator is presently unavoidable. This instability can be dealt with only by a precise spectral monitoring and by replacing the filters accordingly. For this reason attempts would be useful to develop real ozone filters which can replace glass filters. In any case chamber experiments require a careful selection of the filter material used and must be accompanied by a continuous UV-B monitoring.

REFERENCES

Bener, P. 1972. Approximate values of spectral intensity of natural ultraviolet radiation for different amount of atmospheric ozone. p. 1-59. In: Contract AF DAJA-68-C-1017 Final Technical Report, Davos-Platz, Switzerland

Caldwell, M.M, L.B. Camp, C.W. Warner, and S.D. Flint. 1986. Action spectra and their role in assessing biological consequences of solar UV-B radiation change, p.87-96. In:

R.C.Worrest and M.M. Caldwell (eds.). Stratospheric ozone reduction, solar ultraviolet radiation and plant life. Springer, Heidelberg

Green, A.E. 1983. The penetration of ultraviolet radiation to the ground. Physiol.Plant 58:351-359

Köfferlein, M., T. Döhring, H.D. Payer, and H.K. Seidlitz. 1994. Xenon Lighting Adjusted to Plant Requirements. Proc. Internat. Workshop Lighting for Plants, 27-30 March, 1994, Madison, WI, USA.

Payer, H.D., P. Blodow, M. Köfferlein, M. Lippert, W. Schmolke, G. Seckmeyer, H.K. Seidlitz, D. Strube, and S. Thiel. 1993. Controlled environment chambers for experimental studies on plant responses to CO2 and interactions with pollutants. In: E.D.Schulze and H.A. Mooney (eds.). Design and Execution of Experiments with CO2 enrichment. Commission of the European Communities, Brussels, in press

Seckmeyer, G. 1989. Spectral measurements of global UV-radiation. Meteorol. Rundschau 41: 180-183

Seckmeyer, G., and H.D. Payer. 1993. A new sunlight simulator for ecological research on plants, J.Photochem.Photobiol. B21: 175-181

Tevini, M., U. Mark, and M. Saile. 1989. Plant experiments in growth chambers illuminated with natural sunlight, p.240-251. In: H.D. Payer, T.Pfirrmann, and P. Mathy (eds.). Environmental research with plants in closed chambers, Commission of the European Communities, Brussels