Climate Change Research: Evaluation and Policy Implications
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Impact of enhanced solar UV-B radiation on plants from terrestrial ecosystems

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Abstract

The methodology of a UV-B supplementation and UV-B filtration system is described. The response to enhanced UV-B of terrestrial plant species ranges from very sensitive to tolerant or even a positive response; crop plant species tend to be more sensitive to elevated UV-B than wild plant species.

Enhanced UV-B is expected to cause changes of both structure (competitive relationships, species composition) and functioning (plant-herbivore relationships, process of decomposition).

1. INTRODUCTION

1.1. Background

Decrease in stratospheric ozone over the last decade has been revealed by satellite measurements. As a result a gradual increase in solar ultraviolet-B radiation occurs. Measurements of UV-B radiation in the Swiss Alps indicate an annual increase of UV-B-radiation of 1% since 1981 (Blumthaler and Ambach, 1990).

1.2. Solar UV-B and terrestrial ecosystems

Solar UV-B radiation has important biological and ecological effects. Many crops and natural plant species demonstrate reduced growth, under enhanced UV-B radiation but there is a wide range of sensitivity to UV-B radiation between plant species and cultivars. A major part of research of UV-B effects relates to crop species and only a few UV-B effect studies are known of plant species of natural ecosystems (SCOPE 1992).

Most studies of UV-B effects on plants have been conducted in greenhouse or in controlled environment cabinets with UV-B lamps. Relatively low levels of Photosynthetic Active Radiation (PAR), in controlled environment studies may prevent induction of photo-repair of UV-damage. This has led to an overestimation of growth reduction of plants exposed to enhanced levels of UV-B. Outdoor experimental UV-B supplementation systems, with natural levels of PAR provide more realistic responses of plants to enhanced UV-B.

1.3. Scientific aims

Our research aimed at development and application of outdoor UV-B supplementation and UV-B filtrations systems and to assess effects of solar UV-B radiation to plant species of terrestrial ecosystems.

2. METHODOLOGY

2.1. UV-lamp systems

In experimental studies with enhanced levels of UV-B irradiance UV-lamps are used that are pre-burnt and filtered with cellulose acetate as a cut off filter of wavelengths smaller than 280 nm. The cellulose acetate filters are renewed twice a week to avoid reduced transmission of UVcover UV-B lamps over control treatment that receive no UV-B irradiance, but where the UV-B levels are the same as in the treatment that receive no with enhanced UV-B (see Figure 1).

Fig. 1. Philips TL12/40 lamps are applied both in indoor and outdoor studies of UV-B effects on plants. The plots shown in the photograph, which are exposed to solar UV-B + UV-B supplied by the lamps, refer to monocultures and mixed cultures of the dune grassland species *Calamagrostis epigejos* and *Holcus lanatus*. Thus the effect of enhanced UV-B on competitive relationships between plant species is analysed.

We use Philips TL12/40 lamps both in indoor controlled environment studies and in outdoor studies in an experimental field and in natural ecosystems.
Two outdoor unenclosed systems are applied: **1. UV-B Supplementation system and 2. UV-B filtration systems.**

2.2. UV-B Supplementation system

A lamp system to supplement ambient solar UV-B over experimental plots and over natural vegetation has been developed and applied (Fig. 1).
At present this outdoor UV-B supplemenation system is applied in a "square wave" mode of enhanced UV-B radiation. This implies switching UV-B lamps on for a fixed period around midday, when natural solar UV-B is greatest.
Currently an outdoor solar tracking UV-B supplementation is developed and installed. This involves continuous measurement of solar UV-B levels using appropriate UV-B sensors (Yu et al. 1991). This allows accurate simulation of enhanced UV-B throughout the day. There is evidence that plant responses to enchanced UV-B supplied in the solar tracking modulated mode differs both qualitatively and quantitatively from responses to UV-B supplied in the square wave mode.
The development and testing of this solar tracking UV-B supplementation is in close cooperation with Dr. Andy McLeod, Institute of Terrestrial Ecology, Huntingdon, United Kingdom and Dr. Gaetano Zipoli, IATA-CNR, Florence, Italy.

UV-B lamps are mounted above the vegetation and are maintained at a constant height above the canopy. UV-B sensors will measure and track ambient solar UV-B radiation. Dual UV-B sensors are used beneath both treatment and control racks with UV-lamps, spaced such that one is unshaded from direct sunlight by lamps or frame. The unshaded sensor is selected by the control system preventing shading effects from interfering with feedback control of output of UV-lamps. The lamp output is adjusted to give a constant multiple of UV-B radiation above ambient UV-B radiation. Increases of UV-B radiation relative to ambient UV-B irradiance relating to 20% ozone depletion under clear sky are realized.

2.3. UV-filtration system

Various types of solid plastic filters are installed above precultured plants in pots or above natural vegetation. These filters absorb either (a) little solar UV-B (and UV-A) (Acrylate filter), (b) all UV-B (Mylar polyester film on top of acrylate filters) and (c) all UV-A + UV-B (Lexan filter).

The transmission spectra of these three filter types are given in Fig. 2.

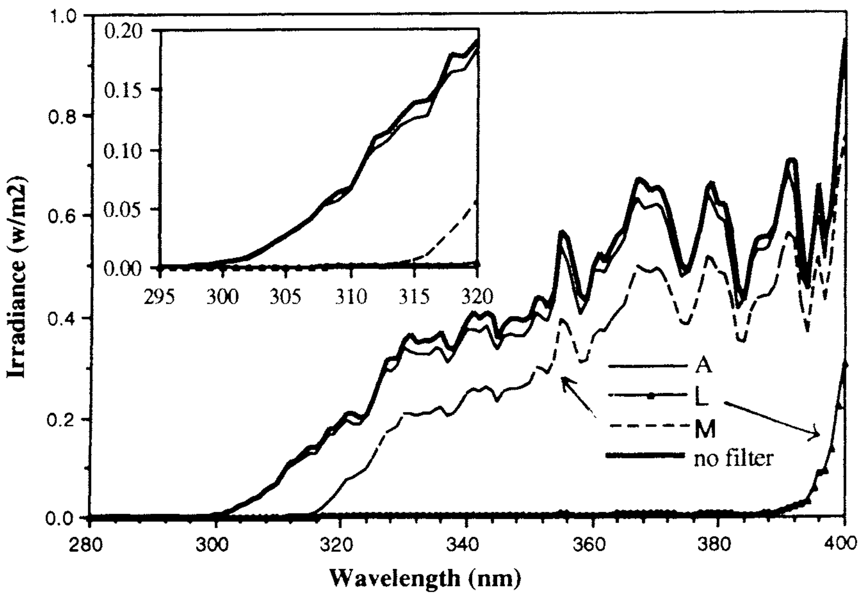

Fig. 2. Solar UV-irradiance (August 1992, 13.00 h), on a clear sky day, beneath the various filter types (A = acrylate, L = Lexan, M = Mylar), compared to full sunlight (no filter). Measurement with a Optronic spectroradiometer (OL 752, Optronics Laboratories, Florida, USA).

The development and testing of low-cost solid plastic UV-B filters allow outdoor and ecosystem studies of reduction of ambient levels of solar UV-B radiation. In practice it will allow research of responses of plant from natural terrestrial ecosystems (Fig. 3).

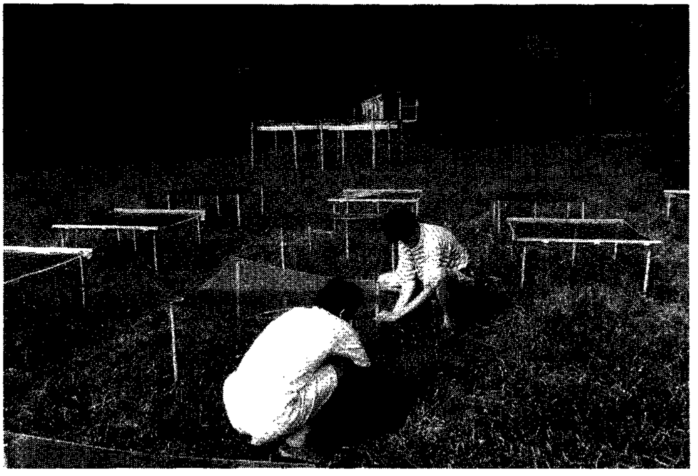

Fig. 3. Application of solid plastic UV-B filters in the study of reduction of ambient solar UV-B radiation on plant species of a dune grassland ecosystem. The height of the plastic UV-B filters can be adjusted according to seasonal development of the vegetation. At the background a rack of UV-lamps over the dune grassland vegetation is shown as a UV-B supplementation system.

3. RESPONSES OF TERRESTRIAL PLANTS TO ENHANCED SOLAR UV-B IRRADIATION

Solar UV-B effect studies have been performed on a number of crop and native plant species both in controlled environment (greenhouse), unenclosed outdoor (experimental garden) and field studies in a dune grassland ecosystem (Tables 1 and 2).
A wide range of sensitivity to enhanced UV-B measured in indoor controlled environment experiments, exists among crop species. Cultivars of crops such as soybean (*Glycine max*) vary greatly in sensitivity to UV-B.

Of the natural plant species from Dutch coastal ecosystems: the salt marsh ecosystem and dune grassland ecosystem, no apparent sensitive plant species were found both in indoor and outdoor studies. It should be noticed that no natural plant species of the Leguminosae (a plant group with many plant species sensitive to UV-B) have been subjected to enhanced UV-B radiation levels in outdoor experiments.
The woodland understorey species *Alliaria petiolata* indicates to be sensitive to enhanced UV-B. It may be that plant species occurring in open habitats (*Calamagrostis epigejos*, *Spartina anglica*) and being exposed to relatively high levels of ambient solar UV-B have evolved UV-B adaptation mechanisms. Other species occurring in the woodland understorey with reduced PAR and reduced ambient UV-B, seem to be relatively UV-B sensitive. This hypothesis is studied in current research.

Table 1. Survey of qualitative plant responses to enhanced UV-B in indoor controlled environment studies. Daily biologically effective dose of UV-B relating to 20-50% ozone depletion under clear sky.

	Response to enhanced UV-B			
	negative very sensitive	response sensitive	no significant response	positive
Crop species				
Pisum sativum	■			
Phaseolus vulgaris		■		
Vicia faba	■			
Lycopersicon esculentum		■		
Cucumis sativus	■			
Triticum aestivum		■		
Zea mays			■	
Natural plant species				
Verbascum thapsus			■	
Calamagrostis epigejos				■
Plantago lanceolata		■		
Alliaria petiolata		■		
Aster tripolium			■	
Elymus athericus		■		
Spartina anglica			■	
Holcus lanatus			■	
Silene vulgaris			■	

The reader is referred to Rozema (1993) for more detailed information.

Table 2. Survey of qualitative plant responses to enhanced UV-B in outdoor studies. Daily biologically effective dose of UV-B relating to 20-50% ozone depletion under clear sky.

	Response to enhanced UV-B			
	negative very sensitive	response sensitive	no significant response	positive
Crop species				
Vicia faba		■		
Triticum aestivum		■		
Zea mays			■	
Natural plant species				
Calamagrostis epigejos				■
Plantago lanceolata		■		
Urtica dioica			■	
Holcus lanatus			■	
Verbascum thapsus			■	
Silene vulgaris			■	

The reader is referred to Rozema (1993) for more detailed information.

4. ECOLOGICAL EFFECTS OF OZONE DEPLETION; IMPLICATIONS FOR ENVIRONMENTAL POLICY

1. Responses of terrestrial plant species to enhanced UV-B range from very sensitive to tolerant or even a positive response. This broad range type of response possibly reflects the intrinsic heterogeneity of the various terrestric ecosystems. Grassland ecosystems are much more exposed to full solar UV-B than under storey plants from forest ecosystems.

2. Adaptation to enhanced UV-B may consist of two types of mechanisms.
a. UV-B tolerant plant species avoid enhanced UV-B radiation flux at sensitive metabolic sites by absorption of UV-B by epidermal structures and dissolved, UV-B absorbing compounds such as flavonoids.
b. UV-B tolerant plant have effective UV-B repair mechanisms, in contrast with UV-B sensitive plant species.
The nature and occurrence of these adaptation mechanisms has been analysed only for a few plant species. Understanding of UV-B repsonses of all groups of terrestrial plant species needs research priority.

3. Crop plant species tend to be more sensitive to enhanced UV-B than wild plant species. This may indicate that during the breeding procedure domesticating wild species to crop plants adaptation to (high) UV-B has been lost. Maybe a trade off exists between high productivity and sensitivity to UV-B. This is an intriguing hypothesis. It might indicate that plant species may loose (genetically determined) adaptations to solar UV-B.
This implies that certain crops or certain cultivars of crops will be less productive with increasing solar UV-B. It is unknown whether selection for increased tolerance to enhanced UV-B will be successful and over what time period.

4. There are many uncertainties in the knowledge of UV-B effects on plant life in terrestrial ecosystems:
- effects of UV-B on reproductive biology are largely unknown, some of the reproductive features will be vulnerable to enhanced UV-B.
- Little is known of UV-B effects on "lower plants" like mosses ferns, fungi and algae.
- The effect of an enhanced UV-B flux is unknown in a "multiple stress" environment such as UV-B air pollution; UV-B x nutrient and water deficiency
- There are some indications that enhanced UV-B will cause increased occurrence of plant diseases by fungi, bacteria and viruses.

5. Consequences of enhanced solar UV-B to terrestrial ecosystems are expected to be substantial:
- there will be a shift to dominance of UV-B resistant plant species
- the altered biochemistry of plant species exposed to high UV-B fluxes may not only affect plant-herbivore relationships but also change the process of decomposition of leaf litter (Figure 4).

5. NATIONAL AND INTERNATIONAL COOPERATION

National and International contacts.
Between the different national UV-B research groups exchange of experimental results and methods occurs. Every six months a meeting is organized by one of the participating groups. During these meetings results are presented and discussed. Close collaboration between different groups exists on assessing the impact of UV-B on DNA Damage. Immunological

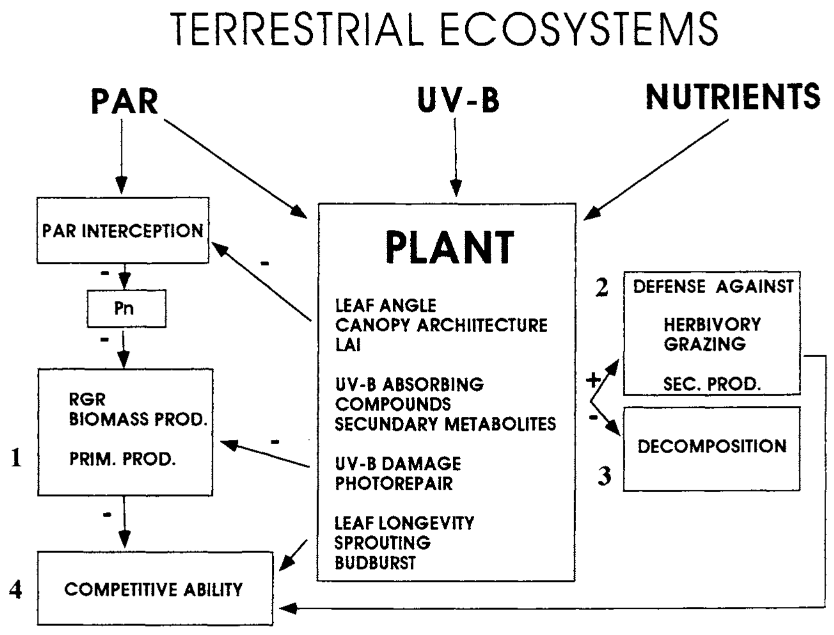

FIG.4. Conceptual model structure Impact of Enhanced Solar UV-B on Terrestrial Ecosystems: Physiology, Functioning and Dynamics.
Ecosystem Functions: 1. Prim. Prod.= Primary productivity; 2. Sec. Prod. = Secundary Productivity; 3. Decomposition. Ecosystem structure: 4. Competitive ability.
PAR = Photosynthetic Active Radiation; Pn = Net Photosynthesis; RGR = Relative Growth Rate; LAI = Leaf Area Index.

techniques used in skin cancer research are now also applied to assess DNA damage in marine algae and terrestrial plants.
Contacts exist with research groups in Germany (prof. M. Tevini, Karlsruhe) and the United States (prof. A.H. Teramura and Dr. J. Sullivan, Univ. of Maryland, Washington), who are well known for their work on UV-B effects on terrestrial plants. Results were presented and discussed during visits to these research groups in 1992, 1993, 1994.

5.1. National cooperation

1. Dr. L. van Liere, Dr. A. Veen, RIVM, UV-B and aquatic Ecosystems.
2. Dr. W. Gieskes, Dr. A. Buma, RUG, DNA-UV-B-damage, UV-B dosimetrie.

5.2. International cooperation

3. Dr. A. McLeod, ITE, Huntingdon, U.K.,
4. Prof.Dr. M. Tevini, Dr. J. Ros, TU, Karlsruhe,
5. Prof.Dr. A.H. Teramura, Un. Maryland & Hawai,
   Dr. J. Sullivan, USA,

5.3. International workshop UV-B and Biosphere

The groups involved in this project and in the project on UV-B and algal communities (nr. 851054) will organize an international workshop on the influences of UV-B radiation on terrestrial and aquatic ecosystems. That will be held towards the end of 1995.

Sponsors: the Dutch Ministry of Housing, Physical Planning and the Environment, the Dutch Organisation for Scientific Research, the Royal Dutch Academy of Sciences and the European Community.

6. REFERENCES

1 M. Blumthaler and W. Ambach, 1990. Indication of increasing solar ultra-violet-B radiation flux in Alpine regions. Science 248, 206-208.

2 J. Rozema, Plant responses to atmospheric CO_2 enrichment: interactions with some soil and atmospheric conditions. Vegetatio 105/105, 173-190 (1993).

3 J. Rozema, G.M. Lenssen and J.W.M. van der Staaij, The combined effect of increased CO_2 and UV-B radiation on some agricultural and salt marsh species. In: J. Goudriaan, H. van Keulen and H.H. van Laar (eds). The greenhouse effect and primary productivity in European agro-ecosystems, Pudoc Wageningen, pp. 68-71. (1990).

4 J. Rozema, J. van de Staaij, V. Costa, J. Torres Pereira, R. Broekman, G. Lenssen, and M. Stroetenga, A comparison of the growth, photosynthesis and transpiration of wheat and maize in response to enhanced ultraviolet-B radiation. In: V.P. Abrol. et al. (eds.). Impact of global climatic changes on photosynthesis and plant productivity. Asia publishing house, Sittingbourne, U.K. pp. 163-174 (1991).

5 J. Rozema, H. Lambers, S.C. van de Geijn and M.L. Cambridge, CO_2 and Biosphere. Kluwer, Dordrecht, pp. 484 (1993).

6 J. Rozema, M. Tosserams, J. van de Staaij, E. Magendans, H. Nelissen, and T. Brouwer, Impact of enhanced solar UV-B radiation on plants from terrestrial ecosystems. Proceeding EEG Workshop UV-B-München, GSF (1994).

7 SCOPE, Effects of increased ultraviolet radiation on global ecosystems. Proceedings of a workshop arranged by the Scientific Committee on Problems of the Environment (SCOPE), Tramariglio. Sardinia. pp. 47 (1993).

8 J.W.M. van der Staaij, G.M. Lenssen, M. Stroetenga and J. Rozema, The combined effects of elevated CO_2 levels and UV-B radiation on growth characteristcs of *Elymus athericus*. Vegetatio 104/105, 433-440 (1993).

9 J.W.M. Staaij, R. Huysmans, W.H.O. Ernst and J. Rozema, The effect of elevated UV-B (280-320 nm) radiation levels on *Silene vulgaris*: a comparison between a highland and a lowland population. Environmental Pollution (1994.).

10 J.W.M. van de Staaij, Enhanced solar ultraviolet B radiation: consequences for plant growth. Ph.D. Thesis, Vrije Universiteit, Amsterdam, (1994) 130 pp.

11 M. Tosserams and J. Rozema, Effects of supplemental UV-B radiation (280-320 nm) on the dune grass land species *Calamagrostis epigeios*. Environmental Pollution (1994).

12 W. Yu, A.H. Teramura and J.H. Sullivan, Model YMT-6 UV-B modulation system, manual of operation, final raport to US EPA, Corvallis, Oregon, USA (1991).