UV4Plants

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Front and back cover photographs: View of the Negev from Midreshet Ben-Gurion, Israel. Images obtained with a digital mirrorless camera converted to "full spectrum", using a NIR long pass filter with half-maximum transmittance ($\tau_{0.5}$) at $\lambda \approx 720$ nm (front cover, *Near infrared*), a UV short pass filter with $\tau_{0.5}$ at $\lambda \approx 390$ nm (front cover, *Ultraviolet-A*) or a UV and IR cut band pass filter with $\tau_{0.5}$ both at $\lambda \approx 370$ nm and $\lambda \approx 690$ nm (back cover). (Photo credit: P. J. Aphalo).

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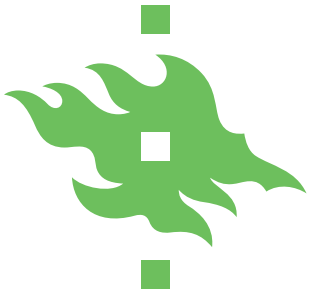

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Contents

From the editors' desk

We think that the Bulletin is a valuable tool that helps keep our UV4Plants community together. As we make progress in our aim of building a global role for the association, the Bulletin will help more members learn to know each other (meet-a-member, profiles). Current restrictions to international travel and lock-downs due to the pandemic make this role of the Bulletin even more important. Our Bulletin also informs about activities of our association such as conferences and workshops, past and future. It provides tutorials about methods, guidelines for design of experiments and minimum requirements for reproducibility which are important for achieving UV4Plants' contribution to encouraging good quality and useful UV-research. Book, software and equipment reviews can members's decisions. Very importantly, the Bulletin also provides a forum where to express opinions and viewpoints. Publishing all this content under-open access and in a publication with long-term archival practice not only helps members but advertises the existence of our association. To better fulfil these roles, changes to this Bulletin have been implemented.

We (Marcel Jansen, Titta Kotilainen and Pedro Aphalo) discussed several months how to improve the functioning of the Bulletin's "editorial office" and made a proposal to the UV4Plants management committee, which was accepted. At the time we were facing operational problems that prevented timely publication. The use of our time was not efficient, section editors found it difficult to use the editorial user interface of OJS and the spread of responsibilities across multiple section editors made tracking of the progress of submissions through the work flow very difficult. Pedro did no longer have enough free time to take care of the three roles of acquisitions editor, handling editor and production editor (typesetting and publication). Of the sections editors only Marcel, Titta, and Matt played very active roles in the most recently published issues of the Bulletin but they had been lacking clearly assigned "official" roles.

In the new scheme responsibility for editorial decisions about acceptance/revision/rejection are shared by the three editors, who consult each other in unclear cases. In addition the following changes to the allocation of tasks to editors and to the handling of manuscripts were implemented earlier this year:

1. Three editors do all editorial management. We no longer have section editors.
2. The tasks of the editors are split according to the work flow instead of subject sections: Marcel Jansen as acquisitions editor, Titta K. Kotilainen as handling editor and Pedro J. Aphalo as production editor and administrator for the OJS server.
3. Section editors became members of the new editorial review board.
4. Instructions and messages in our on-line manuscript submission system were revised for clarity.
5. We aim at faster manuscript turn-around with the help of reviewers.

Several changes to the Bulletin itself have been implemented starting from the

present issue.

a. Page layout changed from two-columns to one-column to make the Bulletin easier to read on screen.
b. Fewer sections with a broader scope: Commentaries, Reports, Articles, Doctoral thesis abstracts, Book, software and equipment reviews.
c. Introduce the use of thematic categories (currently 12) as a classification orthogonal to sections.
d. Two regular columns: Meet-a-Member (hosted by Marcel A. K. Jansen) and Hints and Tips (hosted/written by Pedro J. Aphalo).
e. The Bulletin will be published twice per year, in June and December.

We invite manuscript submissions for upcoming issues, both from members of our association and non-members. We hope you will find that the changes described above are an improvement, but if not, or if you have suggestions about how to make the Bulletin more useful or attractive to both readers and authors, please, do send your feedback to us at mailto:bulletin@uv4plants.org.

Wishing you enjoyable and instructive reading,

Marcel A. K. Jansen, Titta K. Kotilainen, and Pedro J. Aphalo, Editors-in-Chief.
Cork, Helsinki, and Joensuu, August 2020.

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Letter from the President

Gareth I. Jenkins, ORCID: 0000-0002-1855-4875

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DOI: 10.19232/uv4pb.2020.1.02

I sincerely hope that all our members, friends and colleagues, together with their families, are well and managing to stay safe in these uncertain and challenging times. The Covid-19 pandemic has changed the way most of us live our lives and it is unlikely that we will return to our previous 'normality' in the near future. Like many others, I have been working from home; our research has essentially stopped and we do not know when it will be possible to start again. I know that the situation is very similar in other countries.

From a UV4Plants perspective, we hope that it will be possible to hold our postponed Network Meeting in October (see the message from the organisers, Wolfgang Bilger and Frauke Pescheck). We will continue to monitor the situation over the coming months and decide on the meeting format as soon as we can; if it is not feasible to have the meeting in Kiel we will try to organize some form of virtual meeting if possible. We will update you when we have news about the plans. In the meantime, I hope everyone will stay safe and well.
Best wishes,

Gareth Jenkins, President UV4Plants.

News

UPDATE: UV4Plants Network Meeting", Kiel 2020

Dear colleagues in Plant UV research!

Time marches on and October is coming soon. Unfortunately, the virus is still very active and we cannot realise a personnel meeting. Instead, the Managing Committee and we decided to let the meeting happen virtually. This means that the 3rd Network Meeting of the UV4Plants Association will be the 1st virtual one! On one hand it is quite sad that we will not see each other, on the other hand this format opens our meeting to participants from all over the word! This is a great chance and fascinating! The virtual meeting will take place from October 13th to 16th every day from 12:00 – 18:00 CEST. The time frame is the best compromise to accommodate as many time zones on Earth as possible. We will reorganise the scientific programme accordingly, but our plan is to stick as far as possible to the old programme. Therefore, we will include all accepted oral presentations and posters that we had before. However, those who want may update their abstract. Also new registrations and submissions are welcome and we would be glad if this information could be distributed as much as possible! Deadline for new submissions and changes in abstracts is September 18th. Registration will be open until September 30th.

The digital format will also save a lot of money and we reduce the registration fees to 40 Euros, and for students to 20 Euros. The difference will be refunded.

Digital posters offer many new possibilities! For example, one could zoom into details during discussions with colleagues, maybe use animations or include other creative ideas. We encourage presenters to adapt their posters to a 16:9 screen format but not to prepare more than one slide, please.

The Training School will also be in a virtual format and will take place in the week from October 5th to 9th.

Stay well! We hope to welcome you all in our virtual meeting in October!

Frauke Pescheck and Wolfgang Bilger

https://kiel2020.uv4plants.org/

■ Meet-a-Member
Alenka Gaberščik

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DOI: 10.19232/uv4pb.2020.1.20

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Which places did you work at before? My career started in an elementary school. After one year of teaching I became a researcher at the Lek pharmaceutical company. In 1981 I joined a research group at the National Institute of Biology, and finally 22 years ago, I got the position of lecturer at the Department of Biology. In the 1980s I attended two one-month courses on terrestrial ecosystems at the Agricultural Institute of Zaragoza. I received my PhD in 1990 at the University of Ljubljana. My research work has always been linked to ecosystem structure and function and plant ecology. The result of an international cooperation in aquatic plant research are many applications related to the Water Framework Directive and a recently published book named "Macrophytes of the Danube River", which I co-edited. Among the ecosystem studies, I have to mention the long-term research on Lake Cerknica (Fig. 4.1), about which I also edited a scientific book titled "The Vanishing Lake".

Why did you choose to work on plant UV-effects? I have always been interested in light, which is a source of energy for plants and ecosystems, and finally also for us, humans. My interest was also in how plants take advantage of specific environmental factors, including UV radiation. UV-B radiation research in Slovenia has been initiated by dr. Jože Bavcon. In his PhD project, we studied ecophysiological responses of plants. In the late 1990s, we were invited by prof. Jelte Rozema to participate in the European project

Figure 4.1: Lake Cerknika, one of the vanishing-lakes of Slovenia. UV4Plants members will recall this lake, as it was the destination of an excursion for delegates of the 2018 UV4Plants meeting in Bled.

Figure 4.2: Alenka Gaberščik at a park.

UV-AQTER, in which leading UV scientists also collaborated, namely prof. Lars Olof Björn, prof. Janet Bornman, and prof. Donat Häder. The project team was really excellent, both in human and professional terms. The project meetings were unforgettable and the list of high quality publications derived from the project was extensive. After the project ended, prof. Lars Olof Björn remained our good friend and constructive consultant in our further research.

What is your research-specialisation? Initially, we searched for the negative effects of increased UV-B radiation on various ecological groups of plants, ranging from hydrophytes and amphibious plants to crops and tree species, to determine their potential for the accumulation of phenolic substances and to overcome stress. We also investigated how elevated UV affects the quality of phytoplankton as a source of food for zooplankton. Nowadays we are primarily interested in UV as a formative environmental factor for plants, especially in combination with other factors, such as water shortage and the availability of certain micronutrients in crops. We are also interested in the optical properties of leaves and bark, and in the fate of radiation, including UV that reaches the surface of plants. From this point of view, we also examined the influence of different substances at the plant surface, such as dust on leaves and periphyton on aquatic plants' leaves, on the absorbance of different wavelengths.

Of which UV-related accomplishment are you most proud, and why? We produced huge data sets that led to important conclusions regarding strategies of UV-absorbing compounds accumulation, e.g., many aquatic plants produce saturated amounts of these substances because of the unpredictable radiation environment in the water. The exception is a free-floating ancient species *Ceratophyllum demersum*, which has dose-dependent response that is related to increased need for energy, as measured by respiratory potential (ETS activity). We also produced data showing high adaptability potential to UV in amphibious species. Another important aspect was interaction of drought and UV, where UV mitigated the negative effects of water limitation, resulting in increased biomass production in buckwheat species and also in some cereals. We showed the important role of diatoms dwelling on aquatic plant leaves in absorbing UV and transmitting PAR, and therefore offering protection to the leaves. Our studies also revealed that silica prickle hairs in grasses may scatter UV radiation.

Can you tell a funny story relating to your work on UV-effects? When we established our first UV plots in the Ljubljana Botanical Garden, people were very curious, coming close to the plots, examining plants and asking different questions. Then we fixed a label saying "UV radiation experiment" on the fence and suddenly people started to avoid the plots.

Have you got any hints, tips or other advice to share? For biologist-researcher or for any human, it is important to be aware that there is no free lunch in nature. Everything in nature is a result of cost/benefit relation, and every response of an organism is a kind of trade-off of benefits and costs. Many traits of organisms that appear during evolution benefit organisms, but only in a specific environment. Any change of this environment makes these traits less functional or even useless. Having all this in mind makes the experiments (and life) more reliable.

What made you join UV4Plants? Joining UV4Plants was a logical consequence of our cooperation in the UV4Growth COST project that gathered high quality scientists with sparkling ideas and cutting-edge research in UV radiation and plants. Involvement in the society enables scientific communication, exchange of ideas, and collaboration in research work.

How would you like UV4Plants to develop in the future? The recent mode of action seems constructive, since it enables exchange of knowledge and ideas, which is very important for young scientists. Regular meetings are not only an opportunity to gain new knowledge, but also a chance to establish new friendships and meet old friends.

Editorial-board-reviewed article.
Published on-line on 2020-09-12.
Edited by: Titta K. Kotilainen.

■ Meet-a-Member
Andy R. McLeod

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DOI: 10.19232/uv4pb.2020.1.21

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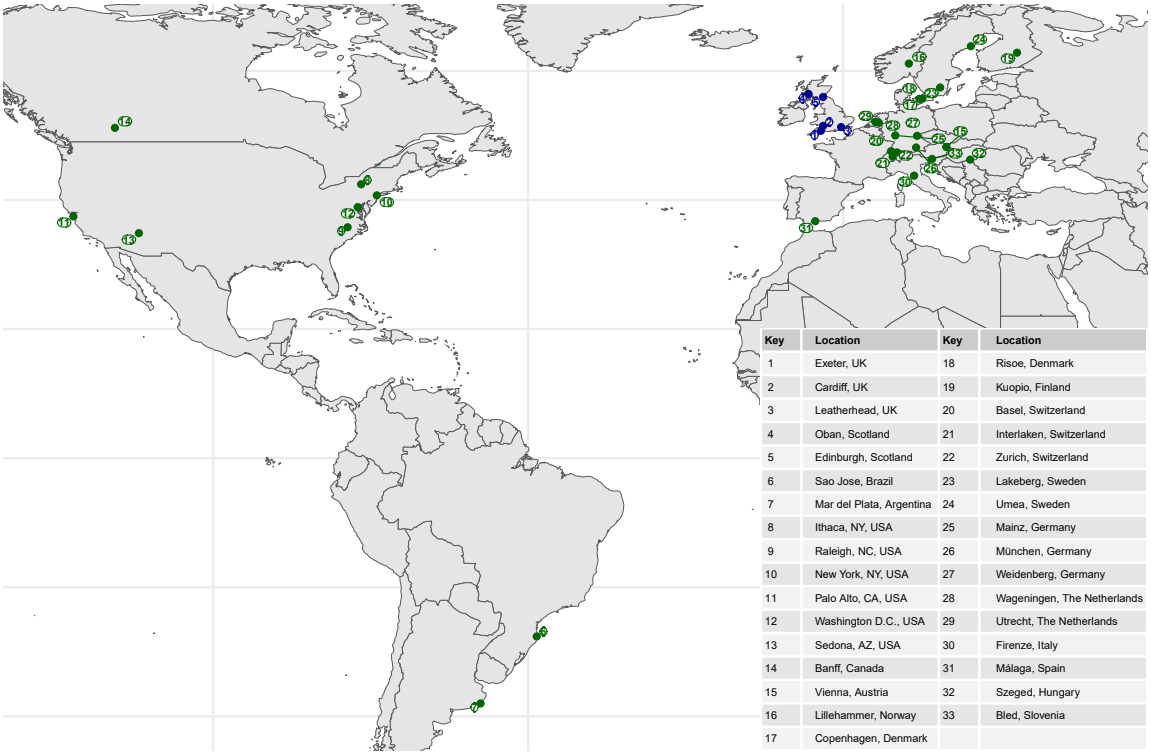
Which places did you work at before? For example, where did you do your PhD, postdoc(s) and so on I completed my PhD at the University of Exeter, UK on the primary production and photosynthesis of the common reed *Phragmites australis* (Fig. 5.1). I measured above and below ground biomass, leaf photosynthesis, light and temperature profiles and modelled canopy photosynthesis. I was then appointed as a Research Officer in the Biology Section of the Central Electricity Research Laboratories, Leatherhead, UK specifically to develop and build outdoor systems for studies of air pollutants (SO_2 and O_3) on crops and forests (with no enclosure or chamber). These later evolved globally for studies of elevated CO_2 effects into the widely-used FACE systems. This work is reported in Special Issues: *Agriculture Ecosystems & Environment* (1991) **33**(3) and *Plant, Cell & Environment* (1995) **18**(3). Outdoor experiments led me to conclude that indirect biotic and abiotic interactions with pollutants were as important, or even more important, than direct physiological effects on plant growth.

Why did you choose to work on plant UV-effects? I remember being intrigued by a conference poster on UV effects by Alan Teramura which also appealed to my use of outdoor experiments (see Fif.). In 1992 I moved to the Institute of Terrestrial Ecology (ITE) at Monks Wood, UK. When I was asked for comments on who might be suitable for studies of UV impacts of ozone depletion on ecosystems I suggested that I would like to be involved. This

Figure 5.1: Time line showing important events in Andy R. McLeod's career.



Key	Location	Key	Location
1	Exeter, UK	18	Risoe, Denmark
2	Cardiff, UK	19	Kuopio, Finland
3	Leatherhead, UK	20	Basel, Switzerland
4	Oban, Scotland	21	Interlaken, Switzerland
5	Edinburgh, Scotland	22	Zurich, Switzerland
6	Sao Jose, Brazil	23	Lakeberg, Sweden
7	Mar del Plata, Argentina	24	Umea, Sweden
8	Ithaca, NY, USA	25	Mainz, Germany
9	Raleigh, NC, USA	26	München, Germany
10	New York, NY, USA	27	Weidenberg, Germany
11	Palo Alto, CA, USA	28	Wageningen, The Netherlands
12	Washington D.C., USA	29	Utrecht, The Netherlands
13	Sedona, AZ, USA	30	Firenze, Italy
14	Banff, Canada	31	Málaga, Spain
15	Vienna, Austria	32	Szeged, Hungary
16	Lillehammer, Norway	33	Bled, Slovenia
17	Copenhagen, Denmark		

Figure 5.2: Important places in Andy McLeod's career. In blue sites of study and employment, in green scientific visits and presentations outside U.K.

enabled me to visit the UV facilities used by Alan and Joe Sullivan at the University of Maryland, USA and I also received much advice from Martyn Caldwell and Charles Ashurst. I remain exceedingly grateful for their advice and assistance. This enabled me to construct an outdoor modulated UV lamp system and use this to evaluate effects on plants and led to my ongoing interest.

What is your research-specialisation? I was trained as an ecologist, hydrobiologist and plant ecophysiologist and my research has addressed several fields of study. After working on air pollution effects for 13 years, my UV research specialised in using modulated outdoor lamp supplementation systems, and in collaboration with many colleagues, addressing the many aspects of physiology and ecology that influence plant responses, particularly biotic and abiotic interactions.

Most recently I have focussed on mechanisms for photochemical emissions

Figure 5.3: Andy McLeod using a range of filtered gas bags to measure photochemical production of dissolved gases in seawater at the ocean surface during the longest day of 2018.

from freshwater and marine sources using lab exposure systems and sunlight on the ocean surface to measure gas production in seawater (see Fig. 5.3). However, aquatic work was a new area and I have learned much from experienced colleagues in the Association and the wider community. I continue to co-supervise a project on the role of UV in macular degeneration in the human eye in which knowledge from UV studies on plants has proved very valuable to the medical team.

Of which UV-related accomplishment are you most proud, and why? In 2006 I was intrigued by a Letter to Nature which suggested that emissions from plants by an unknown mechanism might contribute up to 30% of atmospheric methane. I thought that UV might be involved and, in collaboration with many colleagues, I investigated whether UV irradiation of pectin in plant cell walls resulted in formation of methane (*New Phytologist* (2008) **180**, 124–132) and the mechanisms involved (*Plant, Cell & Environment* (2009) **32**, 1–9). We then scaled emissions globally using modelled UV levels and leaf area index (*New Phytologist* (2010) **187**, 417–425) and measured emissions from many species (*Plant, Cell & Environment* (2015) **38**, 980–989). The global scaling suggested that UV-driven leaf emissions contributed < 1% of global at-

mospheric methane emissions, much smaller than the original 30% reported. The paper was selected for inclusion in a Special Online Issue of *New Phytologist* that commemorates Sir Arthur Tansley who introduced the ecosystem concept into biological studies.

Can you tell a funny story relating to your work on UV-effects? After a PhD viva on UV effects on plant organic matter, the examiners, including me, hatched a plan (whilst drinking wine) to test whether UV could explain methane on Mars by UV-driven emissions from the organic matter in meterorites. Yes really! And we hadn't had that much wine. We had no dedicated finance but each person could contribute in some way (including access to a meteorite sample). I was to provide a 1000 W xenon arc lamp (the one in Fig 2.8 of the Beyond the Visible handbook) and get it to Utrecht, in The Netherlands. I took three hours to fill it with polystyrene granules in an enormous rucksack before boarding a ferry from the UK to Amsterdam on foot. Unusually, the customs officer asked to search my rucksack but opened my briefcase first. He examined all my papers on UV effects on plants, smiled and just waved me on. Six months later returning by car I was directed into a shed for a full car search by sniffer dogs. Fortunately, I had my Health & Safety documents and gave the customs officer gauntlets and a face visor (as xenon bulbs can explode). He listened to my story about methane on Mars, grinned and waved me on without a search. So, there are many good reasons to prepare your Health & Safety documents on UV hazards. The experiments were eventually published in *Nature* (2012) **486**, 93–96, so plant ecologists really can contribute to planetary science.

Have you got any hints, tips or other advice to share? Never be surprised by the range of biotic and abiotic interactions with UV exposure outdoors that can influence your results.

And, a few technical points to avoid uncontrolled exposures in an outdoor supplementation system that tracks sunlight.

1. As well switching lamps on/off by software control near sunrise/sunset, also use a separate timer on the lamp power supply to turn off during hours of defined darkness (and adjust times weekly through the season).

2. Add a separate electronic circuit that also turns off the power to lamps if it is not pulsed regularly by the modulation control software (to ensure the software hasn't stalled).

3. Use an uninterruptable power supply to avoid problems during short power failures.

These features enable you to avoid uncontrolled and possibly unmeasured exposures due to control systems stopping caused by software glitches and

electricity voltage fluctuations or failure. It is especially important in long-term experiments over several years.

What made you join UV4Plants? This was a logical decision even after formal retirement in order to maintain contact with friends and colleagues and to develop my knowledge, aid writing up past work and hopefully some future research activity.

How would you like UV4Plants to develop in the future? I think it is important to maintain international knowledge and capabilities in many science fields and the Association has a clear role in relation to UV effects on plants. Thus, the transfer of experience to younger scientists has particular value. I would like to see a continuation and development of Training Workshops in conjunction with conferences and perhaps hold some joint meetings or sessions with other relevant societies. The experience of UV studies on plants also has considerable value in other related disciplines where UV effects in the field are often still not fully appreciated or ignored in ecological field studies.

Who would you like to appear in a future "Meet-a-Member"? Patrick Neale

Editorial-board-reviewed article.
Published on-line on 2020-09-12.
Edited by: Titta K. Kotilainen.

■ Doctoral thesis abstract

Light quality affects leaf pigments and leaf phenology

Doctoral candidate: Craig C. Brelsford, ORCID: 0000-0001-7084-352X
Supervisor: T. Matthew Robson

Date of defence: 2020-06-04

Organismal and Evolutionary Biology Research Programme
Faculty of Biological and Environmental Sciences
Doctoral Programme in Plant Sciences (DPPS)
University of Helsinki

ISBN: 978-951-51-6136-9.
URL: http://hdl.handle.net/10138/314777

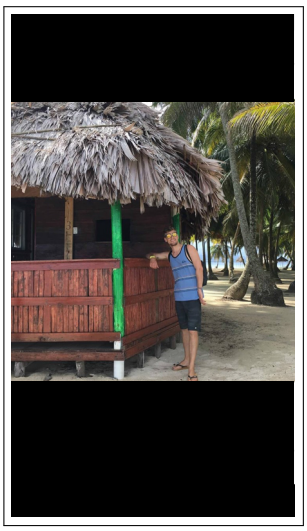
Bio of Craig C. Brelsford

Place of Birth: Poole, Dorset, UK
Biology BSc (Hons) 1st, University of Bristol
Research Technician at University of Cambridge in the Forest Ecology and Conservation Group

Short presentation I've always had a curious mind, and during my years at school I most enjoyed science, philosophy, and writing. I followed these through to University where I gained a 1st in Biology at the University of Bristol. After brief stints as a Field Biologist with the Mauritian Wildlife Foundation, and working with an ecological consultancy in the UK, I was given the opportunity to work as a Research Technician for Professor David Coomes at the University of Cambridge. It was this work—spending a memorable eight months of fieldwork in the jungles of Borneo—which harboured an appreciation for plants.

It was also during this time that when checking my emails I stumbled upon an advertisement for a PhD in Plant Biology at the University of Helsinki. Having wanted to try living in another European country, and not having a clue about Finnish culture, I naturally applied and was lucky enough to get the position.

Now having come through the other side, I can say that a PhD is a great opportunity to gain a range of skills suitable for a career within academia or outside. Throughout my PhD I found my biggest interests were in writing, learning to code, and teaching others. I now apply all of these in my current position as a Technical Writer and Instructional Designer. In short—I write and help produce interactive online courses for different companies. Our team helps teach topics on anything from software, to sustainability and engineering. It also means that I get to stay in Finland, and enjoy the important things in life such as going for walks in the forest, picking mushrooms, and hitting the sauna with friends.



PhD Thesis Abstract

Light quality varies in space and time, and plants are able to detect and respond to these environmental cues. Plants must time when their leaves come out in spring and fall off in autumn, to maximise opportunities for photosynthesis whilst conditions are favourable. Similarly, they must optimise the amount of sun-screening pigments in their leaves, to minimise the harmful effects of ultraviolet radiation at high irradiance.

Solar radiation reaching the Earth, as well as its composition, vary diurnally and seasonally with solar angle. During twilight, plants are able to detect changes in red:far-red light, and use this to help time their spring and autumn phenology. When forest canopies leaf out in spring, and cause canopy closure, the understorey becomes mostly covered in shade. This shade also causes a low red: far-red ratio, that plants are able to detect and increase their stem elongation. However, the amount of blue and UV radiation also varies in space and time, and we know considerably less about how plants

respond to these changes in the blue-and-UV region.

Using a combination of controlled indoor experiments, literature review, and manipulative field experiments, we set out four aims. 1) How do blue and UV-A radiation affect leaf pigments under controlled conditions? 2) How does blue light affect spring bud burst under controlled conditions? 3) How do blue and UV radiation affect leaf pigments and leaf phenology for understorey plant species? 4) How important is light quality as a phenological cue?

We found that both under controlled conditions and in the field, blue light had a large positive effect on the accumulation of flavonoids, most likely governed by cryptochrome photoreceptors. Interestingly, the flavonols in more light-demanding species of plants were more responsive to changes in light quality, particularly blue light. Similarly, blue light advanced spring bud burst in tree species both in the lab and in the field. We also report that both blue light and UV radiation can advance autumn leaf senescence in understorey plants. Lastly, when critically comparing the effect sizes of light quality treatments on phenological responses in trees, we found that light quality effects on spring phenology are generally small. However, the effects reported on autumn phenology are much larger. This adds to the complexity of drivers affecting autumn phenology, and may be one reason why autumn phenology is typically much harder to forecast compared to spring.

Future work should seek to understand how other environmental drivers such as temperature will interact with light quality to affect leaf pigments and leaf phenology. It will be important to understand how climate change could produce potential phenological mismatches in cues between the canopy and understorey, and even between different organisms such as plants, herbivores, and pollinators.

Publications in the thesis

Brelsford, C. C., L. Nybakken, T. K. Kotilainen, and T. M. Robson (2019). "The influence of spectral composition on spring and autumn phenology in trees". In: *Tree Physiology* 39.6. Ed. by A. Polle, pp. 925–950. DOI: 10.1093/treephys/tpz026.

Brelsford, C. C., L. O. Morales, J. Nezval, T. K. Kotilainen, S. M. Hartikainen, P. J. Aphalo, and T. M. Robson (2018). "Do UV-A radiation and blue light during growth prime leaves to cope with acute high-light in photoreceptor mutants of Arabidopsis thaliana ?" In: *Physiologia Plantarum* 165, pp. 537–554. DOI: 10.1111/ppl.12749.

Brelsford, C. C. and T. M. Robson (2018). "Blue light advances bud burst in branches of three deciduous tree species under short-day conditions". In: *Trees* 32.4, pp. 1157–1164. DOI: 10.1007/s00468-018-1684-1.

Brelsford, C. C., M. Trasser, T. Paris, S. M. Hartikainen, and T. M. Robson (2019). “Understory light quality affects leaf pigments and leaf phenology in different plant functional types”. In: DOI: 10.1101/829036.

This article: DOI: 10.19232/uv4pb.2020.1.22

■ Doctoral thesis abstract

Light after death: the importance of spectral composition in litter decomposition processes

Doctoral candidate: Marta Pieristè, ORCID: 0000-0001-6515-0833
Supervisors: Dr T Matthew Robson (Helsinki), Prof. Matthieu Chauvat (Rouen)
Co-supervisors: Dr. Estelle Forey (Rouen), Dr. Alan G Jones (Scion Research, New Zealand)

Date of defence: 2020-06-16

UFR Sciences et Techniques, Université de Rouen-Normandie
EdNBISE, Ecole doctorale Normande, de Biologie Intégrative, Santé, Environnement
Faculty of Biological and Environmental Sciences, University of Helsinki
AGFOREE, Doctoral Programme in Sustainable Use of Renewable Natural Resources

ISBN: 978-951-51-6136-9.
URL: http://hdl.handle.net/10138/315216

Bio of Marta Pieristè

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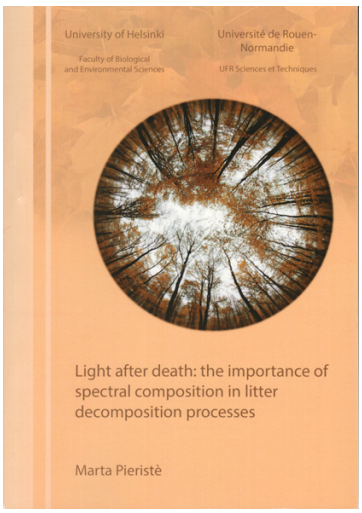
BSc in Forest and Environmental Sciences Università Politecnica delle Marche, Ancona, Italy
MSc in Wildlife and Environmental Science and Management University of Florence, Firenze (Italy)
Thesis title: Influence of roe deer feeding sites on browsing intensity in an Austrian mountain forest (In collaboration with BOKU University, Vienna, Austria)

Research visit to Forestry and Forest Products Research Institute, Japan, Tsukuba Collaboration in 2 field studies examining plant response to sunlight and plant traits variation as a consequence of exposure to different spectral regions of sunlight.

Cooperation to the creation of the Science nature trail at Lammi Biological Station (Finland) Design of several citizen-science activities for families and young students related to forest ecology.

Short presentation I was always fascinated by nature and forests since a very young age. For this reason, I decided to study forestry and environmental management. After having the opportunity to work with different research groups during my internships in Italy and Austria, I felt like research could be my career pathway and I decided to start a PhD in Plant biology.



PhD Thesis Abstract

This dissertation focuses on the effect of sunlight on leaf litter decomposition. Sunlight can affect litter decomposition positively or negatively through the process known as photodegradation. Photodegradation is the ensemble of direct, indirect and mediated mechanisms. Short-wavelength solar radiation, carrying high energy, has the capacity to directly break down relatively stable components of plant tissues, such as lignin and cellulose, through photochemical mineralization causing the release of volatile carbon compounds into the atmosphere. Photochemical mineralization produces more-labile molecules, which can enhance the activity of microbial decomposers through a process known as photofacilitation or photopriming. Solar radiation has also the ability to indirectly alter decomposition through negative effects (photoinhibition) on both the activity and community composition of decomposer organisms.

We examined the process of photodegradation under forest canopies in

a temperate and a boreal environment. Through two field experiments, we tested the effects of photodegradation on mass loss and carbon content during leaf litter decomposition in each environment (I in France and II in Finland). We also studied these processes under controlled conditions in a filter experiment (II). In France, we performed an additional field experiment, in the same forest as the first, to analyse the effect of photodegradation on microbial assemblages colonizing the litter (III). In these experiments, we employed "photodegradation-litterbags", bespoke litterbags adapted from classical litterbags used in litter decomposition studies incorporating different types of film filter-material, allowing us to manipulate the spectral composition of sunlight. Finally, we conducted a meta-analysis (IV) to summarise the effect of photodegradation driven by different spectral regions of solar radiation at the global scale, and across different biomes, and to test whether the photodegradation rate is modulated by initial litter traits.

This dissertation highlights the importance of blue light as a major driver of photodegradation in a temperate mid-latitude forest understorey, with the potential to enhance both litter mass loss and carbon loss. However, at a higher latitude, the full spectrum of sunlight decreased mass loss, suggesting that the effect of photodegradation is specific to each biome. Forest canopies not only modify the amount of incoming solar radiation and its spectral composition, but also shape the microclimate of the understorey, producing unique combinations of temperature, moisture and snow-pack depth. Hence, each canopy generates novel interactions of solar radiation and other environmental factors which act on leaf litter to determine the photodegradation rate. At both boreal and temperate latitudes, our spectral manipulations revealed the effect of photodegradation to be litter species-specific, with recalcitrant litter experiencing higher rates of photodegradation. In terms of microbial decomposition, we highlighted how blue light, UV-A radiation and green light, act synergistically to shape the structure of microbial decomposer communities, with bacteria tending to dominate in sunlight and fungi in dark conditions.

The results of our meta-analysis show that the direction and magnitude of photodegradation are dependent on the spectral region considered. We highlight the crucial role of blue light and UV-A radiation as drivers of photodegradation across biomes. Blue light has a positive effect in enhancing mass loss, while UV-A radiation has a negative effect. Moreover, our meta-analysis shows that the rate of photodegradation at the global level is modulated by climate and ecosystem type; whereby arid and semiarid ecosystems with low canopy cover experience the highest photodegradation rates. On the other hand, initial litter traits failed to predict the rate of photodegradation on the global scale, despite being important at the local level; suggesting that different traits could be important in different biomes.

Photodegradation is known to have a role in the carbon cycle, as the process of photochemical mineralization causes the release of volatile carbon compounds into the atmosphere. Therefore, we can expect photodegrada-

tion to reduce the amount of carbon sequestered by ecosystems. However, further research is needed to estimate the actual contribution of photodegradation to the global carbon cycle. Moreover, this contribution is likely to be affected by climate change, which modifies environmental factors such as temperature and the amount and pattern of precipitation; these factors together with spectral irradiance determine the photodegradation rate.

Overall, our results show that the process of photodegradation has an effect on litter decomposition in the understorey of mid- and high- latitude forests, despite the low irradiance to which litter in these ecosystems is exposed. Blue light appears to be more important than other spectral regions in driving photodegradation in these habitats. However, the photodegradation rate is modulated by both climate and ecosystem type.

Publications in the thesis

Pieristè, M., Q.-W. Wang, T. K. Kotilainen, E. Forey, M. Chauvat, H. Kurokawa, T. M. Robson, and A. G. Jones (2020). *Crucial role of blue light as a driver of photodegradation in terrestrial ecosystems on the global scale: a meta-analysis*. Manuscript.

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■ Methods

High intensity UV-B and UV-A radiation from plasma-based sources

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Introduction

Ceravision is a privately owned SME specialising in lighting systems based on high-pressure electrodeless discharges. In particular, it concentrates on sources for the generation of UV-A and UV-B radiation. These were developed primarily as light sources for supplementary lighting in greenhouses and grow-rooms. This work has contributed to a more wide ranging interest in lighting for horticulture.

Plants grown outdoors are subjected to varying amounts of both UV-A (315 to 400 nm) and UV-B (280 to 315 nm) depending on geographical location and time of the year. It has been known for a long time that radiation in the range 280 to 550 nm (i.e. UV-A, UV-B and blue light) is important to the growth and development of plants (Schäfer and Nagy 2006). There is solid evidence indicating that UV-A and UV-B radiation perceived through UVR8 and cryptochrome photoreceptors drives photomorphogenic plant responses including gene regulation, flavonoid biosynthesis, leaf and epidermal cell expansion, stomatal density, and increased photosynthetic efficiency (Bornman et al. 2019). Exposure to UV radiation may also induce the synthesis of specific proteins involved in resistance to microbial attack. However, unnatural ratios between irradiance in different bands of the spectrum can result in disturbances to plant growth and even damage, making the spectral quality of radiation an important factor in the use of artificial light in plant cultivation (Bornman et al. 2019).

The term 'high-pressure electrodeless discharges' will most likely not be familiar to those outside the lighting industry and so this article will outline the fundamental principles of conventional high-pressure discharge lamps, i.e. those with electrodes, before giving an overview of electrodeless high-pressure discharge light sources. This article reviews the technology behind

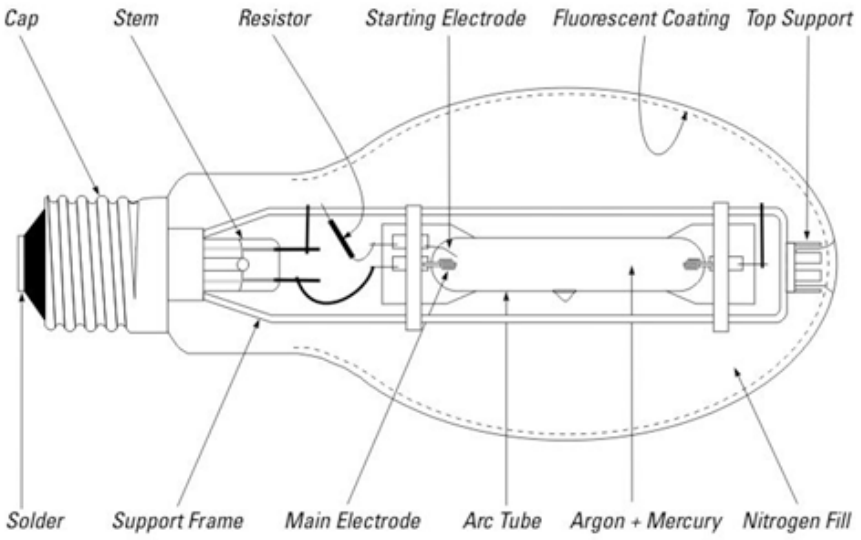

Figure 8.1: Diagram of a typical high-pressure mercury lamp. Image source: http://lamptech.co.uk/. Reproduced by permission.

plasma light sources and the advantages of their use in horticulture compared to other types of discharge lamps. Ceravision's research and development programs on the use of UV radiation in horticulture are briefly presented. The article concludes with a description of the Company's recent initiatives with its research collaborators in the UK and Europe. We have previously drawn the lighting industry's attention to the importance of UV radiation for plants (Stocks and Mucklejohn 2019) and here we aim to draw the attention of the plant science community on our novel UV-lighting technologies.

High-intensity discharge lamps

High-pressure discharge lamps, commonly known as high intensity discharge (HID) lamps, were until recently the mainstay of street and road lighting until they began to be replaced by LED sources. The characteristic golden-white colour appearance of the high-pressure sodium (HPS) lamp is still widespread in road lighting and exterior floodlighting throughout much of Europe. In recent years the HPS lamps' highest-growth application has been for horticultural lighting in greenhouses and grow-rooms. The various parts of a typical HID lamp are shown in a diagram (Figure 8.1) while photographs of many different types of lamps can be found at http://lamptech.co.uk/.

High-pressure discharges are those with operating pressures >100 000 Pa

(>1 atm) whereas low-pressure discharges, such as linear and compact fluorescent lamps, typically have operating pressures <1000 Pa. High-pressure discharges are considered to be in local thermodynamic equilibrium which means the composition of the discharge can be calculated from the thermodynamic properties of the chemical species present. Low-pressure discharges are not in local thermodynamic equilibrium. The first generation of HID lamps was based on mercury discharges, such lamps are no longer permitted to be placed on the market for general lighting purposes in most countries because of their low efficiency. However, these lamps are permitted for specialist applications such as the generation of UV radiation.

Addition of various metal halides to the mercury discharge provided lamps with higher efficiency and better colour rendering properties. The first generations of metal halide lamps had arctubes fabricated from fused silica. The main disadvantages were the relatively poor maintenance of the light output and colour changes through life. Reactions of the metal halides, especially the alkali metal and lanthanide halides, with the fused silica arctube restricted life and performance. The launch of metal halide lamps with ceramic arctubes from the mid-1990s onwards addressed many of the limitations of the earlier generations.

High-pressure sodium (HPS) lamps first became commercially available in the 1960s and have since undergone a series of improvements and adaptations. They are efficient, low cost and highly reliable. They are very effective at producing photosynthetically active radiation (PAR) due to the broadened sodium D-line emissions over the range 500 to 700 nm.

HID lamps are operated with an ignitor to initiate the discharge and a ballast to control the current. The original copper-iron ballasts are increasingly being replaced by electronic control gear (ECG) which also provides the starting mechanism.

Electrodeless high-intensity discharge lamps

Electrodeless HID lamps (also known as high-intensity plasma lamps), as the name suggests are discharge lamps which have no internal electrodes. The lack of electrodes confers a number of benefits when compared with electroded discharges. The constraints on arctube geometry are different. Lamp survival factors are extended because the economic life of regular discharge lamps is generally controlled by the life of the electrodes. Thirdly, there is greater freedom of choice for the chemical composition of the discharge atmosphere, which again in conventional discharge lamps is limited by reactions involving the electrode systems. At high temperature, halogens readily react with tungsten, the metal most commonly used for electrodes, thus metal halide discharge lamps are restricted to using iodides other than for high performance, short life lamps.

Apart from the electrodes, the two types of discharges produce light us-

ing the same mechanisms, i.e. from thermally excited atomic and molecular transitions. Commercially available lamps operate in the microwave region (frequency range 300 MHz to 300 GHz) and are driven from a resonant structure integral with the arctube. The use of microwaves implies the need for either a magnetron or solid state microwave oscillator. These devices have the drawback of either lower efficiency than the ballasts for regular discharges or in the case of solid state devices, until very recently, much higher cost. These disadvantages have to be offset by improved performance from the discharge.

For both electrodeless and electroded discharges the discharge volume tends to consist of a cylindrical or approximately cylindrical geometry. This has implications for the light generating mechanism. In the case of electroded lamps the power is dissipated on the axis of the discharge. In the case of an electrodeless discharge, microwaves penetrate the discharge space from the arctube wall to the skin depth of the discharge. This can lead to very different temperature profiles within the discharge that can lead to different emission characteristics. These manifest themselves as differences in the relative amounts of thermal atomic and molecular emissions.

Ceravision's UV420 luminaire

The Ceravision UV420 luminaire (Figure 8.2) was developed to supplement photosynthetically active radiation (PAR) lighting in greenhouses and grow-rooms. In many commercial installations 1000 W HPS lamps are the light source of choice. This source produces the PAR efficiently but the spectral power distribution (SPD) is heavily weighted towards the red end of the visible spectrum, there is relatively little radiation emitted below 550 nm. Most greenhouse glasses do not transmit UV-B radiation and hence plants grown under such conditions do not benefit from this stimulus. The UV420 luminaire is specifically designed to provide UV-B, UV-A and blue (400 to 500 nm) radiation.

When selecting the metal halides best suited to providing UV-B and UV-A radiation, metals with strong emission lines in the 280 to 550 nm range can be selected from well-established collections of atomic electronic energy levels such as those compiled by NIST (Sansonetti 2003) or held in the Kurucz database (Smith et al. 1995). For example, thallium halides would be selected if intense radiation were required in the region centred on 535 nm and indium halides would be used to generate intense radiation centred on 410 and 455 nm.

To obtain radiation throughout the 280 to 550 nm region, a combination of atomic and molecular radiation is essential if elements outside of Groups 4 to 12 (the Transition Metals) are used. The emission and absorption properties of many diatomic metal halides are not well characterised. A survey of some such molecules contained in the NIST Chemistry WebBook (Linstrom 1997)

Figure 8.2: The Ceravision UV420 luminaire. left: detail, right: in use over industrial hemp.

shows that the molecular constants for many species of interest are subject to large uncertainties or are not listed. The data available do, however, allow calculation of the approximate wavelengths emitted for transitions from the first excited state to the ground state. The intensity of radiation emitted cannot be predicted without the temperature and wavelength variations of the net emission coefficients. These parameters are reported for very few diatomic metal halides and thus experimentation has proved to be the best approach to determine the contributions of various diatomic molecules to the overall optical emission. Gnybida et al. (2014) describe in detail the calculation of the local emission and absorption coefficients for a molecular transition.

Unsaturated arctubes, i.e. those in which the metal halides and mercury are fully evaporated, provide the most resilience to changes in SPD with input power. Thus, component volatility and dose composition are important selection criteria. The SPD can be tailored to application specific requirements by careful selection of the metals, halides and concentrations.

The ratio of output from the UV420 luminaire between 280 to 550 nm compared to 280 to 1100 nm is >0.70. A typical value for this ratio in a 150 W ceramic metal halide (CMH) lamp (saturated dose conditions) with

correlated colour temperature 4000 K would be ≈0.35 (Guest et al. 2008).

The output from the UV420 can be modified by changing the glass filters: figure 8.3 shows the relative SPD with filters which give the maximum UV-B (lower panel), intermediate UV-B (middle panel) and low UV-B (upper panel) output, respectively.

Specialist knowledge is essential to select the most appropriate material for the reflector and the glass filters as most materials commonly used in the lighting industry are intended for visible light, and steps are taken to prevent emissions in the UV range. A soda lime glass filter is suitable for absorbing most UV-B radiation from the light source whereas a borosilicate glass with high UV-B transmission is used to provide the maximum UV-B output. A borosilicate glass filter of a different composition is selected to provide intermediate levels of UV-B radiation.

Horticultural trials with Ceravision's UV420 luminaire

Andrew Fuller and his team at the Bridge Farm Group have conducted a series of trials exposing strains of industrial hemp, rosemary and lavender to UV-A and UV-B radiation. UV420 luminaires (Ceravision, Milton Keynes, UK) were used to supplement the lighting provided by high-pressure sodium lamps at selected stages towards the end of the plants' growing cycle, prior to harvest. The plants exposed to UV showed a significant increase in the yield of essential oils, i.e. the terpenes and flavonoids that are responsible for flavour and aroma, compared to the controls which were not exposed to UV radiation. In most crops the payback to the grower depends on the yield of specific components of plant biomass rather than on total biomass yield. This is most obvious when produce is used as raw material for extraction of various compounds including vegetable oil, protein or different essential oils. In an interview with Shane Torpey (MIGRO, a supplier of LED luminaires, https://www.migrolight.com/about/), Andrew Fuller explains the advantages of enhancing the production of essential oils from plants from a producer's viewpoint, while recognizing the need for further research, see 'Using UV to increase CBD in UK Industrial Hemp Facility' in https://www.youtube.com/watch?v=n765oOU_MMo.

The initial trials have shown, as could be expected, complex responses of plants to different UV wavelength ranges and intensity. More work is required to better tune the treatments for different plant cultivars and species and desired target plant responses. However, relatively low-energy UV and blue radiation inputs can deliver a large improvement in the yield of certain terpenes and flavonoids of commercial interest. Management of the radiation spectrum can enable growers' control over the quality of their final product and have great potential for the future'. Studies using different luminaires have also shown that exposure to UV-B radiation can be accompanied by a reduction in the incidence of grey mould, *Botrytis cinerea* (Costa et al. 2013;

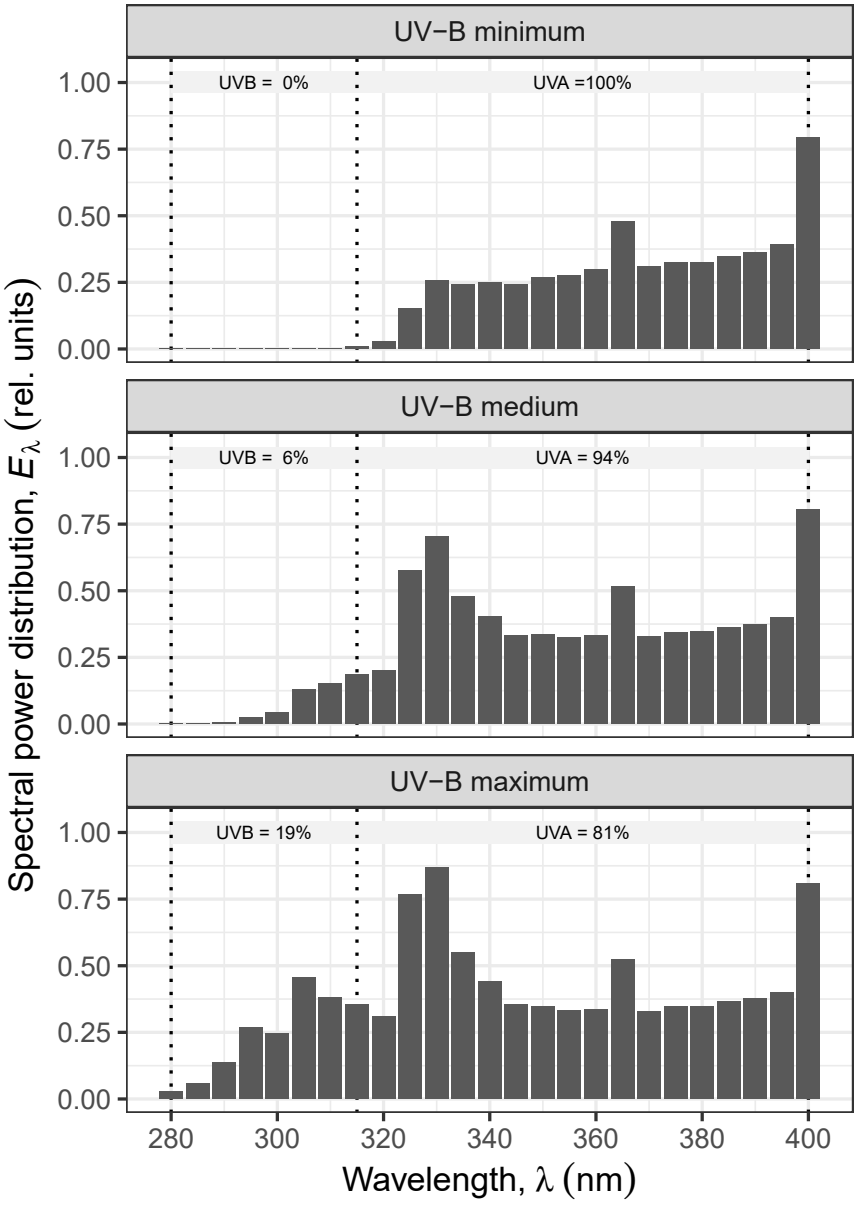

Figure 8.3: Spectral power distribution (SPD) of the UV420 luminaire fitted with three different long-pass filters. The relative units shown are energy based, i.e., the plots only describe the shape of the spectra, while spectral irradiance in absolute units ($\mathrm{W\,m^{-2}\,nm^{-1}}$) will depend on the distance to the lamp, which varies among use cases.

Heuvelink 2006).

When using light sources of any type in the workplace, employers must comply with the applicable national regulations. Within EU countries these regulations would have been derived from the Directive regarding the exposure of workers to risks arising from artificial optical radiation (EU 2006). In particular, exposure of personnel to UV radiation should be strictly controlled with eye and skin protection used.

Estimating irradiance from the sun

To help growers estimate suitable values of exposure to UV-A and UV-B for plants grown indoors it is vital to have realistic values for the irradiances that are encountered by plants in their natural growing environment. A possible target for the research and growing communities might be to replicate the complete solar spectrum at a given location on the Earth's surface. Thus, by knowing the lighting conditions where plants naturally flourish, artificial lighting installations may be designed to closely match the corresponding spectral power distributions and variations through the day and from day to day. On the other hand, knowingly altering such spectrum could serve as a tool for enhancing the commercial yield of valuable products compared to that obtained outdoors.

Several models are available for estimating solar irradiance differing in their reliability and ease of use. For scientific research libRadtran (Emde et al. 2016) and TUV (Madronich and Flocke 1998) two radiation transfer models, are the currently the preferred ones. Simpler and easier to use models maybe preferable for advising growers. The authors have used the Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS) (Gueymard n.d.) from the National Renewable Energy Laboratory (NREL) in Colorado and the simplified approach described by Bird & Riordan (also from NREL) (Bird and Riordan 1986) to calculate the global spectral solar irradiance at various locations on the Earth's surface. The former model has spectral resolution 0.5 nm for 280 to 400 nm, 1 nm for 400 to 1750 nm and 10 nm for 1750 to 4000 nm.

Lighting calculations

Ceravision has been working with academic institutions, in particular University College London and Laboratoire plasma et conversion d'énergie (LAPLACE) in Toulouse, to develop tools to help growers estimate the number and type of luminaires needed to give a target irradiance for a pre-defined area and to assess the likely environmental impact of their lighting operations.

To quantify the distribution of light from luminaires, manufacturers measure their intensity in a series of different directions. This is done in a standardised way and information is published in an intensity file. The two most

widely used file formats are those with extensions `.ies` (IES 2020) and `.ldt` (Keysoft Solutions Ltd. 2020). Knowing the distribution of light from the luminaires, the area being lit and the distribution of luminaires across the area, it is possible to calculate the fraction of the radiation flux leaving the luminaire that hits the reference plane. Dialux (`https://www.dialux.com`) and Relux (`https://www.relux.com`) are industry standard software packages, free to download, for lighting design and visualisation that have links to .ies and .ldt files provided by luminaire manufacturers. By knowing the SPD and the total flux from the luminaire, the irradiance ($\mathrm{W\,m^{-2}}$) and the photosynthetically active photon flux density (PPFD) ($\mathrm{\mu mol\,m^{-2}\,s^{-1}}$) in any given wavelength band can then be calculated.

In conjunction with our research partners we have built a database of light sources together with their SPDs, fluxes and luminaires to calculate irradiances, total power demand and power loadings for an installation. Irradiances can be calculated in ranges UV-B, UV-A and PAR. The total electrical power available to a site is often a limiting factor in the design of a commercial greenhouse, as it has to support lighting, heating, cooling and ventilation. A detailed account of this work is in preparation and will be published elsewhere.

Environmental impact and life cycle assessment

When it comes to evaluating the quantifiable effects of products or services on the environment, life cycle assessment (LCA) is probably the most efficient and widely recognized tool. Thanks to a 'cradle to grave' approach, LCA identifies and quantifies, throughout the life of products, the physical flows of matter and energy associated with human activities (extraction of raw materials, manufacturing of the product, distribution, use, collection and disposal at end-of-life). Each of its flows correspond to indicators that illustrate the overall potential impact of the system on our environment. With regard to lighting, 'smart' technologies have made it possible to improve energy efficiency during use phase and thus greatly decrease the impact on the environment.

The traditional functional unit used for assessing light sources, $1\times10^{6}\mathrm{lm}\cdot$ h, is not appropriate for horticultural applications as the lumen is a quantity based on the response of the human eye over the range 380 to 780 nm. Consequently, as a result of a recent collaborations we are proposing a new approach to quantifying the environmental impacts and life cycle assessments for horticultural lighting systems based on functional units expressed as the products of irradiance ($\mathrm{W\,m^{-2}}$) and time (Mucklejohn, S. A., Preston, B., Moutsi, A., Bertin, K., Zissis, G. and Raynham, P , unpublished).

The new assessment approach is based not on the output of the light source, nor on the light source plus the luminaire and electronic control gear, but on the irradiance and uniformity delivered by the lighting installation to

a reference plane for a set length of time, e.g. 1000 h. A plane surface has been used for simplicity and repeatability because the actual irradiance impinging on the plant varies as the plant grows and new leaf formation creates shade to older/lower parts of the plant.

This approach reflects the importance of the lighting design as well as the characteristics of the light source, gear and luminaire. It is widely accepted that uniformity is an important factor in lighting for horticulture and various designs can be used to illustrate the compromises between average irradiance and uniformity. Because the SPD over wavelengths from 280 to 1200 nm plays a vital role in the response of plants to radiation, we have defined functional units for several wavelength ranges (unpublished results).

The future

The move away from magnetrons to high-power solid-state microwave generators will continue and will bring higher efficiencies and devices that are more compact. Although very efficient LEDs with long life expectancy are available for wavelengths of 365 nm and longer, currently available LEDs emitting at shorter wavelengths have very low conversion efficiencies and are relatively expensive.

The largest increase in benefits to society from a more widespread use of UV in horticulture is most likely to come from extensive collaboration between plant scientists, commercial growers and suppliers of the infrastructure, including lighting, needed for indoor growing environments. Experiments carried out under carefully controlled, repeatable conditions will be essential to realise the potential of the various opportunities in the application of UV that are now available thanks to technological progress. These advances may subsequently enable a more sustainable approach to global food security as well as healthier food and population.

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■ Commentary

The taste of UV light: using sensomics to improve horticultural quality

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UV and greenhouses: friends or foes?

Greenhouse horticulture is in its broad definition the production of plant products within, under or sheltered by structures that provide protection against biotic and/or abiotic stress. In greenhouses, horticultural crops can grow protected from infectious agents and adverse weather conditions, allowing off-season, year-round production. However, greenhouse production often comes with a trade-off, which is a skewed light environment with a lack of UV light.

In some instances, the blockage of UV by greenhouse glass and plastic covers is beneficial from a commercial perspective, especially on tropical latitudes where plants can often encounter higher UV levels, which may impair plant growth and nutrient absorption (Krause et al. 1999; Verdaguer et al. 2017). On the other hand, reduced UV inside greenhouses may reduce the synthesis of metabolites associated with crop protection against biotic and abiotic stress, such as flavonoids, terpenoids and alkaloids (Yang et al. 2018). This reduction in the amount of protective compounds may not be seen as an important limitation in a protected environment, but these metabolic changes caused by reduced UV exposure may in fact negatively impact on product quality. For example, it is possible to improve of the aroma and taste of greenhouse tomato by exposing plants to low levels of supplementary UV light (Dzakovich et al. 2016).

Bridging the gap

When it comes to defining what sensorial quality is, the most relevant and straightforward description is based on the way humans perceive a given food through their senses; eye sight, smell, taste, touch and hearing. These senses act as gatekeepers for food choices. Nowadays no new food production process is worth developing unless the final product will have a sensory quality accepted by consumers (Tuorila and Monteleone 2009). The need to consider sensory product quality resulted in increased interest in studies that integrate sensory analysis into the context of how environmental factors, such as UV light, influences horticultural product quality (Carvalho et al. 2018; Charles et al. 2017; Dzakovich et al. 2016; Lipan et al. 2019). A new and highly challenging consequence of this is the integration of the scientific knowledge on metabolites acquired by plant scientists with the product quality as defined by consumers.

Research in the field of plant photobiology has expanded our understanding of how UV shapes plant metabolism, especially when it comes to specific metabolite classes such as flavonoids, anthocyanins and terpenoids (reviewed by Thoma et al. 2020). Some of these compounds are known to influence colour, aroma and taste of horticultural products, thereby impacting on product quality (Abbas et al. 2017; Kayesh et al. 2013). However, the overall quality of a horticultural product depends on its metabolic signature as a whole rather than on an increment or a reduction of few metabolite classes (Tieman et al. 2017).

Whilst improvements in horticultural quality have been inferred mainly on changes in the concentration of selected metabolites (i.e., target approaches), there are virtually no data linking metabolic effects of UV to product quality as defined by consumers. Supplementary daily doses of UV during greenhouse tomato production improves fruit aroma and taste as evaluated by a sensory panel (Dzakovich et al. 2016); however, it is still not clear which are the metabolic signature of horticultural products that makes consumers consider them as products with high sensorial quality.

One promising strategy to fill this knowledge gap would be to apply top-down systems biology approaches, which combines system-wide data originating from “omics” technologies with mathematical modelling to uncover relationships among genes, proteins, and molecules. Among these top-down systems biology approaches, metabolomics, the comprehensive analysis of all metabolites in a studied biological system, is opening new roads to further our understanding of how metabolites orchestrate various processes in plants. For example, application of metabolomics combined with genomics on plant breeding programs can identify specific markers associated to performance of distinct traits (Fernandez et al. 2016). In the context of sensorial quality defined by the consumers, sensomics, a cutting-edge science concept that integrates metabolomics and network analysis with novel sensory analysis methods, such as the ‘repertory grid method’ and the ‘rate-all-that-apply

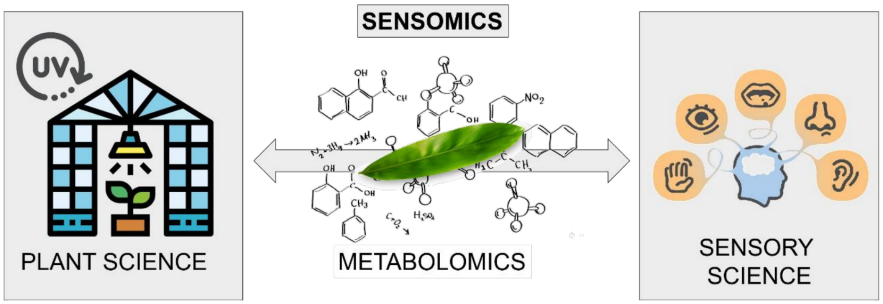

Figure 9.1: Sensomics concept to improve horticultural quality. Sensomics combines plant science with advanced analytical tools and sensory analysis to generate uniquely new insights in horticultural quality.

method' (Aguiar et al. 2018), can provide the necessary link to translate what is happening inside the plant into a person's experience of food quality (Figure 9.1).

Sensomics and UV light: the case of dill

The horticultural industry in northern Europe usually competes with imported produce from more southern (equatorial) latitudes where light conditions are favourable for field growth. From a sustainability and resilience perspective it is important that growers in northern Europe produce food with improved quality. Such improvement in quality is also a key to the competitiveness of the local horticultural industry that operates in an international market.

As a way of addressing the challenges faced by the Scandinavian horticultural industry, we are applying sensomics to improve the quality of horticultural products traditionally grown in the region. For example, we have explored the quality of dill (*Anethum graveolens* L.) produced at commercial standard conditions in greenhouses in the presence or absence of supplementary UV. Plants were exposed continuously during 4-hour daily to either UV-A- or UV-B-enriched light using fluorescent lamps (3.6 $\mathrm{W\,m^{-2}}$ plant-weighed UV-A or 0.083 $\mathrm{W\,m^{-2}}$ plant weighed UV-B) in the presence of a background of photosynthetically active radiation (150–200 $\mathrm{\mu mol\,m^{-2}\,s^{-1}}$, 16 $\mathrm{h\,d^{-1}}$) (Qian et al. 2020). Untargeted metabolomics analysis using gas chromatography coupled to ultra-high resolution mass spectrometry revealed that, compared to the control, plants exposed to supplementary UV in greenhouses had a metabolic signature similar to 'gold standard' samples. These 'gold standard' dill samples are imported from southern latitudes and were assessed by a sensory panel of trained volunteers (at Örebro University's School of Hospitality, Culinary Arts and Meal Sciences) as a high-quality product. The shift in dill metabolite profile induced by UV light appears to have a positive

impact on product quality as defined by consumers. Sensory analysis showed a move in the sensory quality of UV-exposed dill from the outset towards the desired situation (i.e., from control to 'gold standard') by about 30%, enabling us to find associations between metabolic signatures and product quality.

Further sensomic analysis of other horticultural products including basil, cabbage, lettuce and coriander will help us to define metabolic signatures associated with other high-quality products and establish, most likely species-specific, UV light regimes in greenhouses to grow horticultural products with improved quality. We also envision that discovery of associations between overall plant metabolism and sensory quality will support horticultural breeding.

The project is still ongoing and our promising results will benefit not only the plant science community for scientific reasons, but also primary producers, food industry, and first and foremost, consumers.

Acknowledgement

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■ Methods

Absorbance, absorptance and friends

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Introduction

Most photobiologists sooner or later have to measure light absorption by objects such as plant leaves, optical filters or solutes in a liquid medium. The physical quantities we measure may vary: absorbance, optical density, absorptance, transmittance and reflectance. For each of these quantities there is also variation in how they are defined and in the symbols used to represent them. The main authority for chemical notation is the *International Union of Pure and Applied Chemistry* (IUPAC) and as photochemistry is closely related to photobiology, IUPAC definitions are suitable and broadly used in plant physiology (Braslavsky 2007). I will use the definitions and symbols recommended by IUPAC (Braslavsky 2007; Cohen et al. 2007) and the *Système international d'unités* (SI units). Johnsen (2012) discusses the proliferation of units and describes a subset of them, based on the uses in his field of research, and several of the definitions he gives are not consistent with those currently recommended by IUPAC. Even if in the field of plant photobiology the IUPAC definitions are usually followed, as I will do here, researchers should be very attentive both as readers and writers about the existence of alternative definitions and the use of the same symbols for different physical quantities. In addition, some of the consistently used and named quantities can be difficult to distinguish from each other for non-experts. My aim here is to provide guidance for the use of these quantities in research on plants.

Reflectance

Reflectance is the fraction of the incident radiation that is reflected,

$$\rho = P_{\text{refl}}/P_0,$$

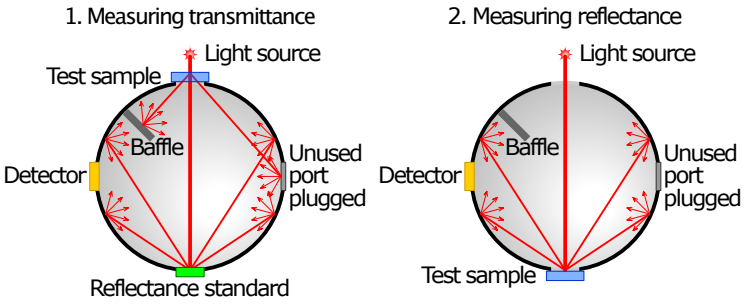

Figure 10.1: An integrating sphere in two different configurations, as used to measure total transmittance and total reflectance, respectively. Source: Wikimedia Commons. Creator: cmglee. Revised by: P. J. Aphalo. License: CC BY-SA 3.0.

where P_{refl} is the reflected radiation and P_0 the incident radiation[1]. Simple enough, but in most cases ρ depends on the angle of incidence of the illumination, so for ρ to be interpretable this angle must be known. How we collect the reflected light also matters, giving rise to two different quantities, specular reflectance ρ_{specular} and total reflectance ρ_{total}. For measuring ρ_{total} we use in most cases collimated light for illumination at only a small angle of incidence (θ_1) and collect all reflected light with an integrating sphere with its port seated against the illuminated side of the object (Figure 10.1). For ρ_{total} we use as white reference ($\rho_{\text{total}} \approx 1$) a surface that scatters the light. To measure ρ_{specular} we use collimated light for illumination and measure reflected light over a narrow angle and on a plane normal to the light beam used illumination, using a probe usually based on a coaxial arrangement of optical fibres. In this second case, we can easily take readings at different angles to describe how ρ_{specular} varies. For objects that scatter light, $\rho_{\text{specular}} < \rho_{\text{total}}$. Reflectance ($\rho$) is defined as a "summary" over a broad range of wavelengths, a range that depends on the light source and sensor used. To measure a reflectance spectrum we combine a light source with a wide and "featureless" emission spectrum with the use of a spectrometer as sensor. The quantity we obtain is spectral reflectance, given by $\rho(\lambda) = P_{\text{refl}}(\lambda)/P_0(\lambda)$, where λ stands for wavelength.

For a plane interface, such as that between air and a polished glass plate, the reflectance at different angles can be calculated from the refractive indexes (Figure 10.2). It depends on the relative refractive index between two media, such as air and glass. I assumed an interface with a relative refractive index of 1.5, which is close to that between crown glass or acrylic and air. If light is moving from air into the glass or acrylic, $\rho \lesssim 0.1$ for small incidence

[1] We use P as symbol, instead of the usual E or Q as the discussion is valid for radiation expressed on both an energy- or photon basis, and for both irradiance and exposure, as long as units are used consistently for the different terms in each equation.

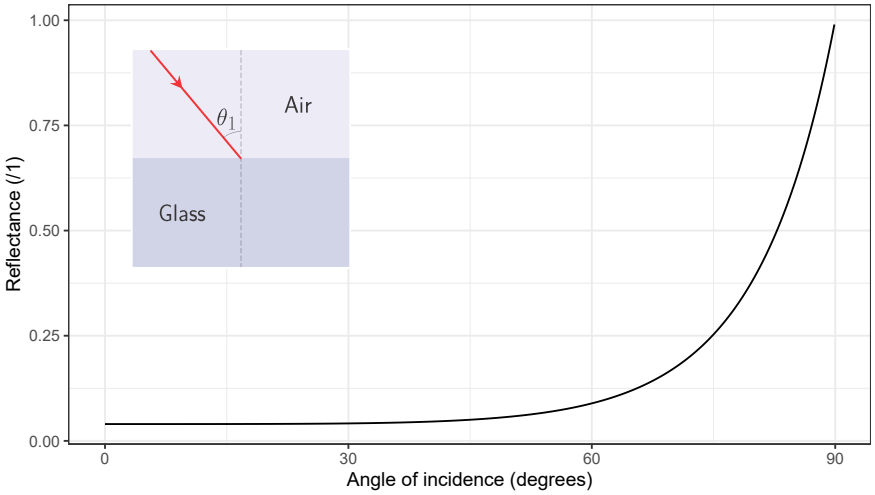

Figure 10.2: Reflectance of a single plane interface as a function of the angle of incidence (θ_1). Computations are for an interface between air and crown glass, i.e., for relative refractive index $n = 1.5$. See the Appendix for code used.

angles ($\theta_1 < 30°$) and then increases rapidly reaching $\rho \approx 0.5$ at $\theta_1 = 75°$ and $\lim_{\theta_1 \to 90°} \rho = 1$ when the light beam is close to parallel to the interface surface (Figure 10.2). In most cases we are dealing with two interfaces, one on each face of the glass or acrylic pane, resulting in a further decrease in transmittance. The dependency on the angle of incidence is, obviously, important when using wavelength-selective filters but also crucial for the design of glass-houses at medium and high latitudes.

The same formulae apply to metals, but in the case of metals the refractive index is given by a complex number with a Real component n and an imaginary component k. Reflection of diffuse, i.e., Lambertian, light at plane interfaces and reflection of collimated light by scattering media are beyond the aims of this paper.

Transmittance

Total transmittance is the fraction of the incident radiation that is transmitted through an object,

$$\tau = P_{\mathrm{tr}}/P_0,$$

where P_{tr} is the transmitted radiation and P_0 the incident radiation. In practice we usually measure τ with normal illumination and collect all the transmitted light, which in the case of objects that scatter the transmitted light

requires an integrating sphere for measurement (Figure 10.1). Transmittance can be also expressed as internal transmittance, $\tau_{\text{internal}} = P_{\text{tr}}/(P_0 - P_{\text{refl}})$, i.e., using as reference the light actually "entering" the object, rather than the incident one. For some objects which do not scatter light, such as glass filters with a polished surface, ρ varies little with λ and a constant conversion factor can be used to inter convert τ_{internal} and τ_{total} values. For objects like plant leaves, the conversion requires that $\rho(\lambda)$ is known. As above if measured across the spectrum, we obtain the spectral equivalents, $\tau(\lambda)$ and $\tau_{\text{internal}}(\lambda)$. Light extinction corresponds to $1 - \tau$ and its use is frequent in atmospheric sciences or when considering light in plant canopies.

Absorptance

Absorptance is the fraction of the incident radiation that is absorbed by an object,

$$\alpha = P_{\text{abs}}/P_0,$$

where P_{abs} is the absorbed radiation and P_0 the incident radiation. As above if measured across the spectrum, we obtain the spectral equivalents, $\alpha(\lambda)$.

As there is no other fate possible for incident radiation, $\rho + \tau + \alpha = 1$, and consequently, in theory, each of ρ, τ and α can take values in the range zero to one. If we exclude reflectance we get $\tau_{\text{internal}} + \alpha = 1$. On the other hand $\rho_{\text{specular}} + \tau + \alpha \leq 1$, as $\rho_{\text{specular}} \leq \rho_{\text{total}}$ (This is so because ρ_{specular} does not include the scattered component of reflectance.)

The easiest way of demonstrating the importance of the difference between internal and total transmittance is using an example. In Figure 10.3.A $\rho(\lambda)$, $\tau(\lambda)$ and $\alpha(\lambda)$ are plotted as a stack, showing that their sum is always equal to 1. In Figure 10.3.B we plot only $\tau(\lambda)$, or total spectral transmittance, which is identical to the lower layer of the stack in Figure 10.3.A. In Figure 10.3.C we plot $\tau_{\text{internal}}(\lambda)$, where we see that $\tau_{\text{internal}}(\lambda) + \alpha(\lambda) = 1$.

Absorbance

In this case we have two definitions in use, mostly in different fields of research: (decadic) absorbance, A_{10} or A, and napierian absorbance, A_{e}. The definition of (decadic) absorbance is

$$A_{10} = log_{10}(1/\tau_{\text{internal}}),$$

or its equivalent

$$A_{10} = -log_{10}(1 - \alpha).$$

In the case of napierian absorbance, we need only substitute log_{10} by log_{e},

$$A_{\text{e}} = log_{\text{e}}(1/\tau_{\text{internal}}),$$

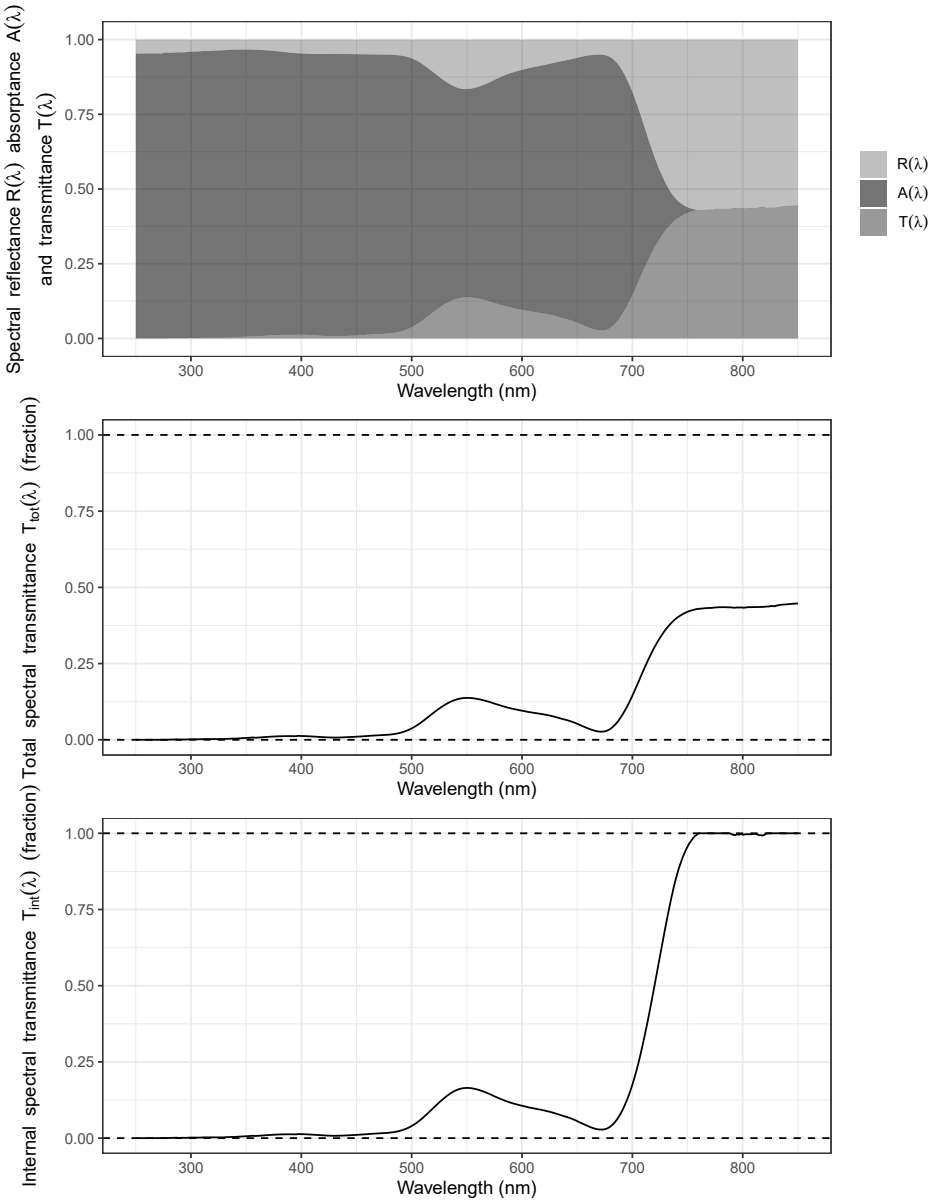

Figure 10.3: Optical properties of the adaxial side of an Arabidospis (Ler) leaf. A. Total spectral transmittance, spectral absorptance and spectral reflectance from the same leaf; B. Total spectral transmittance; C. Internal spectral transmittance. One observation from (Wang et al. 2020). See Appendix for code used.

or its equivalent

$$A_e = -log_e(1 - \alpha).$$

From these equations it follows that $A_{10} = A_e \cdot log_e(10)$ and $A_e = A_{10} \cdot log_{10}(e)$.

While absorbance is defined as

$$A_{10} = log_{10}(1/\tau_{internal}),$$

optical density is denifed as

$$\text{OD} = log_{10}(1/\tau_{total}),$$

i.e., optical density is the equivalent of absorbance but based on *total* transmittance instead of *internal* transmittance.

As for ρ, τ and α above, if A (or OD) is measured across the spectrum, we obtain the spectral equivalents, $A_{10}(\lambda)$ and $A_e(\lambda)$. With the definitions above becoming dependent on wavelength (λ), for example spectral (decadic) absorbance is defined as

$$A_{10}(\lambda) = log_{10}(1/\tau_{internal}(\lambda)),$$

or its equivalent

$$A_{10}(\lambda) = -log_{10}(1 - \alpha(\lambda)).$$

Absorption of light by homogeneous semi-transparent media is a cumulative process along the light pass, resulting in exponential decay, as described by Lambert-Beer's law,

$$I_l = I_0 \, e^{-a \cdot l}.$$

This curvilinear relationship is the reason why absorptance is not proportional to solute concentration or path length while absorbance is. The attenuation of radiation passing through homogeneous media is an exponential process with respect to both the length of the light path (l) and with increasing values of the absorption coefficient, a (K also used), where a is expressed in m^{-1}. In other words, while, a is an intensive property of a material, A_{10} is an extensive property of an object.

When we are interested in the concentration of a solute, we define the molar extinction coefficient $\epsilon = a/c$, where c is the molar concentration, resulting in an alternative formulation of the Lambert-Beer's law,

$$I_l = I_0 \, e^{-c \cdot l \cdot \epsilon},$$

The coefficient ϵ is expressed[2] in $m^2 \, mol^{-1}$, assuming concentration c is expressed in $mol \, m^{-3}$.

The data in Figure 10.4 simulate the effect of thin layers of flavonoid solutions at two different concentrations. We can see that attenuation per unit of path length is strongest immediately below the illuminated surface. We can

[2]We show here SI units only, although some other units are still in use.

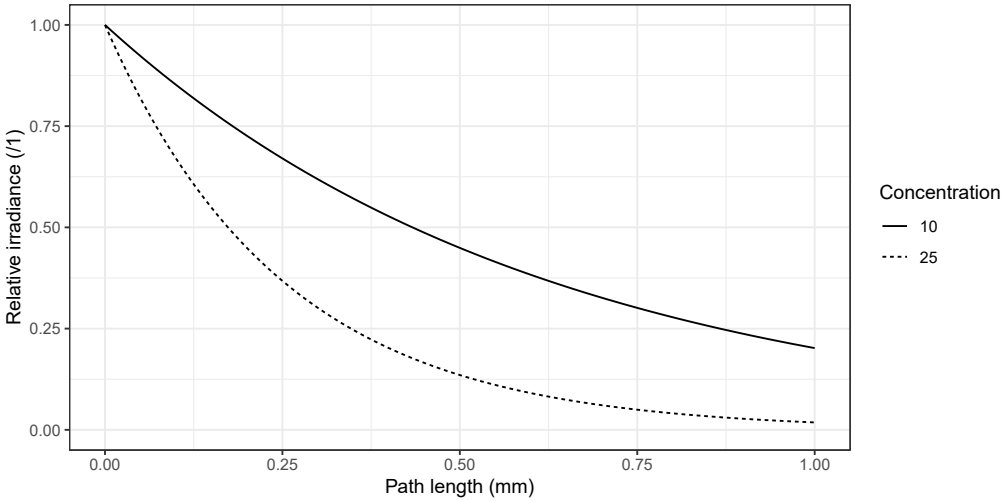

Figure 10.4: Light attenuation in a homogeneous semi-transparent medium. Relative irradiance (I_l) is plotted as a function of the length (l) of the light path. Plotted values were computed using Lambert-Beer's law assuming solutions of quercitrin at concentrations of 10 and 25 $\mathrm{mol\,m^{-3}}$ and extinction coefficient $\epsilon = 16 \times 10^4\,\mathrm{m^2\,mol^{-1}}$ (ϵ for $\lambda = 350\,\mathrm{nm}$ from Latouche et al. 2012, Figure 1). See Appendix for code used.

also see that the effect of solute concentration on the transmitted irradiance is most noticeable deeper into the layer. The depth into the layer at which attenuation is 50% depends on the concentration (Figure 10.4). It should be remembered that the Lambert-Beer's law does not apply to scattering media like plant tissues and colloidal suspensions.

Units and symbols

All of ρ, τ, α, A and OD are unitless quantities, describing ratios between values expressed in the same units. While A and OD are always expressed as some small positive number, ρ, τ, and α can be expressed either as fractions of one (/1) or as percentages (%).

The symbols R, T and A are also commonly used in place of ρ, τ, and α. However, although IUPAC accepts this use of R and T, it reserves A for absorbance. Not being these quantities fundamental or directly derived from such quantities, no symbols are defined for them in the SI standard.

Box 10.1: Estimating epidermal UV-screening with the Dualex

Because absorbance, A, is proportional to the concentration of a light-absorbing solute, $A_{10} \propto$ [solute], it is used widely in spectrophotometry. Similarly, the Dualex instruments (Force-A, Orsay) measure a quantity that approximates the absorbance of the epidermis of leaves on a band centred at $\lambda = 375$ nm (Goulas et al. 2004). This index quantity is assumed to be useful as a proxy of the concentration flavonoids in the epidermis. However, when we are interested in the degree of protection, transmittance, τ, is more informative than absorbance. This instrument measures the attenuation of radiation reaching the chlorophyll in the leaf mesophyll by comparing the excitation of chlorophyll fluorescence by radiation of different wavelengths. The conversion of $A(\lambda = 375\,\text{nm})$ into $\tau(\lambda = 375\,\text{nm})$ is straightforward. As $\tau = 10^{-A_{10}}$, it follows that a value of $A_{\text{epidermis}} = 2$ from the Dualex can be interpreted as meaning that $\approx 1\%$ of the UVA at $\lambda \approx 375$ nm impinging on the epidermis reaches the mesophyll and $\approx 99\%$ is attenuated. Because of the way the Dualex works, comparing two wavelengths, only the difference in epidermal reflectance between $\lambda \approx 375$ nm and $\lambda \approx 655$ nm is measured and consequently the A estimate from the Dualex is not a true absorbance neither a true optical density, OD, estimate but instead something in-between. This must be taken into consideration when discussing protection for leaves that are highly reflective in the visible, because true UVA protection will be significantly better than that estimated by Dualex instruments.

Practical considerations and applications

Depending on the aims of a study, or the problem at hand, ρ, τ, α, A or OD may be the most informative quantity. Depending on the object measured and equipment used, τ_{internal} or τ_{total} may be easier to obtain. In many cases by default or as only option an instrument may provide values for a quantity that is not the one most appropriate for our study. In such cases, the relationships and equations described above may allow us to convert the measured values (see, Box 10.1).

If we measure a solution in a cuvette with a spectrophotometer and we use as reference the same or an identical cuvette with solvent as reference, we can assume that we have discounted the effect of reflections. Instead if we measure a filter, such as a piece of polyester film, and the reference is no film, our measurement includes the effect of reflections at the film surface. If we express the readings as transmittance, in the first case we have measured τ_{internal} while in the second cases τ_{total}. If we use logarithms then we obtain absorbance A and optical density OD, respectively.

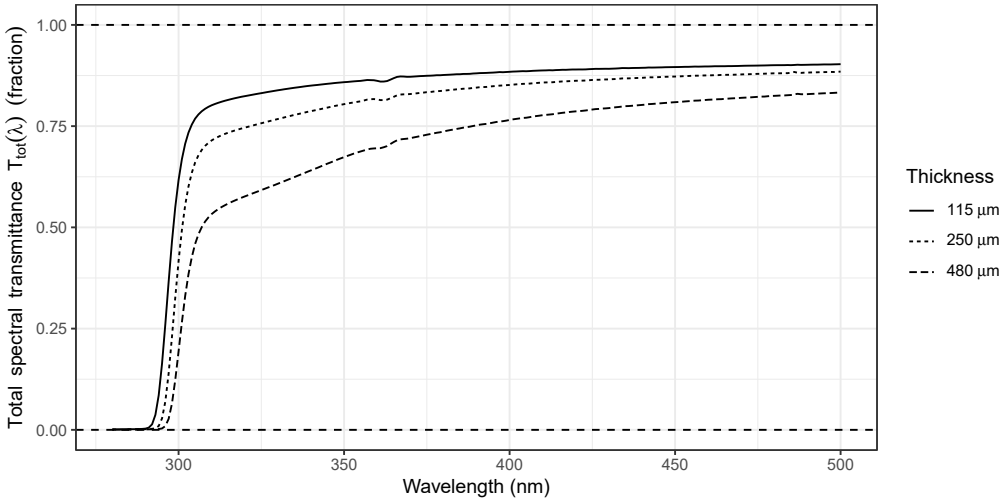

Figure 10.5: Effect of celullose diacetate film thickness on total transmittance. See Appendix for code used.

Internal transmittance, τ_{internal}, makes it easy to compute the effect of changes in transmission with changes in the length of the light pass, such as when using different spectrophotometer cuvettes, or the effect of ionic filter glass of different thickness. This is easy to understand from first principles: ρ in non-scattering media is defined by the surface, so ρ is not affected by the thickness of the material. That in the formula below we use the ratio between the thicknesses of the filters as an exponent, stems from the exponential extinction relationship described by the Lambers-Beer law.

$$\tau_{\text{internal,d2}} = \tau_{\text{internal,d1}}^{(d1/d2)},$$

where d1 is the thickness corresponding to the known τ_{d1} and d2 is the thickness for which we want to compute the corresponding τ_{d2}. Figure 10.5 shows measurements of transmittance for cellulose diacetate. Increasing the thickness four times alters the shape of the curve and shifts the wavelength for 50% transmittance by 8.6 nm towards longer wavelengths and decreases the UV-A transmittance by 20%.

If we compare a standard spectrophotometer cuvette with 10 mm light path to a cuvette with a path of 50 mm, a solution that yields $A = 0.2$ in the first cuvette will yield $A = 0.2 \cdot 5 = 1.0$ in the second cuvette. When we need to measure very low concentrations using a longer light path is very useful and using a short light path helps when concentrations are high. Cuvettes with light-paths lengths bewteen 1 mm and 100 mm are easily available, and can greatly increase the range of concentrations that can be measured with a given instrument, as long as they physically fit into the spectrophotometer.

Box 10.2: Measuring reflectance of semi-transparent objects
When we measure reflectance from objects that transmit some of the incident radiation, we need to ensure that no light inpings on the back of the object. For example, the opposing integrating spheres in the SpectroClip-TR (Ocean Insight, Dunedin, FL, formerly Ocean Optics), create an important problem. Part of the transmitted photons will bounce on the lower integrating sphere impinging onto the lower surface of the object and may be transmitted back through the object into the upper sphere. This means that some photons will contribute to both the transmittance and reflectance measurements, which can result in erroneous measurements that seem to indicate that $\rho + \tau + \alpha \geq 1$. The problem is more apparent when measuring samples with high values of τ. For example, in spectral measurements of leaves in the far-red region ($\lambda \gtrsim 700\,\text{nm}$) α is very small and τ nearly 50%, a situation where unless a black object is put behind the leaf during the measurement of ρ, the estimate of ρ will be biased towards values larger than the true ones. It is also possible to apply a correction when processing the data. To obtain the data in Figure 10.3 a black object was put behind the leaf during the measurement of ρ, and the minimum calculated $\alpha(\lambda)$ was very close to zero. The best light absorber that is easily available and thin, is the black flocking sold for covering the inside of optical instruments and cameras (Arax, Kiev; `https://araxfoto.com/`) or special black paint for this same purpose such as *Kameralack Spray* (Tetenal, Norderstedt; `https://www.tetenal.com/`) sprayed on a suitable base material. Not being aware of the limitations introduced by the Spectro Clip's design can lead to substantially wrong data being reported. The same problem will be introduced by the presence of any reflecting material behind the leaf being measured, e.g. a white sheet of paper behind the sample even when using a reflectance probe with a narrow angle of acceptance. Obviously, when measuring at wavelengths that we cannot see, we cannot choose an object that looks black, e.g., black anodised aluminium has hight reflectance in the near infrared.

In the first part of this section we have considered only non-scattering materials. This is the simplest case because if we measure in a normal spectrophotometer a non-scattering material like an homogeneous solution or a piece of glass or acrylic with well polished surfaces estimates of τ will be reliable as the light beam direction will not be disturbed. In contrast, if we measure a suspension of particles in a solvent or a thick film of polythene or similar plastic, we will grossly underestimate τ. The reason is simple, the transmitted light that is no longer collimated will not reach the sensor and will not be measured. In this case, to obtain a reliable measurement, we need to use an integrating sphere to collect the photons leaving the measured object in all possible directions. The obvious way to recognize that scattering is biasing the measurements is to look at the measured transmittance at wavelengths were the material is known to have very high transmittance such as the visible region for polythene. If the measured transmittance is less than 0.9, then the measurement has been biased by the scattering and the reading obtained wrong. Of course, unless scattering is minimal, we can also see its effect when looking through the materials. Depending on how the integrating spheres are attached to the sample, additional complications may arise (see, Box 10.2).

In the previous examples in this section we have considered objects that attenuate irradiance mainly through absorption of light that travels through them. There are filters that attenuate light through selective reflection. With such filters thickness of the base material only minimally affects transmittance, i.e., $\alpha \ll \rho$. Interference filters are produced by deposition of very think layers on the surface of the substrate and $\rho(\lambda)$ is controlled by their thickness. The opposite effect is also possible, and is used to produce antireflection (AR) coatings in glass and plastic filters and windows. AR multicoating (MC) can achieve $\rho < 0.5\%$ over the whole visible region. If we "stack" filters of either type, as long as air gaps remain between them, they can be thought as "functioning independently" of each other.

To estimate $\tau(\lambda)$ for such a stack of filters separated by air gaps, we need to convolute the spectra—i.e., we need to multiply them wavelength by wavelength. The stacking order is in theory and frequently also in reality irrelevant—i.e., it is transitive as for multiplication in algebra:

$$\tau_{1+2}(\lambda) = \tau_1(\lambda) \cdot \tau_2(\lambda).$$

In the case of absorbances we have to add them instead because of the log transformation:

$$A_{1+2}(\lambda) = A_1(\lambda) + A_2(\lambda).$$

Normally transmittance is measured for a light beam impinging on the surface of a filter at 90°. However, the angle of incidence can affect in various ways light attenuation. We will first consider τ_{internal} and how the length of the light path through the filter depends on the angle of incidence of the

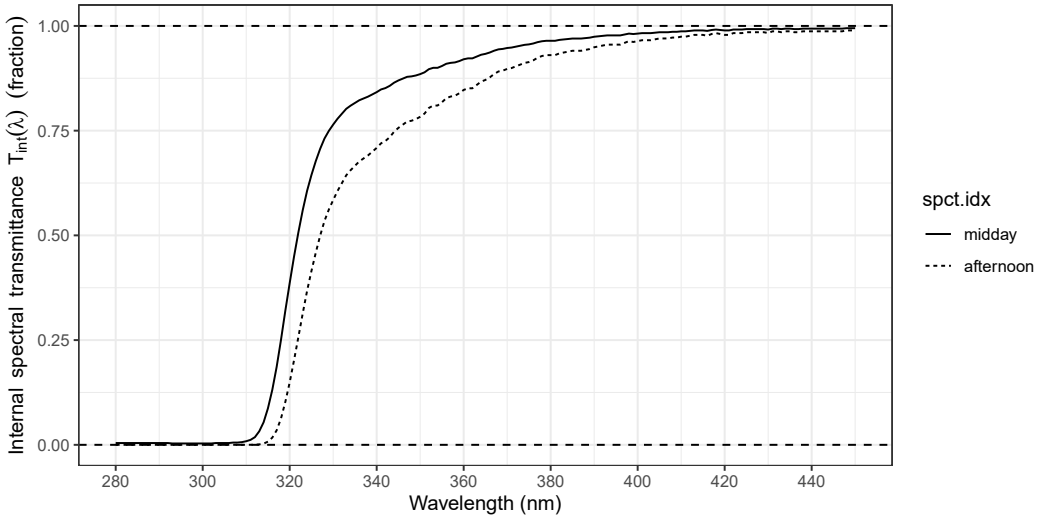

Figure 10.6: Effect of the angle of incidence on the internal transmittance of polyester film 0.125 mm-thick. See Appendix for code used.

light beam (Figure 10.6). If we discount the effect of refraction at the air-filter interfaces, and assume the direction of the beam remains the same inside the filter, we can use simple trigonometry to compute the approximate path length. As an example we will consider the spectral transmittance of polyester 0.125 mm-thick, and that the sun will shine on it at $\theta_1 = 0°$ at noon but later in the afternoon at an angle that doubles the path length of the light through the filter.

Similar considerations apply to the path of solar radiation through the atmosphere and its dependence on the solar zenith angle. In this case the path length is described using (relative) air mass (AM) traversed in the light path. For example, spectral irradiance for AM1.5 is frequently used to characterize solar cells. To derive AM values from solar zenith angle empirical equations are used in most cases instead of geometrical rules.

Above I mentioned that reflectance, ρ, depends on the angle of incidence, and it increases with increasing values of θ_1. So these two effects add up. The angle of incidence of the solar beam on the filters used tends to be infrequently explicitly considered when designing outdoors UV filtration experiments. Although the path length may not have a huge effect for good quality glass or acrylic, reflection will decrease PAR even for clear materials.

In the case of reflective or interference filters which wavelengths are transmitted and which reflected, depends on the angle of incidence, so spectral transmittance in specifications is given at a specific angle of incidence. Usually $\theta_1 = 0$ is used, but some filters, in particular many of those reflecting

infrared radiation, or "hot mirrors", are designed to be installed at other angles, such as 45° so that the thermal radiation is not reflected back towards the light source but instead to the side. Interference filters are available only in small sizes and expensive, and consequently are used for imaging, sensors and some rather small light sources.

The optics of leaves and flowers

The same analysis as above could be, in principle, applied to an object with a heterogeneous internal structure, like a plant leaf with its multiple internal air-water interfaces, but one would have to consider the multiple internal interfaces and their positions. The presence of these interfaces at different angles, plus small particles, cause strong scattering, and thus in this case ρ depends on both surface and internal properties of the leaf. We can still measure ρ, τ and α but predicting based on optical theory the effects of changes in leaf thickness or pigment concentration becomes daunting.

One way of demonstrating the role of air-water interfaces within leaf tissues is to infiltrate a leaf with water using a vacuum chamber. The effect is most spectacular in a variegated leaf such as those from some clones of English ivy: after infiltration with water the green areas become translucent green and the white areas almost transparent. The internal structure of leaves is extremely efficient at trapping light, to the point that it has been copied in a recent design for high efficiency solar cells (Yun et al. 2019). There is also evidence that shade leaves are better light traps per unit dry mass than sun leaves. Modelling of the optical properties of leaves using a ray-tracing approach can be computationally expensive (see the book by Jacquemoud et al. 2019, for an up-to-date account). The optics of leaves, flowers and fruits are described in detail in the book *Nature's palette : the science of plant color* (Lee 2007).

Concluding remarks

Obviously in photobiology, but also in other fields of biology, light- and UV-radiation-based measurements are very frequent. Being aware of key principles of how radiation interacts with objects can be very useful in research. Knowing the different physical quantities in use and how to interconvert them, opens the door to the comparison of results from different studies even across disciplines allowing the more effective review and integration of knowledge. I hope those readers who have reached this far will find the time spent worthwhile.

Acknowledgements

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Appendix

R code for this article, which uses data and functions published as part of the *R for photobiology* suite (Aphalo 2015).

Code for loading R packages.

```
library(grid)
library(magick)
library(tibble)
library(photobiologyFilters)
library(ggspectra)
library(patchwork)
library(wrapr)
```

Code for drawing Figure 10.2.

```
inset.bm <- image_read("refraction.png")
grob.tb <- tibble(x = 0.05, y = 0.9,
                  width = 0.33, height = 0.5,
                  grob = list(rasterGrob(image = inset.bm)))

glass.tb <- data.frame(angle = (0:899) / 10, Rfr = Rfr_from_n((0:899) / 10, n = 1.5))
ggplot(glass.tb, aes(angle, Rfr)) +
  ggpmisc::geom_grob_npc(data = grob.tb,
                aes(npcx = x, npcy = y,
                    label = grob,
                    vp.width = width, vp.height = height)) +
  geom_line() +
  scale_x_continuous(breaks = c(0, 30, 60, 90)) +
  labs(x = "Angle of incidence (degrees)", y = "Reflectance (/1)")
```

Code for drawing Figure 10.3.

```
set_annotations_default("boundaries")
(autoplot(Ler_leaf.spct) /
     autoplot(Ler_leaf_trns.spct) /
         autoplot(Ler_leaf_trns_i.spct))
```

Code for drawing Figure 10.4.

```
k <- 16e4
# concentration 1 mM
beerlamb_1mM.tb <- data.frame(z = 0:100 / 100 * 1e-3)
beerlamb_1mM.tb$I_z <- exp(-1 * 10e-3 * beerlamb_1mM.tb$z * k)
beerlamb_1mM.tb$Concentration <- "10"
# concentration 5 mM
beerlamb_5mM.tb <- data.frame(z = 0:100 / 100 * 1e-3)
beerlamb_5mM.tb$I_z <- exp(-1 * 25e-3 * beerlamb_5mM.tb$z * k)
beerlamb_5mM.tb$Concentration <- "25"
# both
beerlamb.tb <- rbind(beerlamb_1mM.tb, beerlamb_5mM.tb)
ggplot(beerlamb.tb, aes(z * 1e3, I_z, linetype = Concentration)) +
  geom_line() +
  expand_limits(y = 0) +
  labs(x = "Path length (mm)", y = "Relative irradiance (/1)") +
  theme_bw()
```

Code for drawing Figure 10.5.

```
CA.mspct <- filters.mspct[acetate_filters[c(1, 9, 10)]]
autoplot(CA.mspct, range = c(280, 500),
         annotations = list(c("-", "peaks"), c("+", "boundaries"))) %+%
  scale_linetype_discrete(name = "Thickness",
                          labels = c(expression(115~mu*m),
                                     expression(250~mu*m),
                                     expression(480~mu*m)))
```

Code for drawing Figure 10.6.

```
polyester.spct %.>%
  convertTfrType(., "internal") -> short_path.spct

# compute transmittance assuming radiation path-length doubles
polyester.spct %.>%
  convertTfrType(., "internal") %.>%
  convertThickness(., thickness = 0.250e-3) -> long_path.spct

list(midday = short_path.spct, afternoon = long_path.spct) %.>%
     filter_mspct(.) %.>%
     autoplot(., range = c(280, 450))
```

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■ Hints and tips

Reproducibility of UV-research with plants

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Introduction

This is the second installment of what I hope will be a useful, albeit opinionated, regular column in the Bulletin. I aim to focus on important methodological and practical questions that are central to the quality of our research. I will occasionally make diversions into philosophy of science and other subjects relevant to all research activities. Suggestions for subjects to explain or highlight and questions highly welcome.

Lack of reproducibility in scientific research is a broad problem that has woken up the interest of politicians and the general public (Fineberg 2019). For example the US Congress requested the US National Academy of Sciences to produce a report about this problem (Fineberg 2019). Given that eight years have passed since *Beyond the Visible* (Aphalo, Albert, Björn, et al. 2012) was written, it is timely to remind our research community about some problems that keep reappearing both in submitted manuscripts and published articles. I have chosen as the subject of the present column *reproducibility of UV-research with plants*.

In our field of research, the main sources of difficulties seem to be the use of flawed methods, the incomplete description of methods and the misinterpretation of experimental results by ignoring the limitations of the protocols and methods used. Even though rather few papers published in our field are flawed in ways that would require retraction, a very large proportion of papers are unnecessarily weakened in their usefulness and trustworthiness by these problems. In my view, after an initial and significant improvement in the quality of research and reporting during the UV4Growth COST action, in recent years the quality of research and reporting has gradually deteriorated. This is not a phenomenon restricted to low impact journals but affects also very highly ranked journals. Given that flawed papers are being accepted for publication, the problem concerns authors, reviewers and editors.

As this is a column about hints and tips, I will focus mainly on how to avoid

problems that can affect experiments aiming to study responses to UV-B radiation. I will start with the crucial question of what an experiment tests for, continue with other problems that can prevent reproducibility and end with my personal view of why trustworthy scientific research and reproducibility transcend the aims of our own careers.

Controls and treatments

Problem: Use of unsuitable controls and/or treatments and the misinterpretation of the results from badly designed experiments is "bad science", that contributes to inefficient use of resources and contaminates the corpus of shared scientific knowledge.

In any comparative study, controls and treatments are equally important. Control and treatment conditions must be chosen with equal care and described in the same detail. Obviously the quality of what we can infer from their comparison is limited by the weakest of the two. The question of suitable controls in UV research has been already discussed in depth, most frequently in relation to UV-supplementation studies carried out outdoors (Aphalo, Albert, McLeod, et al. 2012; Newsham et al. 1996). The same argumentation concerns laboratory and controlled environments experiments. In all cases, the question is to identify all relevant differences between treatments and controls, and design both controls and treatments in a way that makes the observed effects interpretable.

All light sources have side effects like emission of radiation at wavelengths shorter and longer than UV-B including thermal radiation. Lamps can also shade radiation from other sources and potentially create electromagnetic fields. Broad-band UV-B lamps like the widely used Philips TL12 and Q-Panel UVB313 are not UV-B lamps, they are lamps that emit UV-B radiation as well as UV-C, UV-A, visible and thermal radiation. The UV-B component of the photon emission from these lamps is only about 30% of their total UV plus visible emission. A comparison between the effect of energized "UV-B" lamps vs. no lamps, either outdoors or in the laboratory should never be interpreted as an effect of UV-B radiation. Frequently used pairs of controls vs. treatments are listed in Table 11.1 together with the main differences between them and whether they reliably test for an effect of UV-B radiation or not.

Even if we ignore thermal radiation, possible shading, and other side effects and assess how much of the difference in photon irradiance between control and treatment conditions is in the UV-B band, we obtain values in the range from 33% and 96% (Figure 11.1). The main issue for reproducibility is that these different experimental protocols test for quite different effects: from effects that can be only safely interpreted as a generic effects of a type of lamps to effects that can be rather safely attributed to a specific range of wavelengths. Even within the UV-B band, different wavelengths cannot be expected to be equally effective.

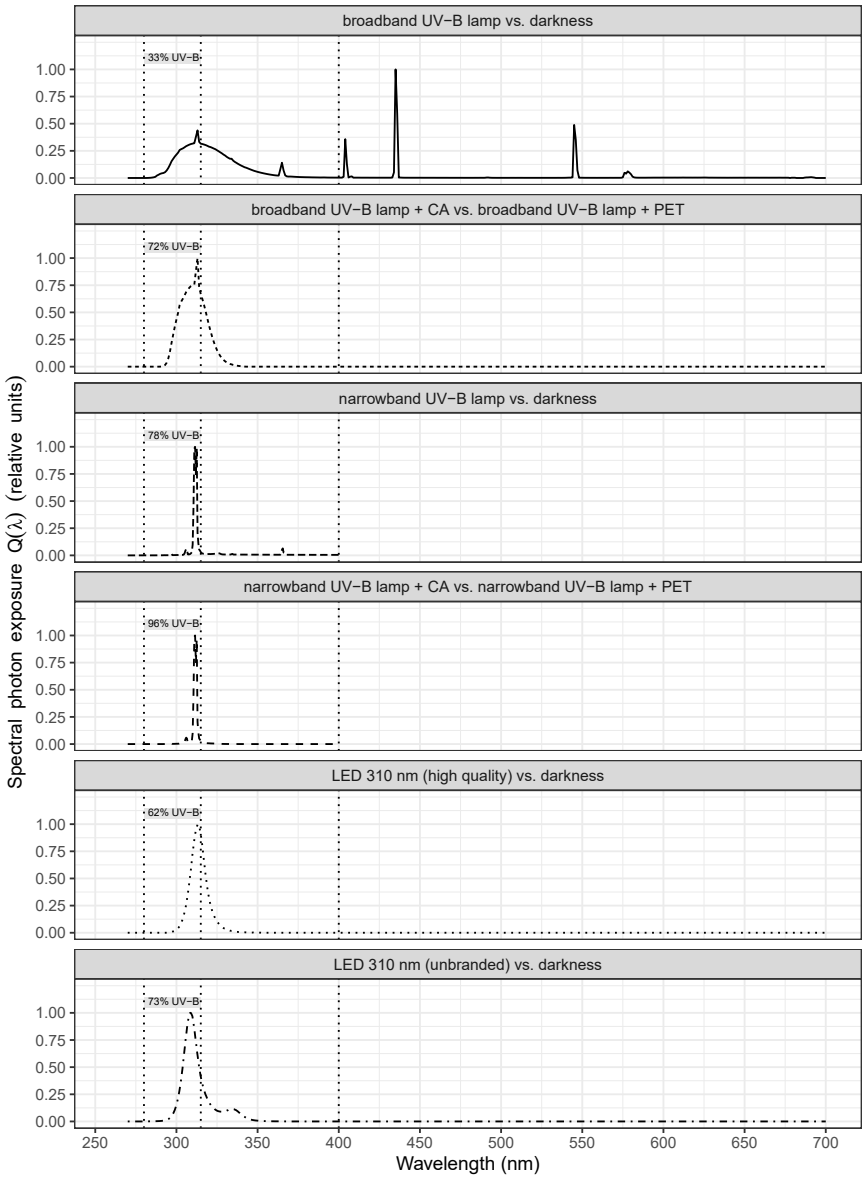

Figure 11.1: Difference spectra for six pairs of UV-B treatment and control conditions in use. The conditions are shown in panel headers as "treatment vs. control". The spectra plotted describe the difference in spectral irradiance between treatment and control in a given pair. Spectra are normalised. The labels show the percentage of UV-B photons compared to the total number photons in the range of wavelengths plotted. The vertical dotted lines show the boundaries of the UV-B and UV-A wavebands. See Appendix for code used.

Table 11.1: Testing for UV-B effects. Pairs of controls and treatments frequently used in experiments reported in the scientific literature to assess responses to ultraviolet-B radiation.

Control	Treatment	Differences	Test for UV-B
darkness	broadband UV-B lamp	UV-C, UV-B, UV-A, VIS, thermal	NO
wb UV-B lamp + PET	wb UV-B lamp + CA	UV-B, (UV-Asw)	YES
darkness	narrowband UV-B lamp	UV-B, (VIS), thermal	(YES)
narrowband UV-B lamp + PET	narrowband UV-B lamp + CA	UV-B	YES
darkness	LED 310 nm (unbranded)	UV-B, (thermal)	(YES)
darkness	LED 310 nm (high quality)	UV-B, UV-Asw, (thermal)	NO

Solution: Always provide information about background illumination and other environmental conditions in as much detail as needed for research to be reproducible and reliably evaluated. Readers should have access to detailed information on both treatment and control conditions including all aspects in which they differ. In the absence of this information it is impossible to assess if the conclusions drawn by the authors of the study are valid. Incomplete description of the test conditions also impedes any attempt to reproduce the experiment. Be careful when drawing conclusions and always inform readers about the limitations of the study and any caveats that may apply.

Background illumination

Problem: A surprisingly large number of papers reporting on experiments carried out in the laboratory fail to mention if the UV-treatments were applied under a background of white light or in darkness. We are also only rarely told under which conditions the controls were kept while the treatments were applied (e.g. same irradiance of visible light, same temperature, etc.). The spectrum and irradiance of the background UV, visible and NIR radiation is almost never reported. The lack of this information makes experiments not reproducible by independent researchers and can easily make results from different studies seem contradictory. This tends to be the result of authors relying on implicit, and frequently unwarranted, assumptions for the interpretation of results, such as "weak background illumination can be ignored".

Does this matter? Yes, because the ratio between different wavelengths affects responses (Krizek 2004; Yan et al. 2020) through signalling interactions downstream of UVR8 and other photoreceptors (Lau et al. 2019; Morales et al. 2015; Moriconi et al. 2018; Rai et al. 2019, 2020; Tissot and Ulm 2020) and because UVR8 can also participate in the perception of UV-A radiation (Rai et al. 2020). Consequently, the interpretation and the range of applicability of the results depends on information about the whole spectrum. Results from

earlier studies that describe methods in enough detail can be re-interpreted in the light of later advances, but those reported with incomplete methods, cannot.

Solution: Always provide information about background illumination and other environmental conditions in as much detail as possible for every single report or article you write. Ensure that you describe in detail any differences in how UV-irradiated and control plants were handled and also what the shared conditions were.

Variation among lamps

Problem: Specifying a lamp type in most cases does not provide enough information. In the long run manufacturers tend to revise the specifications of the lamps they sell without changing the type name or code. There is variation from batch to batch, and for LEDs even between individual LEDs of the same type, so much that many classify them into "bins" or subtypes based on the measured peak wavelength and emission efficiency. Specially the "fantasy names" like "UV-B lamps or UV LEDs" used by some lamp sellers. UV-B, UV-A, and black light broadband lamps all emit visible light and UV-radiation at other wavelengths than those expected from their names. In many cases even codes derived from such names are inconsistently used. The peaks of emission can be at different wavelengths for equivalent lamps from different suppliers (e.g., "black light blue" or BLB lamps have maximum emission at either 385 nm or 368 nm depending on supplier or vintage). In addition the output of both fluorescent lamps and LEDs depends on ambient temperature and on their age.

Be aware that reflections from walls, tables, glass and metal objects, and even clothes can distort the spectrum impinging on plants. Not only reflection is important in the case of UV radiation, many objects fluoresce strongly in the blue or other regions when illuminated with UV radiation, e.g., white paper and clothes, and laundry powders contain fluorescent additives that are added so that paper and clothes look whiter (Björn et al. 2012).

Solution: Whenever possible provide a measured spectrum for the UV source(s) actually used, measured under the same ambient conditions and at the same physical location. Measurements should be done close in time to when the UV sources were used if not at the same time. Do not trust previous measurements or manufacturer specifications.

Petri dishes, microscope cover slides and other barriers

Problem: Rarely the existence or not of a barrier and whether the irradiance or spectra have been measured behind the barrier or in front of it is reported. Even less frequently the exact type and supplier are reported. If light or

UV treatments are applied through the lids of Petri dishes, a cover-slip or microscope slide, a water layer or there is anything else than air in the path of the radiation the spectrum and irradiance could be significantly affected. As we do not see in the UV, what looks transparent, may not be so in UV.

The shape of the barrier or vessel can also make it function as a lens. So irradiation of liquid samples is best done in vessels with a square cross section, i.e., the same reason why spectrophotometry cuvettes are almost never round like normal test tubes.

Solution: Measure (or at least estimate) the spectrum and irradiance and define treatments as received by the target organism behind any barrier that separates it from the light source. Do also remember to take into account that the angle of incidence matters both for glass or plastic barrier and the organism.

Spectral irradiance vs. irradiance

Problem: The definitions of UV-B, UV-A and violet-blue radiation do not coincide with the wavelength regions to which UVR8 and cryptochromes are responsive to (Rai et al. 2020). Conditions described only by UV-B and/or UV-A irradiances or exposures make difficult to interpret the observed responses. Lack of spectral data hinders reproducibility and can prevent the use of the data in meta-analyses,

Solution: Provide spectral data for treatment and control conditions and for growing conditions when reporting results from any photobiological study.

Be distrustful of surprising results

Problem: Over reaction to surprising results. Over-interpretation and too-early dumping of surprising results are embarrassing and wasteful, respectively. Over- and misinterpretation of results are common, specially in those journals that too easily accept newsworthy and controversial reports. In the case of surprising results that are discarded too early we can only guess that this can also easily happen.

Reported values that are incompatible with the description of what and how was measured are worryingly common in publications. One can almost always assess the "sanity" of measured values we obtain. For example molar extinction coefficient values for proteins can roughly and easily be estimated on the basis of the amino acid sequence. This is only an approximation, but if our measured values are nearly two orders of magnitude larger, we should carefully investigate what is going on. If our estimate of water vapour pressure is higher than that expected at 100% relative humidity we should check our instruments. If the UV-B irradiance from our lamps is many times less than what others have reported for the same lamps, filters and distance,

we should check calculations and measuring instruments. These examples are real, and for the last one I know of two cases, due to different problems. Of these four examples two made all the way to publication and two were caught in time.

In the first two cases I have no idea of the cause behind the bad data. In one of last two cases calculation errors were the cause, and in the other case a completely wrong calibration of a new spectrometer, supplied by the manufacturer caused the problem. This may sound disappointing, but in my experience, most unusual and surprising results from routine measurements using usual methods and applying similar treatments as others have earlier used are usually caused by methodological problems and mistakes.

On the other hand, surprising results can be real, and tell an unexpected story, even if caused by mistakes. Deeper problems are caused by jumping to conclusions too easily.

Solution: Be distrustful of any results, specially those that seem too good or too bad to be true. Cool down your enthusiasm or despair, imagine yourself for a while as an external reviewer, picky and suspicious of everything. Ahh…do remember to switch back to your positive and enthusiastic self once you have checked your data and before you deal with the problems you may have found!

Reproducibility and correction of past errors

Problem: The self-correction mechanisms of science are made sluggish by the persistence of misconceptions and the continued use of methods known to be bad (due to tradition?), e.g., the recent growth in popularity of Arnon's equation for quantification of chlorophyll concentration by spectrophotometry, even though it has been known for well over three decades that it yields wrong estimates of the concentration (Porra and Scheer 2018).

Scientific knowledge advances by the revision and correction of previous theories and hypotheses (see Godfrey-Smith 2003, for an introduction to the phylosophy of science). This concerns science as a whole, but also each one of us. We develop as researchers and advance in our career by the same process. There is no shame or problem in changing our opinion and we should be open about these changes. If you are a young researcher, *do not be afraid of changing your mind during the course of your career.* This is how one grows as a researcher. In the same way that we may want to criticise earlier publications or suggest changes or replacements for views from other authors we should be ready to criticise and revise the ideas we have proposed in our earlier publications.

A research report usually contributes data and ideas. These are linked, and this link builds upon earlier ideas and data. Depending on the case, the data or the ideas will be relevant for a longer time, while the link between them will frequently become outdated first. Data for which methods are incom-

plete has little value in itself, as it cannot be reinterpreted in the light of new ideas. Conclusions and knowledge that is built upon evidence whose strength or reliability cannot be independently assessed contribute little to scientific progress. If they guide subsequent research unnecessarily into conceptual dead-ends they disturb the normal progress of scientific research frequently causing expensive distraction of resources.

So, we should strive as a community to retroactively correct if possible or alternatively highlight the flaws and inaccuracies in our own and in other authors' publications, both old and recent. This is simply how science is supposed to self-correct errors and we should not be afraid of doing so.

Solution: Both in terms of career progress and contribution to society avoid thinking only in the short term or with a narrow view. More broadly, the evaluation and rewards systems used for scientific research need to be reformulated so that the premium for doing reproducible and useful scientific research vs. flashy and unwarranted controversial or hastily done but over-interpreted studies is very clearly in favour of the first.

Coda: Research is expensive, but justified based on the benefits it can provide to our society. Bad science derails decision making and biases resource allocation. Even if "bad science", intentional and accidental, has a much more direct and dramatic impact in medicine and health care (Goldacre 2010) than in our research field, the same principles apply and are applicable to efforts to improve plant production and food security (Sadras et al. 2020). There is constant tension in the allocation of funding to research, as most research ultimately competes for taxpayers' money that could be used to improve voters' wellbeing in other more direct ways. We ensure that our work provides the maximum benefit to society if the fruits of our work can be trusted and the quality and relevance of the data we generate can be properly and independently assessed. Transfer of knowledge to stakeholders is a crucial step, but first we need to generate knowledge that stakeholders can trust and use with benefit.

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Appendix

Source code of the R script used to create Figure 11.1 which uses data and functions published as part of the *R for photobiology* suite (Aphalo 2015).

```
library(photobiology)
library(photobiologyLamps)
library(photobiologyLEDs)
library(photobiologyFilters)
library(photobiologyWavebands)
library(ggspectra)
library(wrapr)

photon_as_default()

list("broadband UV-B lamp vs.\ darkness" =
       lamps.mspct$qpanel.uvb313,
     "broadband UV-B lamp + CA vs.\ broadband UV-B lamp + PET" =
       lamps.mspct$qpanel.uvb313 * filters.mspct$Courtaulds_CA_115um_age020 -
     lamps.mspct$qpanel.uvb313 * filters.mspct$McDermit_PET_Autostat_CT5_125um,
     "narrowband UV-B lamp vs.\ darkness" =
       lamps.mspct$philips.tl01,
```

```
    "narrowband UV-B lamp + CA vs.\ narrowband UV-B lamp + PET" =
      lamps.mspct$philips.tl01 * filters.mspct$Courtaulds_CA_115um_age020 -
     lamps.mspct$philips.tl01 * filters.mspct$McDermit_PET_Autostat_CT5_125um,
    "LED 310 nm (high quality) vs.\ darkness" =
      leds.mspct$UVMAX305,
    "LED 310 nm (unbranded) vs.\ darkness" =
      leds.mspct$TY_UV310nm
) %.>%
  source_mspct(.) %.>%
  clean(.) %.>%
  normalise(.) %.>%
  autoplot(., range = c(270, 700), annotations = list(c("-", "labels"),
                                                      c("+", "reserve.space"))) +
  stat_wb_box(w.band = UVB(),
              ymin = 1.05, ymax = 1.15, fill = "grey90") +
  stat_wb_contribution(w.band = UVB(), label.mult = 1e2,
                       ypos.fixed = 1.11,
                       label.fmt = "%3.0f%% UV-B", size = 2, color = "black") +
  geom_vline(xintercept = c(280, 315, 400), linetype = "dotted") +
  facet_wrap(~spct.idx, ncol = 1) +
  theme(legend.position = "none")
unset_radiation_unit_default()
```

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Questions and Answers

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DOI: 10.19232/uv4pb.2020.1.25 

I had planned to start this section in the next issue and inviting readers to submit questions in this one. However, when we were about to go to press I received one interesting question, so here we launch the new section!

Please, submit your questions to mailto:reader.questions@uv4plants.org. I will answer those I am can, and forward other experts otherwise. Not all questions and their answers will be published, but we will attempt to quickly answer all of them through e-mail.

Extraterrestrial and ground-level solar spectrum

Q1: I was reading some literature with respect to the atmosphere and something keeps me puzzled. In the ASPB book "The molecular life of plants" (Jones, 2013; Page 280) they show a figure of the solar spectrum.

The red graph starts at 280 nm (extraterrestrial) while the blue one (ground level) starts at 300 nm. The thing I am wondering, how is it possible that at the top of the atmosphere there are no shorter wavelengths than 280 nm? For all I know at least UV-C (200 nm) should reach the ozone layer (Stratosphere). It makes me wonder if they only measured from 280nm onwards. What are your thoughts about this?

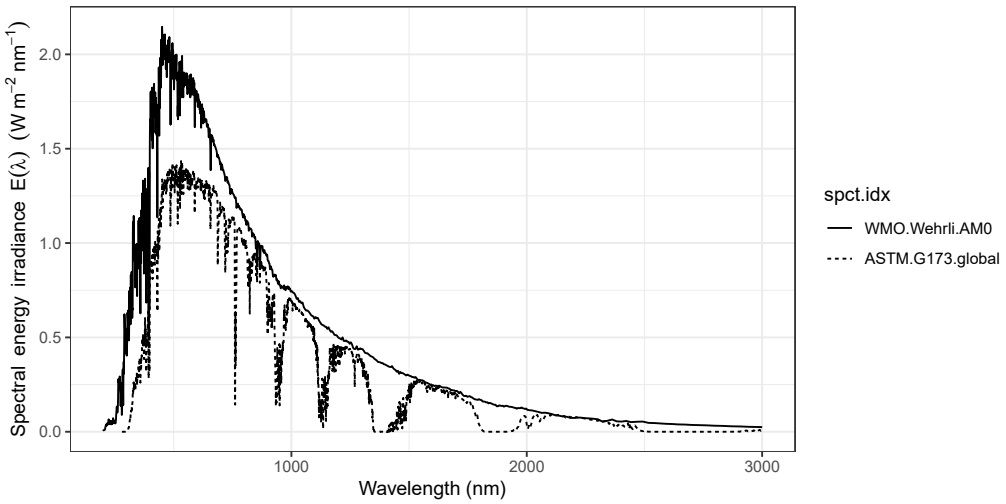
A1: Well spotted! You are correct, the extra-terrestrial solar spectrum is truncated in the figure. When these spectra are used in models as input for computing the spectrum at ground level, the shorter wavelengths are of no interest, but for the figure, of course, they are highly relevant!

I plotted the spectrum that the World Meteorological Organization normally uses. It comes from: Wehrli, C. (1985) Extraterrestrial solar spectrum. Pub. No. 615, World Radiation Center, Davos, Switzerland. The ASTM spectrum for global radiation is for 1.5 air-masses so for roughly an average year-round sun elevation for mid-latitudes. If you need data to make a fresh plot with both spectra, equivalent to the one you sent, the necessary data are all in my R package 'photobiologySun'. If you use R (even if just a little) and want

annotated versions I can show you how to rather easily plot the combined plot.

```
library(photobiologySun)
library(ggspectra)
```

```
autoplot(sun_reference.mspct[c("WMO.Wehrli.AM0", "ASTM.G173.global")],
         annotations = "", range = c(50, 3000))
```



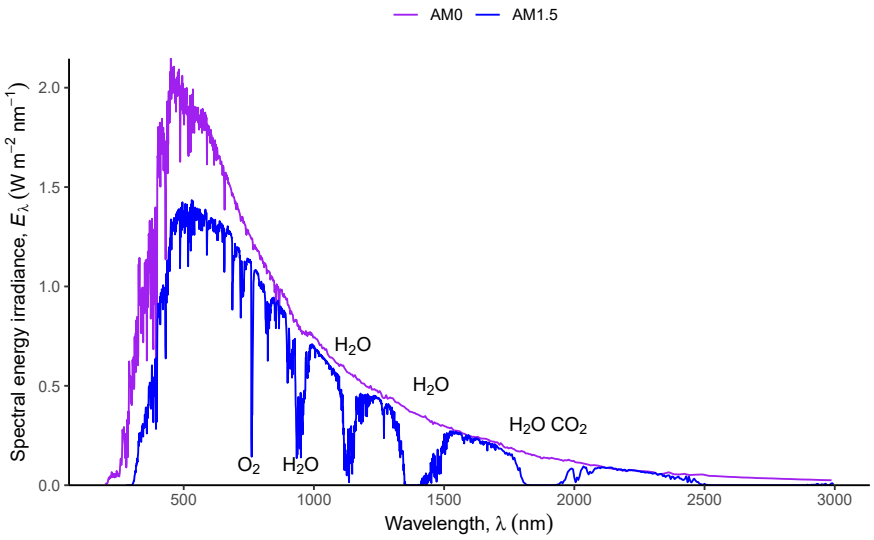
A1': Thank you for the fast reply and the help with getting the full data! I am very unfamiliar with R but I managed to get the graph from the code you sent over.

Q2: I am now trying to format the graph in R in a similar fashion as the original Graph I originally sent you but this also seems to fail. Any suggestions on this?

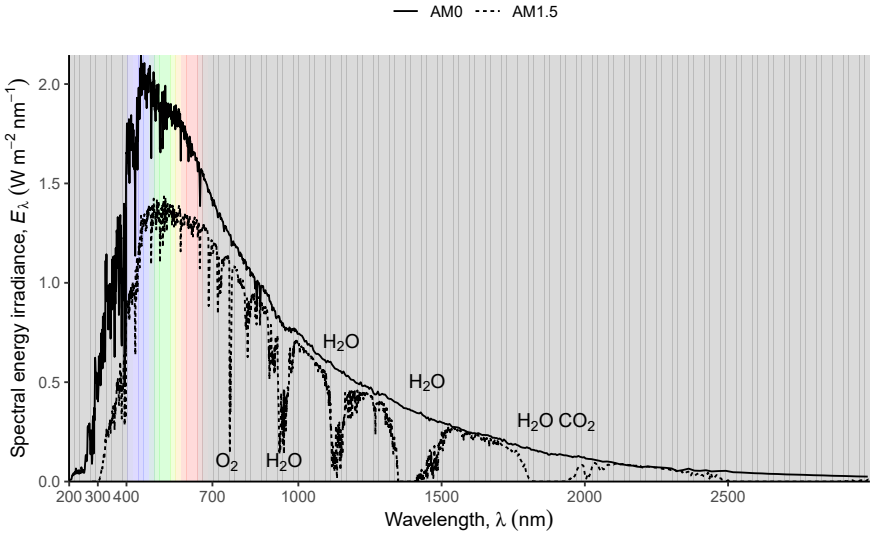
A2: Here are two examples that get you quite close to the original plot. I hope the code is not too intimidating…If you do not mind, I will include your question and this answer as a "Reader's question" in the UV4Plants Bulletin. It could be useful to others in addition to you and me. ;-)

```
ggplot(clip_wl(sun_reference.mspct[c("WMO.Wehrli.AM0", "ASTM.G173.global")],
               range = c(NA, 3000))) +
  aes(color = spct.idx) +
  geom_line() +
  scale_color_manual(name = "", labels = c("AM0", "AM1.5"), #
                     values = c("purple", "blue")) +
  scale_x_wl_continuous() +
```

```
  scale_y_s.e.irrad_continuous(expand = c(0, 0)) +
  annotate(
    geom = "text",
    x = c(750, 950, 1150, 1450, 1900),
    y = c(0.1, 0.1, 0.7, 0.5, 0.3),
    label = c("O[2]", "H[2]*O", "H[2]*O", "H[2]*O", "H[2]*O~CO[2]"),
    parse = TRUE
  ) +
  theme_classic() +
  theme(legend.position = "top")
```




```
ggplot(clip_wl(sun_reference.mspct[c("WMO.Wehrli.AM0", "ASTM.G173.global")],
               range = c(NA, 3000))) +
  aes(linetype = spct.idx) +
  wl_guide(alpha = 0.15, color = NA) +
  geom_line() +
  scale_linetype_discrete(name = "", labels = c("AM0", "AM1.5")) +
  scale_x_wl_continuous(expand = c(0, 0),
                        breaks = c(200, 300, 400, 700, 1000, 1500, 2000, 2500)) +
  scale_y_s.e.irrad_continuous(expand = c(0, 0)) +
  annotate(
    geom = "text",
    x = c(750, 950, 1150, 1450, 1900),
    y = c(0.1, 0.1, 0.7, 0.5, 0.3),
    label = c("O[2]", "H[2]*O", "H[2]*O", "H[2]*O", "H[2]*O~CO[2]"),
    parse = TRUE
  ) +
  theme_classic() +
  theme(legend.position = "top")
```



A2': Thank you very much. Hope to see you on the next UV4PLANTS meeting!

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3rd circular

The International Association of Plant UV Research announces the

3rd Network / 1st virtual Meeting of the UV4Plants Association

October 13th – 16th 2020

Dear colleagues, dear previous or new participants,

the 3rd Network Meeting will be the 1st virtual one of the UV4 Plants Association! This format makes the meeting accessible from all over the world! Therefore, we invite those who wanted originally to participate to stay registered and everyone else who is interested to join! **Please distribute this information to potentially interested people!**

Also in the new format the meeting will be held under the motto

"Plant responses to UV radiation – Diversity in time and space"

which is also reflected in the topics of the sessions. You are kindly invited to contribute to one of the sessions, which are outlined below, together with keynote speakers:

- UV radiation in the physical environment (Gunther Seckmeyer)
- Sensing of UV radiation (Gareth Jenkins)
- Acclimation responses to UV radiation (Paul Barnes)
- Functional photoprotection (Paula Casati)
- Analytical methods (Hans-Peter Mock)
- Application of knowledge (Titta Kotilainen)

All accepted abstracts from the originally planned meeting in April will remain in the programme unless the participation is cancelled. Potential gaps will be filled by new submissions; and there is a lot of space for posters! The deadline for submission of new abstracts will be September 18th, 2020. Registration will be possible until September 30th, 2020, at the e-mail address **meeting2020@uv4plants.org**. Registration fees will be 20 € for students, and 40 Euros for all others.

The meeting will take place from 12:00 – 18:00 CEST every day including oral presentations, poster sessions, informal breaks and time for scientific discussions. A platform will be provided with prepared virtual rooms for the different parts of the meeting.

As before, the meeting will be preceded in the week from October 5th to 9th by a **Training School**, also in a virtual form. The fee will be 20 Euros.

Details about the time schedule of the meeting and the Training School are following soon and will be published on the website of the UV4Plants Association (https://www.uv4plants.org)!

Frauke Pescheck and Wolfgang Bilger

Key aims of the UV4Plants international association are to

- promote and foster research-excellence and good practice in plant UV research through the organisation of innovative events in research, public engagement and education
- provide channels for members to inform the plant UV research community about relevant activities or events of common interest
- enhance the usefulness of plant UV research by facilitating the transfer of knowledge from academia to stakeholders and the general public
- initiate and foster stakeholder contacts as part of an agenda of product development
- liaise with scientific funding bodies to influence their research agenda
- develop with its members the benefits of membership and the relevance of the Association

The Rules of the UV4Plants association, information on membership, management committee and up-to-date news are available at http//www.uv4plants.org.

A new association with a history The origin of UV4Plants was the very successful COST Action FA0906 'UV4Growth' which was active from 2009 to 2014. It brought together photobiologists, molecular biologists, ecologists, meteorologists and stakeholders from agriculture and industry. Many new collaborations were started and new ideas developed.

Three large conferences, and several workshops and training events were organized. Four special journal issues were produced: *Physiologia Plantarum* **145**, 4, *Emirates Journal of Food and Agriculture* **24**, 6, *Plant Physiology and Biochemistry* **93**, and *Plant, Cell & Environment* **38**, 5.

Most participants, the members of the managing committee and the external evaluator all agreed in that a way of continuing and furthering the achievements of 'UV4Growth' was needed.

Invitation to Join UV4Plants UV4Plants welcomes a whole spectrum of members from both academia and industry, applied and basic research. Membership fees for 2016 are EUR 25.00 for students and retired staff, EUR 50.00 for academic members, and EUR 250.00 for industry members. See http://www.uv4plants.org/news/invitation-to-join-our-association/ or contact mailto:secretary@uv4plants.org for details.

UV4Plants

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