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Foreword

Ultraviolet radiation and its impacts on agriculture and forests

1. The UV-B problem

Although ultraviolet radiation (400–280 nm) comprises only a small portion of the solar spectrum, it has a disproportionately large photobiological effect on both plants and animals due to its absorption by important biological molecules such as proteins and nucleic acids. This is particularly true in the UV-B (320–280 nm). Ultraviolet radiation has shaped life and its evolution on Earth for as long as that life has existed and in a sense there has always been a UV-B problem, particularly when species moved to locales where they were not adapted to the UV-B regime.

Scientific knowledge and data that is pertinent to UV-B radiation might be said to have begun in the 1880s with the discovery that there is essentially no radiation at the Earth's surface below a wavelength of 293 nm. The knowledge at that time that ozone absorbed strongly at short wavelengths, and especially below 293 nm suggested the presence of an ozone layer in the atmosphere.

In the 1920s, G.M.B. Dobson developed an instrument to measure the total column ozone (TOC) in the atmosphere, and a network of these instruments (Dobson spectrophotometers) was instituted. Instruments of the Dobson type are still operated in an international network of about 80 stations in 40 countries today (http://www.chmi.cz/meteo/ozon/dobsonweb/network.htm#Dobson). Several papers in this issue use the common measure of TOC, the Dobson unit, or DU, which is the depth, measured in units of 10^{-6} m, that all the atmospheric ozone would take up if it were brought together in a layer at sea level pressure and a temperature of 0 °C. In midlatitudes TOC typically ranges from 250 to 450 DU. The longest continuous Dobson record, beginning in 1926, is from Arosa, Switzerland. A graph of annual averages of these data from 1926 to 1997 shows the considerable variability of ozone over one location that makes detection of long-term trends difficult; however, a trend of decreasing ozone since the early 1970s can be discerned in the record (Heisler and Grant, 2000b). Measurements by Dobson instruments led to the discovery of the Antarctic "ozone hole" in 1985, and associated measurements confirmed that the hole could be attributed primarily to anthropogenic emissions, especially chlorofluorocarbons (CFCs).

Satellite measurements (e.g. Total Ozone Mapping Spectrometer (TOMS), http://www.toms.gsfc.nasa.gov/ery_uv/euv.html) indicate trends in ozone and UV-B and their distribution over the Earth's surface. During the 1997–2000 period, TOMS measurements confirmed that minimum ozone concentrations in the Antarctic were 40–50% lower than the pre-1980 values. In the Arctic, ozone has been more variable than in Antarctic, with depletion depending strongly on temperatures in the stratosphere. Maximum depletion of ozone in the Arctic has reached 30% following cold winters, but has been slight in warm winters. Atmospheric dynamics also cause variations of ozone depletion in the Antarctic. The maximum area of the Antarctic ozone hole (defined as the area with TOC less than 220 DU) peaked in 2000 at about 29 km^2; it decreased in 2001 to about 25 km^2; and then in 2002 the hole was only about 20 km^2 and was much shorter in duration than in recent years. The smaller hole in 2002 is not likely a sign of dramatic permanent ozone recovery, but rather a reflection of a sudden stratospheric warming event (Varotsos, 2003).

In the northern midlatitudes (35–60°N), ozone depths, relative to pre-1980 values, are about 4% lower in winter and spring and 2% lower in the summer

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and autumn. In the southern hemisphere midlatitudes, ozone losses are about 6% during all seasons. Ozone losses in the tropics are generally not significant (United Nations Environment Programme, 2002).

Many of the papers in this issue include in their introductions brief interpretations of the current ozone depletion and UV-B problem. Different authors have slightly different interpretations of the problem, but they generally point out the global increases in UV-B outside of the tropics. The amount of UV-B received at a location depends on many atmospheric factors in addition to TOC: position of the sun (latitude, elevation and season), cloud cover, surface albedo, and atmospheric aerosols. These variables make detection of long-term trends in UV-B difficult. Calculations of UV irradiance using long-term TOC and total solar pyranometer data, a technique described by Diaz et al. in this issue, indicate that UV-B radiation on the Earth's surface has increased since early 1980s by 6–14% at sites distributed over mid and high latitudes in both hemispheres (United Nations Environment Programme, 2002).

Part of the difficulty in determining long-term trends in UV-B by ground-level measurements is the drift in calibration of sensors. Problems with the Robertson–Berger broadband UV-B instruments used in monitoring networks beginning in the 1970's have been thoroughly investigated, and in this issue, Huber et al. discuss effects of humidity and temperature on measurements with these instruments. In the 1990s the USDA UV-B Monitoring and Research Program established a network of about 30 stations, mostly in the United States. Several papers in this issue, for example those by Qi et al. and Bawhey and Grant used data from the USDA network. Data from a United States Environmental Protection Agency network of spectroradiometers are presented here by Kimlin et al. These networks are expected to provide information on long-term trends as the duration of their record expands.

Although international agreements to limit emissions of CFCs are lauded for their success and tropospheric levels are decreasing, these chemicals have a half-life ranging from 50 to 150 years in the stratosphere, where they will continue to deplete the ozone layer for decades. Though ozone-depleting substances in the stratosphere are expected to be presently near their peak, evidence for trends of stratospheric ozone recovery is not expected for at least another decade (Weatherhead et al., 2000). Decreased ozone levels are not expected to recover to the pre-1970 levels until 2050 and only then if all member countries continue to implement the Montreal Protocol (McKenzie et al., 2003). Many factors, including feedbacks from rising concentrations of greenhouse gases, could delay the recovery process (Montzka et al., 1999; Shindell et al., 1998).

2. Organization of the issue

The 21 papers in this special issue include the four broad subjects of total column ozone measurement; instrumentation for measurements of UV-B; methods of determining exposure to UV-B of people, plants, or the above canopy level in general; and the influence of UV-B on crops, trees, or terrestrial ecosystems. The arrangement of papers generally follows this order.

The intensity of UV-B reaching the Earth's surface depends in part on the absorption of UV-B by the total column of atmospheric ozone. Satellite measurements of the total column ozone are often used in estimating surface UV-B exposures. The satellite measurements are an average over a relatively large view angle (and consequently represent conditions over a large surface area). Surface UV-B exposures, however, involve small surface areas of the Earth over the course of hours in the day. Schmalwieser et al. explore the accuracy of once-a-day satellite measurements for an area to represent diurnal variation at a point.

The measurement of UV-B faces several challenges not faced by measurements of photosynthetically active radiation or total short-wave radiation. Consequently the instrumentation used for UV-B measurements is highly dependent on what is to be measured. The second group of papers are involved with the problem of UV-B measurements, beginning with a broad overview of the commonly used instruments by Webb. The second paper, by Huber et al., addresses a potential problem in UV-B measurements made in the past and present—the effect of humidity on the Robertson–Berger meter. This meter is the source of much of the early (pre-1990s) UV-B measurements and is still that basis for a worldwide network. The next paper, by Terenetskaya, describes a novel method of sensing UV-B through chemical transformations in a

UV bio-dosimeter. The Terenetskya paper also makes a contribution to the TOC topic because the proposed dosimeter is suggested as a method of evaluating TOC.

The third group of nine papers is arranged generally from larger to smaller scales. Ciren and Li describe a new method to develop a long-term record of global daily UV exposure (above canopy irradiance) by satellite data analysis. Diaz et al. present a method of estimating daily biologically weighted UV dosages for locations with long-term records of total solar pyranometer data and total column ozone. Kimlin and Taylor compare UV irradiance at Chicago, Shenandoah, and Virgin Islands weighted by plant response action spectra. The paper by Foyo-Moreno et al. gives an account of the methods and results of modeling cloud effects on UV.

Going to the plant scale of estimating UV dosages, Heisler et al. describe the effects of trees on UV dosages for people or other vegetation near the trees. The tree influences on dosage would depend partly on reflectance of leaves, and Grant et al. report on leaf reflectance of 19 tree species and the leaf structures that influence reflectance. Gao et al. describe modeling irradiance in a row crop, and Parisi et al. report on dosage measurements of both UV and photosynthetically active radiation in experiments with supplemental UV-B applied to crops. Bawhey and Grant discuss the effect of heliotropic leaf movement on UV exposure of soybean crops.

The section on UV-B effects on plant life begins with an overview by Flint et al. of methods and some results of studies of UV-B influences on natural terrestrial communities. They discuss use of supplementation by lamps or exclusion of UV-B and the considerable difficulty in creating realistic experimental conditions. This discussion on methods is excellent background for the review by Kakani et al. of 129 published reports of experiments to evaluate UV-B influences on a total of 35 crop species. Kakani et al. conclude that although this large volume of research has yielded much basic information on physiological effects of UV-B, many of the studies used supplemental UV-B that represented scenarios of unrealistically high ozone depletion or had the effect of reductions in the applied PAR that magnified the apparent UV-B effect. Further reports of UV-B effects on physiological process include a 3-year study of UV-B influences on UV-screening compounds, gas exchange, and carbon assimilation in tree leaves by Sullivan et al. Results suggested that in the species studied, the trees used a range of UV-screening compounds to achieve UV-B tolerance. These authors believe that subtle responses to UV-B could have ecological significance despite the absence of large reductions in biomass. Qi et al. describe the changes over the course of a season in UV-B and visible optical properties and absorbing compounds of leaves of pecan (*Carya illinoensis*). Reflectance peaked at 8.3% in July, but absorbing compounds also peaked in the same month, raising questions regarding the mechanism of leaf reflectance.

In following papers, reports on UV-B influences on individual crops include a field study by Gao et al. and a growth chamber study by Reddy et al. on UV-B effects on cotton. Then Kostina et al. describe the interactive effects of enhanced UV-B and selenium on strawberry and barley, which is of special interest because, as Kakani et al. point out, there is a need to understand the interactive effects of UV-B and other plant growth conditions. A short communication by Zheng et al. on a field study of UV-B influences on wheat concludes the issue.

3. Needs for research

The following assessment of research needs on the influence of UV-B in agriculture is suggested to us by the papers in this issue. Many of the papers contain explicit discussions for needed research, and other needs are apparent by the unanswered questions that remain in the work.

Since the mid-1970s a great deal of UV-B effects research has been conducted. However, most studies have been based on the assumption that chronic high levels of UV-B can be expected in the future. Some studies have used UV-B enhancements of 30% or more for midlatitude plants. The most recent assessment (United Nations Environment Programme, 2002) does not indicate that such increases in UV-B are expected. This should prompt changes in the type of research done to prepare agriculture for climate change.

Continuation of studies on the UV-B effects on plants should be conducted at more reasonable exposure levels. Greater use of exclusion filter methodologies to more closely preserve natural spectral irradiance ratios will provide more useful results than UV-B enhancement studies in many situations.

Acute, or short term, enhanced UV-B exposures have occurred in the past and can be expected to occur in the future, regardless of the long term trends, as ozone-depleted air passes over an ecosystem. An understanding of the frequency of occurrence and magnitude of naturally occurring short-term events of high UV-B is needed to develop realistic short-term exposures scenarios for UV-B effects research. Furthermore, compared to the research evaluating chronic elevated UV-B exposure, little research has been done to understand the effects of these short-term high exposures on plants.

Assessment of the chronic or acute effects of UV-B radiation on plants and ecosystems requires knowledge of the exposure. The development of methodologies for the accurate estimation of UV-B exposures where UV-B irradiance measurements are not made is needed to assess UV-B impacts. Research has shown that a merging of the surface-based measurements, which provide good temporal resolution, and satellite measurements, which provide good spatial resolution, is needed to accomplish this task. Work is needed to develop the interpolation method and provide ongoing daily estimates of exposure across the globe.

Natural variation in UV-B across latitudes and altitude provides a laboratory for studies of UV-B effects on plants and ecosystems and should be exploited further. UV-B effects on plants have been shown to interact with other stressors such as heat, water stress, nutrient stress, nutrient and pollutant toxicity, air pollutant stress, and changes in carbon dioxide (e.g. Sullivan, 1997). Since the environmental stresses rarely act in isolation, more research is needed to understand the interactions of UV-B with these stressors. This is particularly true in urban centers and rural regions surrounding urban centers.

The interpretation of UV-B effects research has been hampered, especially in early studies, by inattention to the relative irradiance in the red, far-red, PAR, and UV-A wavebands while the UV-B exposures are enhanced. Greater care needs to be made to provide realistic ratios of different spectral wavebands in the study of effects of enhanced UV-B on plants. This is probably easier to accomplish in field studies than in greenhouse or growth-chamber studies.

The effect of UV-B on plants varies by species and cultivar. This indicates that the impacts of all the plants and animals in an ecosystem should be considered in any UV-B climate change assessments. Since many species grow across a wide range of latitudes, the natural variation in the genetic pool of plants found in naturally high UV-B environments is a resource for enhancing the resistance of many agriculturally important species to changes in UV radiation. Future research should explore the genetic controls on biochemical pathways and physiological mechanisms that provide UV-B protection to plants.

Health effects of UV-B radiation on people is a concern for agriculture and forestry in that outdoor workers in the industry are affected by UV-B and because trees may greatly affect exposure of people to UV-B. In the general population, skin cancer incidence has been rapidly increasing in many countries in recent decades. Increased UV-B irradiance may be partly responsible for some of increases in disease, though cultural changes are probably mostly responsible (Heisler and Grant, 2000a). Additional research is needed to quantify and model the tree influences on UV-B exposure for people and also for the crops in multicropping agriculture.

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