PLANTS IN THE SUN

An increase in ultraviolet exposure due to ozone depletion in the stratosphere would be bad news for us. Research is now showing that plants, including crop species, are also at risk.

Although not top on the list of our national worries, the possibility of plants getting sunburn is starting to cause concern. The Sun's ultraviolet light, which can burn or tan us, can also affect plants. If there's more of it around, as a result of the depletion of the ozone in the stratosphere, will plants be worse off?

The high energy of ultraviolet light (UV) can disrupt some of the complex chemicals of life, including the nucleic acids that comprise genes. The thinning of the ozone layer above the Poles in winter allows more ultraviolet radiation to reach the surface of Earth. The most damaging type is UV-C, but even with ozone thinning almost none of this penetrates to the ground; still harmful, although slightly less so, is UV-B, and it is the increased penetration of our atmospheric shield by radiation in this waveband that is the most worrying.

At the moment, dramatic changes in ozone concentration are confined to the atmosphere far above the Poles, for reasons connected with the low temperatures attained there during winter. However, ozone-poor stratospheric air may occasionally detach from the Poles and reach temperate latitudes during the late spring.

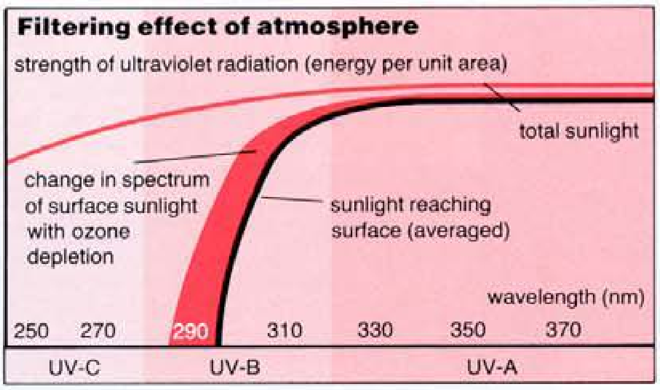
As the concentration of chlorofluorocarbons (CFCs) around the world continues to rise, an increased loss at the Poles may cause a general dilution effect in the ozone layer of the entire planet, making increased UV light at ground level a regular fact of life. As a rule of thumb, a 1% reduction in stratospheric ozone means a 2% increase in the UV-B at the surface. Since 1980, Australia has seen a decrease in the ozone above us ranging from about 2% in Darwin to about 5% in Hobart, meaning that UV-B levels have increased by up to 10% in some places at certain times.

The medical profession has already told us what this means to humans, and the news isn't good. It's worth finding out how plants will be affected, particularly the handful of species vital as food crops. This is what Dr Jan Anderson, Dr Fred Chow and their team at the CSIRO Division of Plant Industry have been doing.

To begin with, the scientists carried out a series of small-scale preliminary screening experiments to test the response of seven crop species to extra UV-B exposure — peas, beans, sorghum, spinach, barley, wheat and maize. Of these, sorghum, wheat and peas proved sensitive; but pea plants suffered the most, and therefore Dr Anderson and her team chose them for further study. They wanted to find out what exactly the ultraviolet light was damaging, and how it had its effects. They used levels of UV-B far higher than those that occur naturally, or would ever be likely to occur in Australian latitudes in the foreseeable future.

The major reason was to ensure that the effects of UV-B stood out clearly; in the field, 'real' environments have a range of ever-changing and uncontrollable stresses that impinge on plant health simultaneously and would thereby confuse any assessment of UV damage. For example, under natural conditions plants receive the greatest amount of UV-B during the middle of the day, when they would be coping with higher air temperature, maximum evaporation of water and greatest light intensity.

Up to a certain point, the higher the total brightness of light, the less effect the ultraviolet component has. This seems to be because plants have mechanisms for repairing UV-induced damage, and these operate better in brighter light.



Because of selective absorption by the atmosphere, sunlight reaching the surface is depleted marginally in UV-A and substantially in UV-B. Radiation in the most dangerous part of the ultraviolet spectrum, UV-C, is completely blocked. Ozone loss will allow more UV-B radiation to penetrate the atmosphere.

Dr Anderson and her colleagues grew pea seedlings in the laboratory with 12 hours of light per day, supplemented with UV-B 17 days after sowing. As a control, an equal number of seedlings received the same total amount of light, but with no ultraviolet component.

A week after starting the UV supplementation, the scientists sampled leaves and ran a range of detailed tests on their biochemistry, concentrating especially on the process of photosynthesis. As if acquiring a suntan, the leaves of the irradiated plants had bronzed; after the experiment finished some of these plants were returned to normal light, where they recovered and produced new green shoots.

Analysis revealed that, inside the leaves, chlorophyll — the green pigment essential for photosynthesis — had declined. During the 8-day test period the UV-B-treated plants lost more than 55% of the total chlorophyll in their leaves, whereas the controls increased theirs by about 12%, in line with normal growth.

Higher plants have two types of chlorophyll, termed a and b. The 'suntanned' leaves mainly lost chlorophyll a. Although some chlorophyll b disappeared too, it didn't start to decline until the fourth day after treatment. The correct ratio of chlorophyll a to b is important for the healthy functioning of leaves; in the treated plants the figure changed drastically, implying to plant physiologists that the peas were experiencing severe stress. (For example, changes to the ratio occur after treatment with some herbicides.)

The scientists noted another dramatic change. The most important enzyme for photosynthesis — colloquially called rubisco — is responsible for picking up carbon dioxide from the atmosphere and attaching it to a molecule within leaf cells. As CO_2 (despite the greenhouse effect) is still present in very low concentrations, rubisco has a hard job, and therefore exists in large quantities. It is, in fact, the most abundant protein in the world.

But after 8 days of supplementary UV-B, the pea leaves' rubisco had declined to a mere 28% of that of the controls'. This means that photosynthesis was devastated by a two-pronged attack. Its energy collection, based on chlorophyll harvesting photons of light, was sharply cut back; and the actual work of carbon fixation (incorporating carbon from the atmosphere into the foodstuff sugar), which this energy powers, declined independently because of the destruction of the chief enzyme involved.

The quantities of a number of other proteins important in photosynthesis also decreased, but for unknown reasons some remained relatively unaffected. Knowing exactly how UV-B 'knocked out' these vital components is part of Dr Anderson's continuing investigation. Ultraviolet radiation can physically disrupt large complex molecules like proteins, but her latest findings suggest that the radiation was actually affecting the expression of the genes that code for the manufacture of the proteins, in addition to hitting the molecules directly.

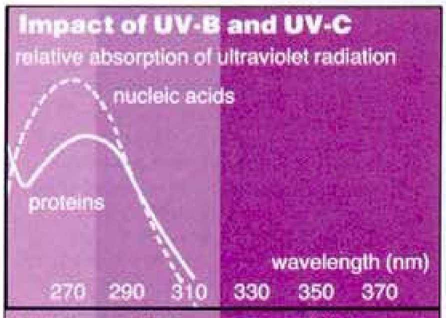
However it may happen, the curtailment of photosynthetic capacity and efficiency can devastate any plant and, if maintained for long enough, inevitably leads to death. It seems certain that the photosynthetic mechanism is a major target of UV-B irradiation, and damage to this would directly cause stunted growth and reduced yields. However, plants are more than just photosynthetic apparatus. Even within the leaves, other pigments are present, such as the red and yellow carotenoids and flavonoids. (These are partly responsible for the colours of autumn leaves, and become visible after the leaves' abundant chlorophyll has broken down prior to shedding.)

Dr Anderson's research showed that carotenoids also declined in the irradiated plants, to about half the level found in the control plants by the end of the 8-day experimental period. But, intriguingly, the latest findings indicate that the flavonoid pigments increase in response to the ultraviolet light. It so happens that flavonoids are quite effective absorbers of UV. Could it be that these pigments are therefore produced in response to UV exposure as a deliberate protective mechanism, in the same way that light-coloured people produce dark UV-absorbing melanin in their skins when exposed to ultraviolet radiation?

The recognition of UV-B as a plant stress is relatively new. Biologists need to do a lot more research before they can definitely say what effect erosion of the ozone layer may have on the planet's vegetation. Already they have confirmed the enormous variability in the tolerance of different plants.

But the fact that most experimental work has used unrealistically high levels of UV-B, and applied it continuously for 12-hour periods rather than simulating the increase and decrease that take place during a real day, does not mean that the findings are purely theoretical. Scientists overseas have recently found a common weed that is so inhibited by any level of UV-B that, even under natural conditions, it must suffer continuous low levels of ultraviolet-light-induced stress.

It may well be that, like so much else, UV stress interacts with other stresses, perhaps becoming more damaging if a plant is already suffering from, for example, drought or salinity. The 'plant-fertilising effect' (see *Ecos* 57) — the enhanced growth caused by an increased concentration of carbon dioxide in the atmosphere — may change if a plant is stressed by extra UV-B; Dr Anderson hopes to study this interaction in the future.



Proteins and nucleic acids, molecules vital to life, absorb radiation in the UV-B and UV-C bands. That is why this type of ultraviolet radiation is most damaging to living things.

Jan Anderson

The bronzing effect of UV-B shows up clearly in the leaves on the left, which have had supplementary UV exposure for 20 days. Those on the right are the same age but received no extra UV.

Research overseas has suggested that forests may be quite vulnerable. Because of their long life-spans, trees tolerant of current UV-B levels may live to experience much higher ones in future, with cumulative effects over the years. Three out of ten conifers tested in the United States showed reduced heights as seedlings when exposed to UV-B.

As we increase our knowledge of how UV-B causes its damage and of the extent of variations in sensitivity to it, we can start the long process of finding varieties that are more tolerant. To date, most study of the impact of UV-B has taken place in the Northern Hemisphere. As Australian conditions and some of our non-crop plants are quite different, further work is needed here too.

Roger Beckmann

More about the topic

Effects of supplementary ultraviolet-B radiation on photosynthesis in *Pisum sativum*. A. Strid, W.S. Chow and J.M. Anderson. *Biochimica et Biophysica Acta*, 1990, **1020**, 260–8.

At sea

We're beginning to find out some of the effects of increased UV-B on terrestrial plants, but what about plants that live in the oceans?

The bulk of the sea's plants are tiny single-celled phytoplankton. (Seaweeds, although some can be large and spectacular, are generally confined close to land and don't have a combined biomass nearly as great as phytoplankton.) Most of the phytoplankton live in the top 100 metres of the oceans and use sunlight to power their photosynthesis, by which, like land plants, they incorporate atmospheric carbon dioxide — in this case dissolved in water — into foodstuffs for the cells' growth.

Dr John Kirk of the CSIRO Division of Plant Industry is an expert on the penetration of light into water. He points out that phytoplankton photosynthesis is already inhibited by the bright sunlight in the top few metres of the sea, and that the component of the light most responsible for this inhibition is the ultraviolet. So what are the implications for oceanic photosynthesis and everything that ultimately depends on it — such as all commercial fisheries — of a possible increase in UV-B brought about by thinning of the ozone layer?

Experiments carried out by scientists in California suggest that, for every 1% loss of ozone, inhibition of photosynthesis in phytoplankton will only increase by about one-tenth of 1%. So, the reassuring news is that likely UV-B increases will really have very small direct effects on carbon fixation.

However, Dr Kirk points out that UV-B affects DNA, and he quotes calculations by the same American researchers showing that the percentage increase in DNA damage is likely to be 2–4 times the percentage change in the ozone layer. As DNA is copied during cell division, it could be that the efficient reproduction of phytoplankton will suffer. This may then, secondarily, lead to a drop in the level of photosynthesis in the oceans.

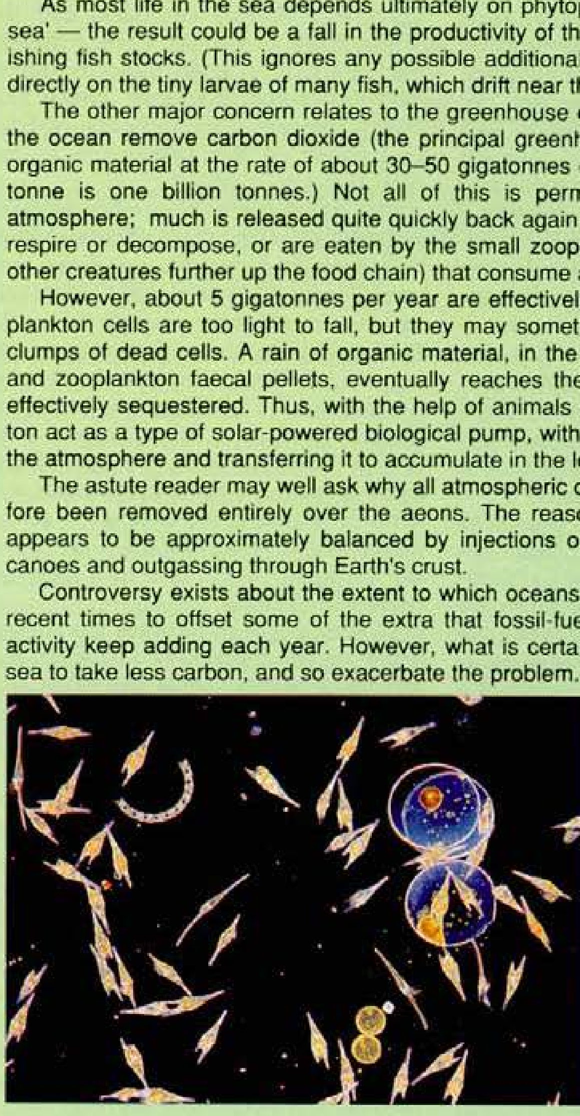
As most life in the sea depends ultimately on phytoplankton — the 'grass of the sea' — the result could be a fall in the productivity of the oceans, reflected in diminishing fish stocks. (This ignores any possible additional detrimental effects of UV-B directly on the tiny larvae of many fish, which drift near the surface.)

The other major concern relates to the greenhouse effect. The phytoplankton of the ocean remove carbon dioxide (the principal greenhouse gas) and convert it to organic material at the rate of about 30–50 gigatonnes of carbon per year. (A gigatonne is one billion tonnes.) Not all of this is permanently removed from the atmosphere; much is released quite quickly back again as CO_2 when phytoplankton respire or decompose, or are eaten by the small zooplankton (and they in turn by other creatures further up the food chain) that consume and respire their carbon.

However, about 5 gigatonnes per year are effectively removed. Individual phytoplankton cells are too light to fall, but they may sometimes aggregate into heavier clumps of dead cells. A rain of organic material, in the form of dead phytoplankton and zooplankton faecal pellets, eventually reaches the deep sea, where they are effectively sequestered. Thus, with the help of animals small and large, phytoplankton act as a type of solar-powered biological pump, withdrawing carbon dioxide from the atmosphere and transferring it to accumulate in the lower depths of the ocean.

The astute reader may well ask why all atmospheric carbon dioxide has not therefore been removed entirely over the aeons. The reason is that the oceanic 'sink' appears to be approximately balanced by injections of CO_2 into the air from volcanoes and outgassing through Earth's crust.

Controversy exists about the extent to which oceans have taken up more CO_2 in recent times to offset some of the extra that fossil-fuel burning and other human activity keep adding each year. However, what is certain is that we don't want the sea to take less carbon, and so exacerbate the problem.



Gustaf Hallegraeff

A mixture of phytoplankton — the 'grass' of the sea. Like land plants, these cells, in their millions, take up carbon dioxide and incorporate it into organic material.