SCOTOBIOLOGY OF PLANTS

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Scotobiology refers to the study of the biology of darkness, and the purpose of this report is to provide a brief overview, together with a few examples, of the ways in which plants utilize darkness in the management of their metabolism, development, and life programs. Plants, unlike animals, cannot close their eyes or dive into a nice dark burrow to escape light pollution during the night. They have had to adapt to light pollution and learn to live with it. For this reason they are less likely to be disturbed by anthropogenic light pollution than animals. But plants do rely on darkness, and have learned to use it in many interesting ways in the regulation of their growth, development and metabolism. Because plants represent by far the greatest proportion of the world's biomass, and because they are ultimately responsible for maintaining the world in a suitable condition for animals to live in, it is worth while to know something about the ways in which plants use darkness and manage light pollution.

First, autotrophic plants – that is, green plants, which make up a large proportion of the plants we see – rely almost completely on light for their organic and much of their inorganic nutrition. So, for them, light is essential, and prolonged darkness is deadly. And, of course, virtually all the heterotrophic organisms in the world (fungi, bacteria, and animals) rely on autotrophic plants for their survival. So we can't do without light – as long as it is kept in its proper place and time.

The process of photosynthesis itself is of interest in this discussion, in that it contains light-dependent and light-independent (i.e. dark) reactions. The light reactions capture light energy and convert it to unstable, short-lived high-energy intermediates. The energy from these intermediates is then used, in the dark reactions of photosynthesis, to reduce carbon dioxide and convert it into the organic compounds from which the plant is made.

Now sunlight is usually much too strong to be fully used – the reactions do not run quickly enough – so much of the sun's energy is wasted. But the high-energy intermediates made in the light reactions do last for periods of seconds to a minute or more, depending on the plant, and they can do their work in darkness. It follows that photosynthesis is much more efficient, in terms of the light energy used, in flashing light than in continuous light. Unfortunately, the sun does not flash. But the leaves of many trees (such as Trembling Aspen) are so formed that they flutter widely in even a slight breeze. This means that they flicker between full sunlight and shadow, so that essentially all the leaves of the tree are in flashing light. The result is that the overall rate of photosynthesis of the whole tree is much greater than it would be if only some of the leaves were continuously exposed to full illumination and some were continuously in shadow.

Seaweeds, which are often swayed to and fro by wave action, exhibit this behaviour, and this has proved invaluable in the on-shore cultivation of seaweeds. Tanks are expensive, and if all the plants are to be illuminated, the tanks must be shallow and very large. However, if the tanks are deep and the seaweeds are stirred (by bubbling air), they rise to the surface at intervals, get a shot of full sunlight, then descend to the depths to "digest" the light energy they absorbed. Then the efficiency of photosynthesis (and thus of growth) is enormously increased. This very clever technique has evolved in many plants, and enables them to make full use of short periods of darkness during photosynthesis. It has been harnessed to develop commercial on-shore growth of seaweed for the extraction of their valuable components, such as carragenin.

Another interesting use of darkness occurs in some very tiny single-celled marine algae. The cells are so small that they do not have room or the nutritional resources to make more than a few protienaceous enzymes at any given time. If these plants are illuminated, they quickly make photosynthetic enzymes and feed themselves happily by photosynthesis. If they are darkened, they immediately break down the photosynthetic enzymes and use the resulting products to make an entirely new set of enzymes that actively pump organic compounds into the cells. So they continue to feed themselves, though in darkness. Plants in which this dark adaptation has developed have a strong competitive advantage over plants that lack it. This is a very good use of the dark!

Other plant reactions to light and darkness are interesting, but not always what one might expect. For example, it is usually thought that when a seed is planted in the soil (i.e. in darkness) its shoot grows up to find the light, and its root grows down to stay in darkness. But this is simply not true. The seed has no way of knowing where the light or darkness is. In fact, the shoot grows up because it is programmed to grow away from gravity – it is negatively geotropic – while the root is programmed to grow toward gravity – it is positively geotropic. Of course, up or down are exactly where light or darkness are to be found. But the geotropisms exhibited by the root and shoot are the result of evolution, which has selected growth responses that are most likely to enable the plant to survive. So it is gravity, not light or darkness, that cause shoots and roots to grow as they do. On the other hand, once shoots get above the ground they develop phototropic behaviour and grow towards light. This response depends on the fact that the growth hormone, auxin, migrates away from the illuminated side of the shoot toward the darker side. Thus the darker side, opposite the light source, grows faster, and the plant bends toward the light. Thus the utilization of darkness mediates the plant's response to light.

I should also mention scototropism, that is, growth towards darkness (as opposed to growth away from light). This has been found in seedlings of tropical vines that climb trees with dark-coloured trunks. The seedling germinates, and instead of growing up and towards light like other plants, it actively grows towards the darkest point in its horizon – hopefully a tree trunk. When it gets there it looses its scototropism and becomes phototropic or negatively geotropic, like other plants, and climbs up the tree trunk it has found. The mechanism for this interesting behaviour has not been elucidated.

Probably the most important aspects of a plant's reaction to and interpretation of darkness are expressed in its developmental behaviour: flowering, dormancy and the onset of senescence. The plant's ability to measure and respond to day length is crucial in enabling it to dovetail its developmental behaviour with the seasons. We are all aware of "long-day" and "short-day" plants. What is not so widely known is that plants do not measure or react to the length of the day. Instead, they measure and respond to night length – the duration of darkness. So short-day plants really require long nights, and should properly be called long-night plants.

The problem for short-day/long-night plants arises from the fact that if such a plant is illuminated briefly during a long night, it responds and interprets the experience as if it had experienced two short nights, rather than one long night with an interruption. As a result its flowering and developmental patterns may be completely interrupted. Now short-day plants normally bloom in the fall, as the days shorten, and they use the long nights to initiate the onset of flowering; and then, as the nights lengthen, the onset of dormancy, which enables them to withstand the rigours of winter. Thus, if the nights are interrupted by light pollution, the consequences can be very severe. Furthermore, the effect of successive experiences of illumination during the night is cumulative. It follow that light pollution, particularly if it is repetitive on a daily (or nightly) basis, can seriously affect the development, flowering and dormancy – and so the very existence – of short-day (long-night) plants.

This brings me to the question of the most serious and consistent light-polluter of the night – one that only astronomers routinely think of terms of serious light pollution. Of course, I refer to the moon. Yet it does periodically illuminate the night quite brightly, and this raises the question of why plants are not adversely affected by the full moon – even short-day plants. In fact, as any gardener knows, the full moon appears to intensify the growth of some plants; and certain crop plants, such as potatoes, are said to contain more protein and to be distinctly more nutritious if harvested during or shortly after a full moon. The ability of short-day plants to ignore the light pollution from the moon is derived from the fact that they have been experiencing the moon essentially forever, and have, through evolution, grown used to it. In other words, nightly light pollution must be somewhat brighter than full moonlight in order to seriously disrupt the developmental patterns of plants. This means that low-level light pollution, which may have bad social (or astronomical) consequences, does not affect plants. But the light pollution from street lights, flood lights or other bright sources can be and often is seriously damaging to plants by affecting flowering and the onset of senility, or of the state of dormancy which is normally essential for the prevention of winter damage or death of the plant. This does not mean that plants cannot detect very low intensities of light – they can, but these low intensity lights do not normally interfere with major developmental or metabolic events.

This has been a very short overview of the scotobiology of plants, and I have avoided detailed description of the mechanistic aspects of plant recognition and measurement of the periodicity and length of darkness. In fact, it must be obvious that plants do not, if fact, detect darkness at all, because darkness is not a thing that can be measured. It is simply the absence of light. So plants in reality experience light, through a series of sensitive photoreceptors (pigments) which are coupled to hormone and enzymic transduction mechanisms that pass messages along to the various metabolic machineries that control the behaviour of the plant. What plants measure is the absence of light, not the presence of darkness. And, as we have noted, darkness is seldom absolute, and for plants (depending on the system in question) “darkness” can in fact contain, for example in bright moonlight, quite considerable levels of light. It is important to keep this point in mind when discussing any quantitative aspects of darkness. Darkness cannot be measured. Only dim light can be quantified.

In conclusion, it is evident that while plants use darkness in many different and interesting ways in the regulation of their growth and metabolism, low-level light pollution of the night does not seriously affect them. On the other hand, bright light pollution, particularly if it recurs on a regular nightly basis, may have serious consequences for plants, particularly for short-day plants, which require long, unbroken nights for the orderly progress of their development.