How plants cope with various light conditions

Light After Darkness

JAN PILARSKI
Institute of Plant Physiology, Kraków, Polish Academy of Sciences
j.pilarski@ifr-pan.krakow.pl

All plants need light to stay alive, although various species harness light in different ways. Moreover, light serves as more than just a source of energy – in alternation with darkness, it also provides plants with valuable information

Both light and darkness have a great impact on plants' metabolic processes. Darkness works to stimulate plant growth - the energy this requires is derived from "dark respiration," a process which involves burning off organic compounds produced under bright conditions. Dark respiration, in turn, is impeded when light is present - plants then switch to harnessing solar energy and activate the photosynthetic process. Under dark and dim conditions, plants grow rapidly in search of better access to light, and they position their leaves so as to absorb as much radiation as possible. Exposure to considerable light, on the other hand, impedes plants' growth and causes them to become more densely constructed, smaller, and thicker, with greener leaves covered with a more protective structure.

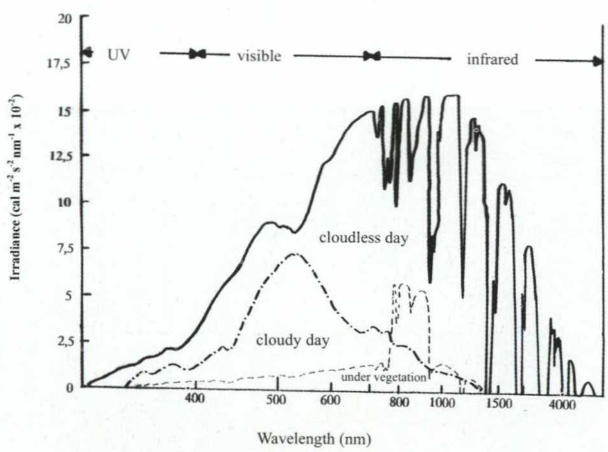
Solar radiation reaches the Earth's surface in wavelengths above 315nm. Nevertheless, plants only put part of this spectrum of available light to use in pho-

Krzysztof Kaliński

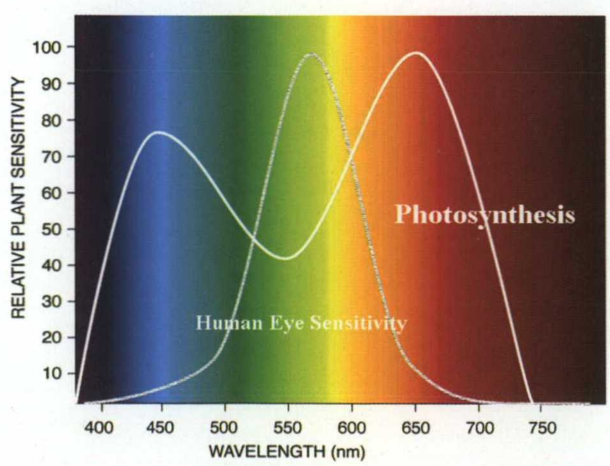
The light that reaches the forest floor is not only weaker, it has a different spectral composition. This is in part due to light passing through or reflecting off the leaves of plants situated higher up tosynthesis. Plant physiologists therefore divide the light spectrum into ultraviolet radiation (UV) in the 315-400nm range, photosynthetically active radiation (PAR) in the 400-700nm range, and infrared radiation above 700nm. The quantities and spectral characteristics of light that reaches plants vary according to the geographic location and elevation, the time of year and day, as well as the particular site in which a plant is growing. Some of these factors have been targeted by research carried out at our Institute.

Light harnessed, light lost

Solar radiation is partially absorbed, reflected, and dispersed as it makes its way through the Earth's atmosphere, as a result of which its spectral breakdown on the surface varies greatly depending on the time of day or year. Our measurements have shown that in the summer, at sunrise, the Sun's light contains a lot of infrared radiation above 700nm in wavelength and very little radiation under 400nm; as the Sun rises the share of radiation in both the PAR and UV ranges increases. Through the afternoon hours (11:00AM-3:00PM) the intensity and spectral breakdown of the Sun's light does not change significantly. After that, these parameters follow a reverse process to that seen in morning hours, as the Sun moves lower in the sky. In the winter, due to the Sun's generally lower position in the sky, radiation intensities are not as great.



The spectrum of solar radiation differs significantly depending on weather and habitat conditions



Plants do not harness light of various wavelengths to the same extent in photosynthesis. Their sensitivity is also different from that of the human eye

The solar radiation energy absorbed by green plants is partially transformed into chemical energy via photosynthesis, giving rise to organic compounds (the products of photosynthesis) that constitute a kind of building material and a source of energy. Photosynthesis primarily takes place in the leaves. Our research has shown that 10% of the PAR-range solar radiation falling on leaves is reflected from their surface and some 85% penetrates into the leaves to varying depths, with the remaining 5% passing straight through. Surface reflection may increase to 20-50% in leaves covered with a thick wax or, for instance, effloresced salt deposits. In the infrared radiation range of 700-1100nm, leaves reflect some 40-60% of the light that falls upon them.

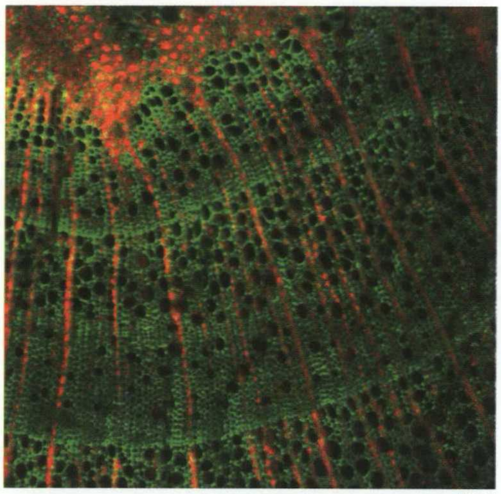
The somewhat weakened radiation that does penetrate inside the above-ground portions of plants is gradually absorbed as it passes through successive cells. PAR radiation is chiefly absorbed by photosynthetic pigments - chlorophylls and carotenoids; radiation in the infrared range is absorbed by water. The maximum absorption of photosynthetic pigments occurs in the violent-blue range (400-500nm) and in the orange-red range (600-700nm); water absorption is greatest in the 900-1100nm range.

Leaf absorption

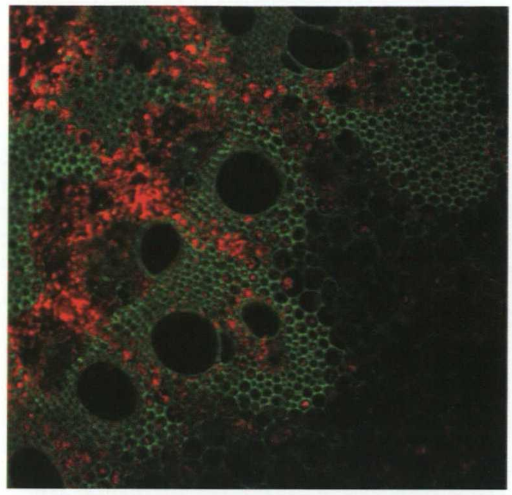
Of the PAR radiation that is absorbed by plants, 90% percent is dispersed as heat, 2% is emitted in the form of fluorescence, 1-5% is harnessed in the photosynthetic process, and 3-7% is utilized in other phytobiological processes. And so, on average, only 1-2% of the solar energy reaching the Earth becomes chemically stored in plant biomass.

In green leaves, the absorption of radiation coincides with the absorption spectrum of photosynthetic pigments. Such pigments absorb some 90% of radiation in the PAR range. This parameter is not significantly affected by leaf thickness - although it is affected by the light conditions, which have an impact on the shape of the leaf blade and on pigment quantities and breakdown. Leaves in the sunniest portion of a tree crown absorb more radiation than shaded, interior leaves.

Plants themselves produce radiation in the form of fluorescence (see microscopic images of plant tissues on the right). Such radiation usually bears less energy than the radiation being absorbed



Jan Pilarski



Jan Pilarski

Certain elements of plant cells show a particular tendency to produce fluorescence: chlorophyll emits red light, while cell walls emit green light

In the infrared range, leaves' absorption of radiation depends on their thickness and water content; the absorption of thin leaves is thus less than that of thick ones. Our research has shown that the 0.1-mm-thick leaves of the oca plant (*Oxalis tuberosa*) absorb only 3% of such radiation, while those of the Guinean "snake plant" (*Sanseviera trifasciata*), 0.8 mm in thickness, absorb as much as 26%.

Light as information

The radiation that is not reflected or absorbed by a leaf passes through it. Our research has shown that green leaves' transmission of radiation is not great, i.e. on the order of a few percent, and contains low radiation in the 400-500 and 600-700nm range, bearing the highest content in the 500-600nm range. The transmission of yellow leaves is greater, at about 30-40%. The fact that leaves mostly reflect rather than absorb radiation above 700nm leaves help plants to avoid overheating.

The spectral breakdown of the light that reaches the leaves of a given plant varies depending on their height above the surface. The leaves in the upper parts of plants are struck by direct solar rays; leaves lower down catch radiation that has been spectrally modified and dispersed, containing a large portion of radiation transmitted by the leaves situated higher up.

Because of their absorption, plants themselves also become light sources, producing radiation in the form of fluorescence (the emission of specific-wavelength radiation as a consequence of the absorption of radiation coming from an outside source). Such fluorescent radiation is usually of longer wavelength (bearing less energy) than the radiation being absorbed. Certain elements of plant cells show a tendency to produce fluorescence: chlorophyll emits red light, while cell walls, made chiefly of cellulose, emit green light. Chlorophyll fluorescence is now frequently utilized in research on photosynthesis, because it allows researchers to assess the effectiveness of the photosynthetic mechanism and even to forecast the size of agricultural harvests in various parts of the world, based on satellite photos.

Light, therefore, can convey important information about plants to scientists. Yet for plants, too, light represents more than just a source of energy. In alternation with darkness, solar radiation also constitutes a source of vital information for plants. Radiation in the 660-730nm range plays a role in controlling plants' reaction to diurnal changes of day and night, called "photoperiodism." Seasonal information carried by the relative length of the day and night causes plants to shift from a vegetative phase into a generative one, and therefore blossom. Short-day plants (such as chrysanthemums) bloom in spring or autumn, when the day is less than 10 hours long. Long-day plants, on the other hand, bloom when light falls on them for longer than 14 hours. The latter include grains and such vegetable plants such as lettuce, spinach, and radishes. In Poland, greenhouse-grown crops frequently need to be supplied with extra light in the spring or autumn. Unfortunately, research has still not yet succeeded in building lamps that can precisely match plant's photosynthetic needs. ■

Further reading:

Pilarski J., Rajba K. (2004). Measurement of light gradient in plant organs with a fiber optic microprobe. *Acta Physiol. Plant.* 26: 405-410.

Pilarski J. Kocurek M. (2005). The content of photosynthetic pigments and the light conditions in the fruits and leaves of sweet pepper. *Acta Physiol. Plant.* 27: 173-182.

Tokarz K., Pilarski J. (2005). Optical properties and the content of photosynthetic pigments in the stems and leaves of the apple-tree. *Acta Physiol. Plant.* 27: 183-191.