PBIO-141
Sensory and Physiological Ecology of Plants

9. Radiation and energy balances

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Outline

Energy balance

Adaptation and acclimation

Boundary layer and canopies

Energy balance

Radiation balance of a leaf

- Every object emits radiation according to its temperature.
- Every object absorbs radiation from its environment.
- Absorptivity and emissivity (ε) indicate the fraction of irradiance absorbed, and the fraction of the ideal emission emitted.
- Absorptivity and emissivity depend on the wavelength, but at a given wavelength are numerically equal.
- A *black body*, a theoretical concept, absorbs all radiation incident on it (absorptivity = 1, ε = 1).

Emitted radiation

- The radiation emitted by a body depends on its temperature, and its emissivity.
- A cold object emits less radiation and at longer wavelengths than a body at higher temperatures.
- The sun emits radiation as a black body at 5800 K (degrees Kelvin). This is called by meteorologists shortwave radiation.
- A leaf will emit according to its temperature, at much longer wavelengths than the sun. This is called by meteorologists longwave radiation.

Emitted radiation

- At ambient temperatures it is normally assumed for plants, animals and water that they are perfect emitters ($\varepsilon = 1$).
- $F = \varepsilon\sigma T_s^4$, where F is the flux of energy emitted, ε the emissivity, σ is Stefan Boltzmann's constant, and T_s is the absolute temperature of the surface of the emitting object.
- At around 280 K most of the energy is in the waveband 5–25 μm.

Absorptance of a leaf

- Of the shortwave radiation, visible radiation is strongly absorbed and near-IR poorly absorbed,
- Longwave radiation is strongly absorbed.

Spectrum

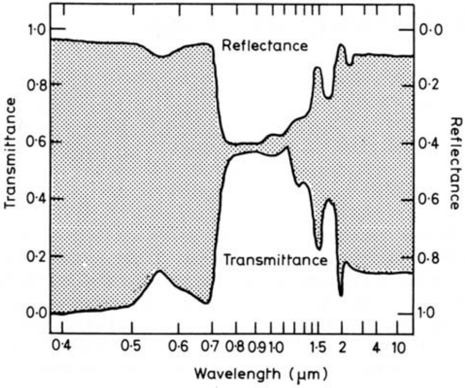


Fig. 2.1 Transmittance, reflectance and absorptance of a typical leaf. Stipple denotes absorptance.

(from Grace 1983).

Radiation balance of a leaf

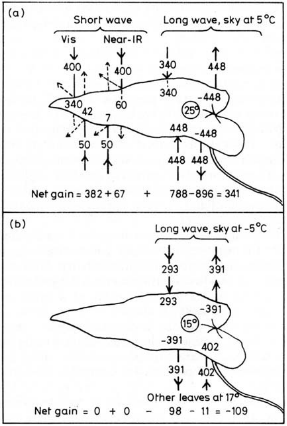


Fig. 2.2 Typical energy fluxes at a leaf in (a) bright sun, and (b) at night, assuming a clear sky and with other conditions as shown on the diagram. Units: W m^{-2}.

the equation in panel (b) of the figure should read

Net gain $= 0 + 0 - 98 + 11 = -87$

(from Grace 1983).

Radiation profile

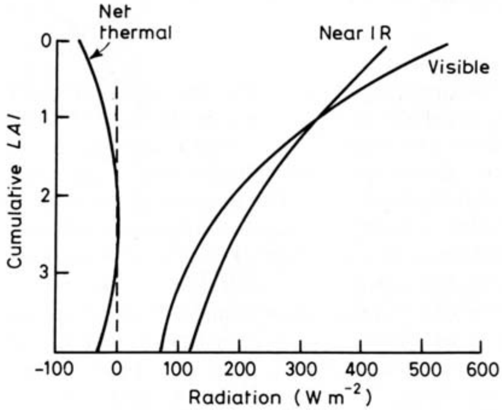


Fig. 2.4 Mean profiles of downward visible, downward near infra-red and net thermal radiation in a canopy with leaves facing all directions and with a leaf reflectance and transmittance of 0.1 in the visible and 0.4 in the near infra-red. (Calculation by Norman [24].)

(from Grace 1983).

Energy balance

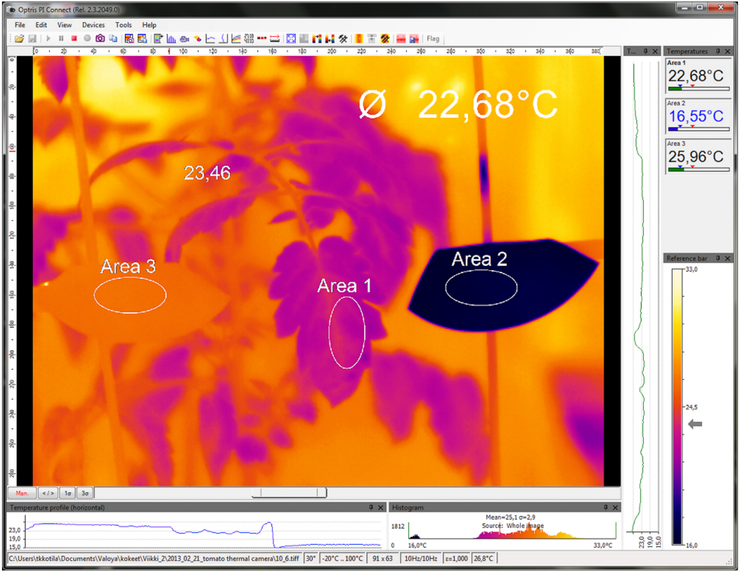
Heat gains by radiation = heat losses:

$$R = \lambda E + C + S + G + P,$$

where R is the net heat gain through radiative exchanges, λ is the heat of vaporization, E is the evaporation and/or transpiration rate, C is the heat lost by convection, S is the heat that goes into storage in the leaf (change in temperature), G is the conduction of heat down the petiole, and P is the energy trapped in chemical bonds through photosynthesis.

- All terms in energy flux units (W m^{-2}).
- G and P are very small in most situations, and S can be ignored if we assume that temperature of the leaf is in equilibrium.

Leaf temperature



Adaptation and acclimation

High reflectance as an adaptation

- Some plants have leaves that reflect more light than what is usual.
- Leaves are covered with hairs (pubescence) or waxes.
  - (In some other species hairs reflect little light but increase the thickness of the boundary layer.)
- These are mostly desert plants.
- Increasing visible light reflectance contributes to lower leaf temperatures in full sunlight.
- In some species there is also acclimation: hairiness depends on the season when leaves are formed.

Encelia farinosa

FDL (from http://en.wikipedia.org/wiki/Image:Encelia_farinosa_form.jpg.

Pubescence and temperature

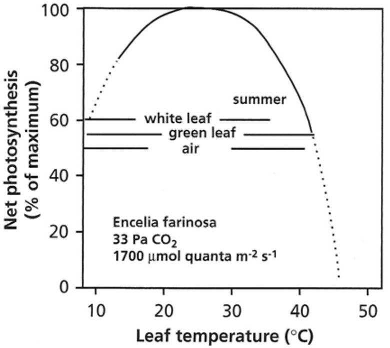


FIGURE 4. Daily ranges of leaf temperatures for green and white leaves of *Encelia farinosa* in the winter and summer, and the temperature dependence of photosynthesis (winter and summer) (Ehleringer & Mooney 1978).

(from Lambers et al. 1998).

Leaf size

Leaf size

Leaf size

- Different species have very different sizes of leaves.
- Some have composite leaves with leaflets of different sizes.
- Leaf margins vary (entire, with teeth, etc.)
- Size and shape affect the aerodynamic properties of leaves, and so the thickness of the boundary layer.
- The boundary layer in turn affects gas exchange and the energy balance (E and C change).
- This is reflected in the temperature of the leaf.

Coupling

- The temperature of small leaves is tightly coupled to that of the air. (Differences in temperature are small.)
- The temperature of big leaves is not tightly coupled to that of the air. (Differences in temperature can be large.)
- Small leaves are common in arid regions.
- Large leaves are common in the humid tropics, specially in the understorey of the forest.
- Some leaves are large, like those of some palm trees, but because their blade in broken up into small pieces function as much smaller leaves.

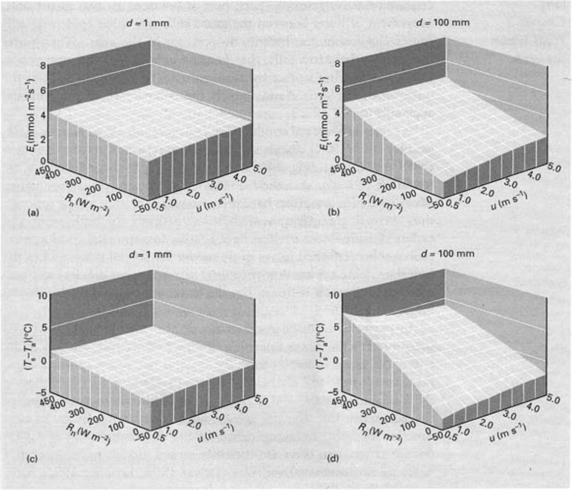


Fig. 2.7 Solution of the energy balance to explore the effect of leaf size (d) and environmental variables on the transpiration rate (a,b) and the difference between the surface and air temperature ($T_s - T_a$, c,d). R_n and u are the net radiation and wind speed respectively. In the calculation the stomatal conductance was 500 mmol m^{-2} s^{-1}, the air temperature was 15 °C and the saturation deficit of the air was 8 mmol mol^{-1}. This corresponds to a temperate environment. Other examples are given in van Gardingen & Grace (1991) from which these figures were obtained.

(from Crawley 1997).

Evaporative cooling

- When a leaf loses water through transpiration, water evaporates in walls of mesophyll cells.
- Evaporation uses energy, and this cools the leaf. (Conversely condensation during dew formation warms slightly the leaf.)
- In hot climates, if transpiration would stop completely at midday temperature of the leaf would rise over the lethal threshold.

Evaporative cooling

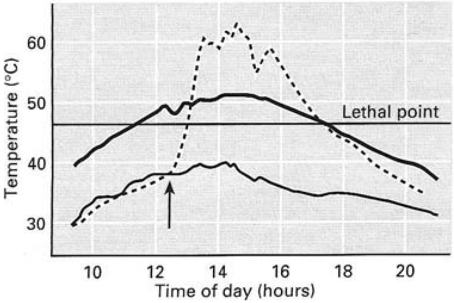


Fig. 2.9 Transpirational cooling in the desert plant *Citrullus colocynthis*. Graph shows air temperature (heavy line), leaf temperature (thin line) and temperature of another leaf which was excised to stop transpiration (broken line). The arrow shows when excision was carried out. (From Lange 1959.)

(from Crawley 1997).

Leaf display and heliotropism

- Leaves of many plants move, but so slowly that we usually do not notice it.
- This affects radiation (shortwave and longwave) interception.
- Which in turn alters leaf temperature, and photosynthetic rate.
- Even when they do not move, the position of leaves affects their radiation balance.

Leaf display and heliotropism

Diaheliotropism Leaves track the movement of the sun, keeping the leaf blade perpendicular to the sunlight beam.

Paraheliotropism Leaves track the movement of the sun, keeping the leaf blade parallel to the sunlight beam.

Nictinasty Leaves move during the night, normally to a vertical position. Sometimes elaborate folding of leaflets.

Nictinasty

Cassia bicapsularis.

Leaf display and heliotropism

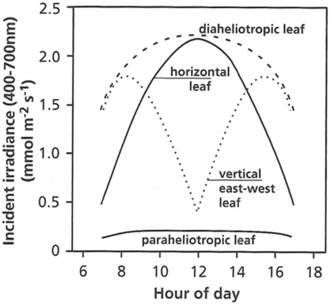


FIGURE 3. Photosynthetically active radiation incident on three leaf types over the course of a midsummer day: a diahelotropic leaf (cosine of incidence = 1.0); a vertical east–west facing leaf; a horizontal leaf, and a paraheliotropic leaf (cosine of incidence = 0.1) (Reprinted with permission from Ehleringer & Forseth 1980). Copyright 1980 American Association for the Advancement of Science.

(from Lambers et al. 1998).

Leaf rolling

Maize, left: well watered, right: not watered.

Boundary layer and canopies

Boundary layer of a leaf

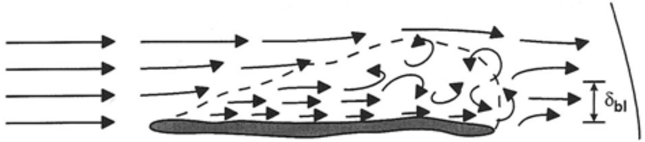


FIGURE 7. Schematic representation of the flow of nonturbulent air across a leaf. The arrows indicate the relative speed and direction of air movement. As air moves across a leaf, there is a laminar sublayer (short straight arrows), followed by a turbulent region. The effective boundary layer thickness (δ_{bl}) averages across these regions (Nobel 1983). Copyright by W.H. Freeman and Company. Used with permission.

(from Lambers et al. 1998).

Wind speed profiles

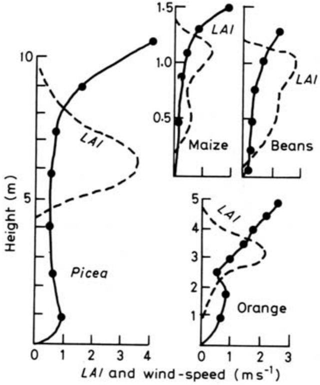


Fig. 3.9 Profiles of wind speed within crops (●) in relation to the leaf area index (---). (From Landsberg and James [46].)

(from Grace 1983).

Water and temperature profiles

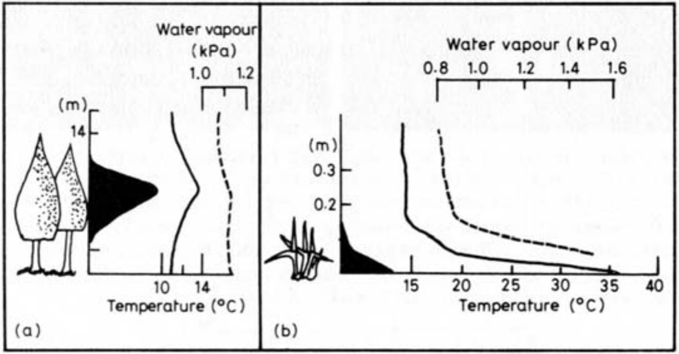


Fig. 5.5 Temperatures (solid lines) and water vapour pressures (broken lines) in canopies of (a) *Picea sitchensis* and (b) *Nardus stricta*. Note that within the forest canopy the gradients are never steep and the absolute values of temperature never very different from those in the atmosphere above. (From Jarvis *et al.* [86] and Cernusa and Seeber [68].)

(from Grace 1983).

References

References

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- Grace, J. (1983). *Plant—Atmosphere relationships*. London: Chapman and Hall, p. 92. ISBN: 0-412-23180-8.
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