Transpiration

- Overview
- Ascent of water
- SPAC
- Environmental factors & Transpiration

Overview

- Role of transpiration
- Ion transport: moves ions, mineral nutrition
- Water uptake
- Energy exchange: Heat loss
- Movement through xylem: vessels & tracheids

Ascent of Water in Plants

- Root pressure

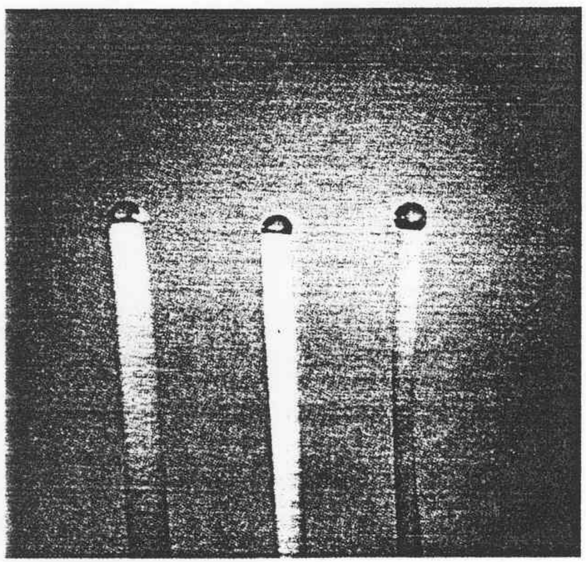
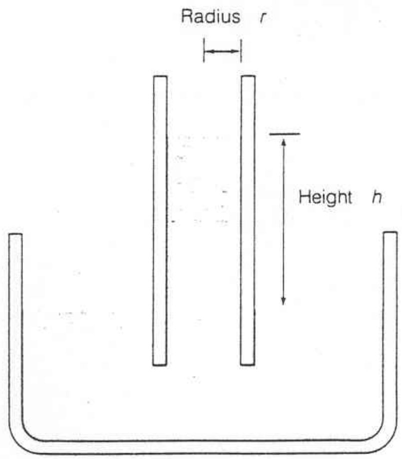


FIGURE 4.4. Exudation from cut stems of zucchini (left), soybean (center), and cucumber (right). The photograph was taken about 30 minutes after excision of the zucchini and soybean stems and about 15 minutes after excision of the cucumber stem. The exudation is a manifestation of the positive pressure (referred to as root pressure) in the xylem of such plants. (Photograph courtesy of Daniel Cosgrove, Penn State University.)

Guttation through hydathodes

Tall trees: gravity component, atmospheric pressure

- Capillarity in apoplast



LIFTING FORCE = circumference × surface tension
$= 2\pi r \times 0.0728\ \text{Nm}^{-1}$

DOWNWARD FORCE = height × area × density × acceleration due to gravity
$= h \times 2\pi r^2 \times 998\ \text{kg-m}^{-3} \times 9.8\ \text{ms}^{-2}$

At equilibrium: LIFTING FORCE = DOWNWARD FORCE

Solving for height: $h = \dfrac{1.49 \times 10^{-5}\ \text{m}^2}{r\ \text{(in meters)}}$

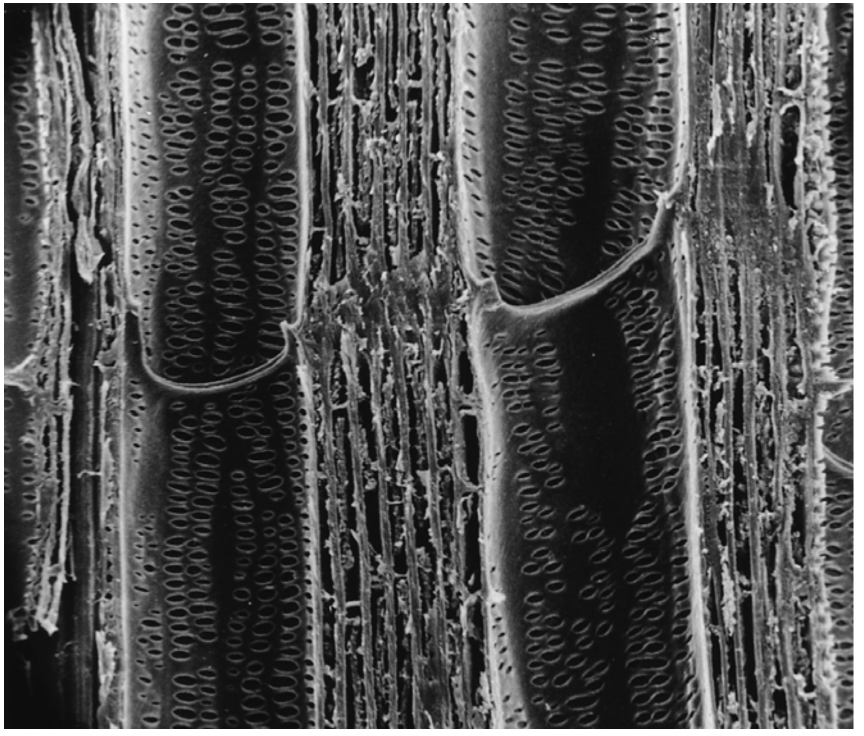
Examples:

Capillary radius (μm)	Height of rise (m)
1	1.49
10	0.149
100	0.0149
1000	0.00149
Typical vessel (75μm)	0.02

FIGURE 3.5. Capillary rise of water up a tube due to the lifting force of adhesion and surface tension. The lifting force is given by the circumference of the tube × the surface tension of water. The weight of the column of water is given by the height × area × density × acceleration due to gravity. The maximum capillary rise depends inversely on the tube radius, as tabulated here: the smaller the tube, the higher the capillary rise. For a typical vessel with a radius of, say, 75 μm, the capillary rise amounts to only 0.02 m. Because this rise is much less than the height of trees, it is evident that capillarity cannot account for water movement up tall trees. The units for surface tension are Newtons per meter (Nm^{-1}). One Newton equals 0.01 Joules per cm.

Xylem: tracheids and vessels

- Pits
- Tapered ends
- End plate
- Tension of -2 to -30 MPa
- Dilute solution of water and ions



Tension in xylem

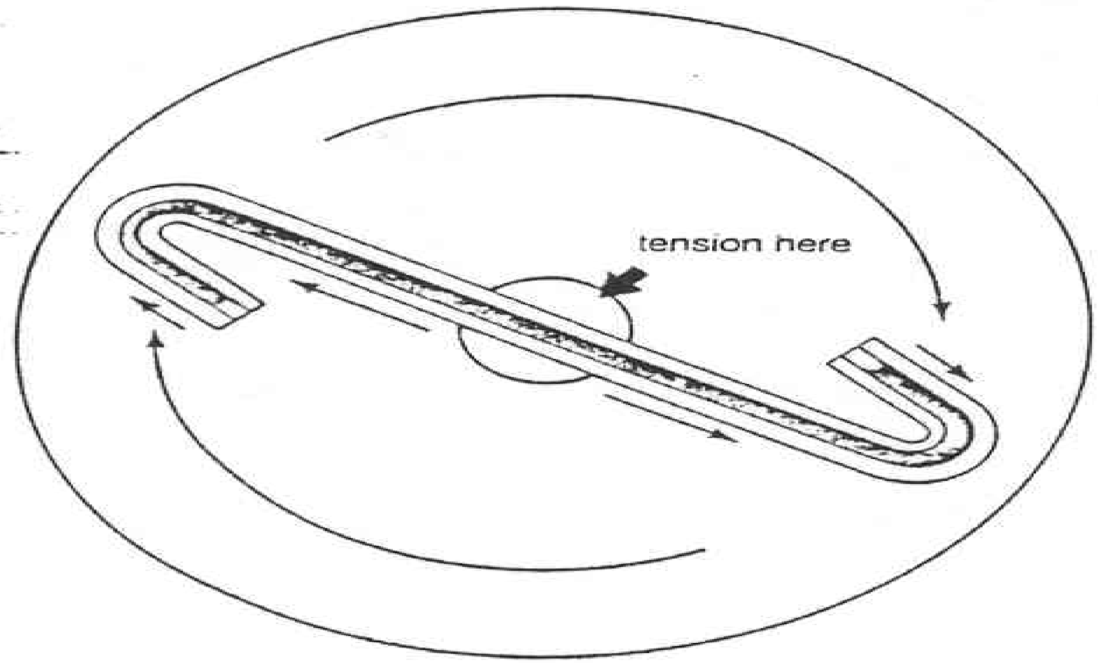
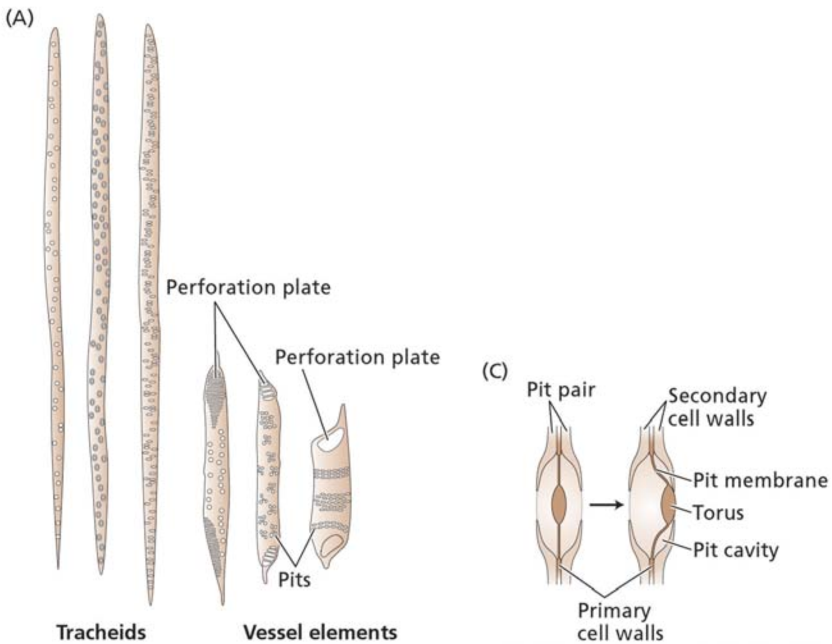


Figure 5-14 Method of measuring the cohesive properties of water with a centrifuged Z-tube. Small arrows indicate the direction of centrifugal force and the principle of balancing. The shape of the Z-tube prevents water from flying out either end of the tube.

xylem

Embolism



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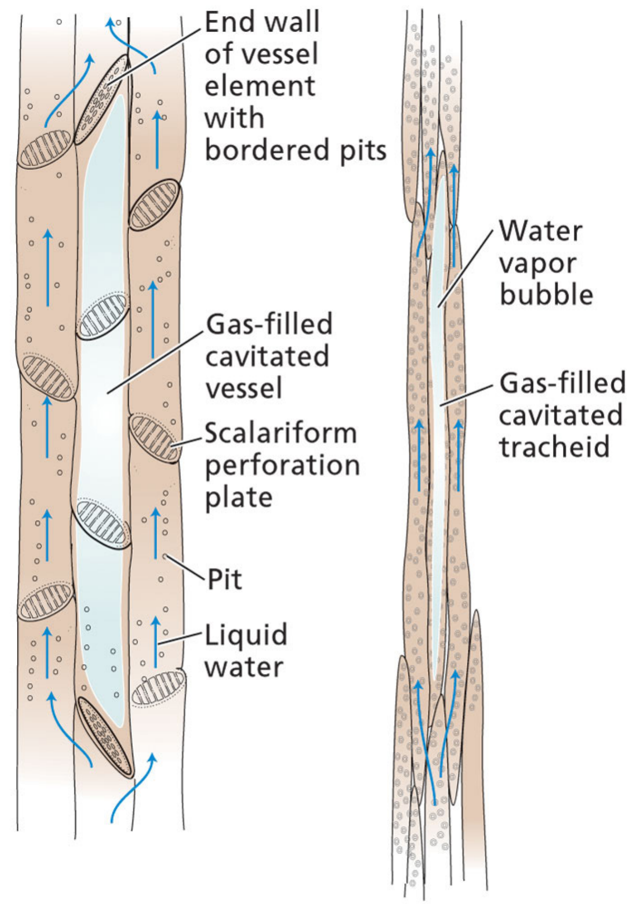

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Water potential of air

$$\psi = \frac{RT}{\bar{V}_w} \ln(\text{RH})$$

TABLE 4.2. Relation between relative humidity and water potential of air, calculated from Equation 4.4*

Relative humidity	*Water potential (MPa)*
1.0	0
0.999	−0.31
0.995	−1.56
0.990	−3.12
0.980	−6.28
0.950	−15.95
0.900	−32.8
0.750	−89.4
0.500	−215.5
0.200	−500
0.100	−718

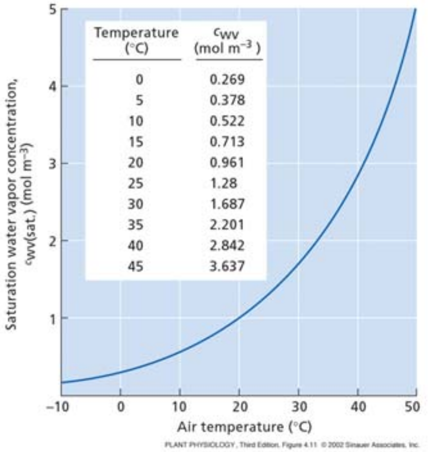
*Assuming a temperature of 20°C (293 °K); at which $RT/\bar{V}_w$ = 135 MPa.

SPAC

TABLE 4.2
Representative values for relative humidity, absolute water vapor concentration, and water potential for four points in the pathway of water loss from a leaf

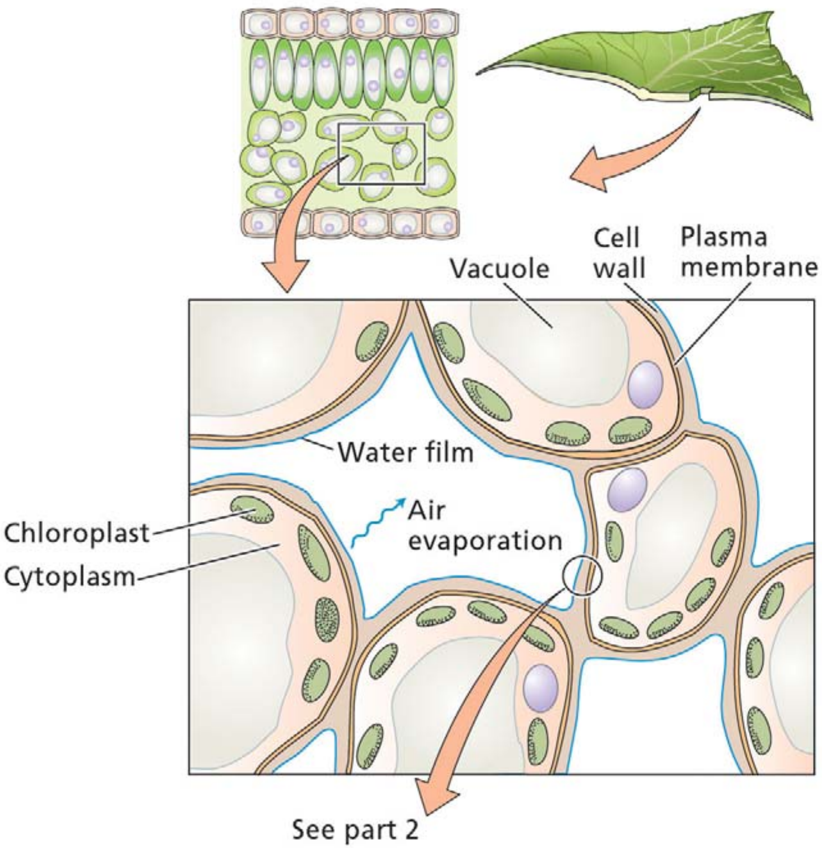
Location	Relative humidity	Water vapor Concentration ($mol\ m^{-3}$)	Water vapor Potential (MPa)[a]
Inner air spaces (25°C)	0.99	1.27	−1.38
Just inside stomatal pore (25°C)	0.95	1.21	−7.04
Just outside stomatal pore (25°C)	0.47	0.60	−103.7
Bulk air (20°C)	0.50	0.50	−93.6

Source: Adapted from Nobel 1999.
Note: See Figure 4.10.
[a]Calculated using Equation 4.5.2 in Web Topic 4.5; with values for $RT/\bar{V}_w$ of 135 MPa at 20°C and 137.3 MPa at 25°C.

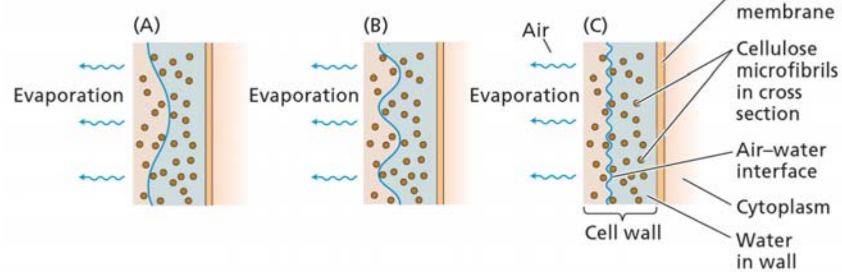


- Soil-Plant-Air continum
- Movement of water due to properties
- Cohesion-adhesion
- Water potential gradient
- Evaporation of water into air
- Vapor pressure deficit
- Relative humidity

Air space in leaf



	Radius of curvature (μm)	Hydrostatic pressure (MPa)
(A)	0.5	−0.3
(B)	0.05	−3
(C)	0.01	−15



Vapor pressure deficit

TABLE 4.3. Representative values for relative humidity, absolute water vapor concentration, and water potential for four points in the pathway of water loss from a leaf.*

Location	Relative humidity	Water vapor: Concentration ($mol\ m^{-3}$)	Water vapor: Potential (MPa)
Inner air spaces (25°C)	0.99	1.27	−3.18
Just inside stomatal pore (25°C)	0.95	1.21	−16.2
Just outside stomatal pore (25°C)	0.47	0.60	−239
Bulk air (20°C)	0.50	0.50	−215

*Refer to Figure 4.9.

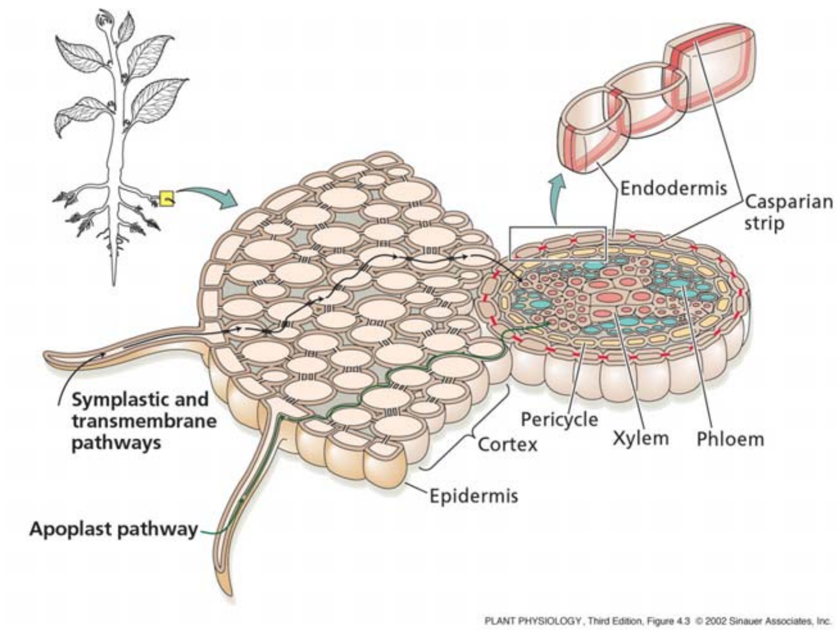
Adapted from P. S. Nobel, *Biophysical Plant Physiology and Ecology*, W. H. Freeman, San Francisco, 1983, p. 413.

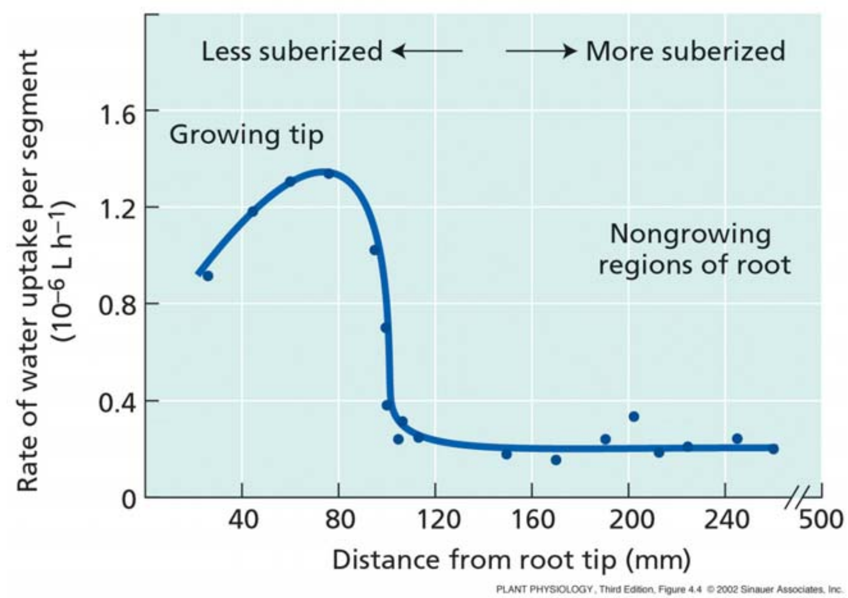
Effect of temperature

TABLE 11.3 The effect of temperature and relative humidity on leaf-to-air vapor pressure gradient. In this example it is assumed that the water content of the atmosphere remains constnat.

Leaf	Atmosphere	$e_{leaf} - e_{air}$
(A)		
T = 10°C	T = 10°C	
e = 1.23 kPa	e = 0.61 kPa	0.61 kPa
RH = 100%	RH = 50%	
(B)		
T = 20°C	T = 20°C	
e = 2.34 kPa	e = 0.61 kPa	1.73 kPa
RH = 100%	RH = 26%	
(C)		
T = 30°C	T = 20°C	
e = 4.24 kPa	e = 0.61 kPa	3.63 kPa
RH = 100%	RH = 26%	

Water uptake in Roots





Mangrove

Figure 9.8 A mangrove tree. Mangroves flourish in tropical tidal zones where the salt content of the water is high enough to plasmolyze the cells of most plants. The mangroves still obtain water via osmosis, which takes place because the mangrove cells accumulate an unusually high concentration of organic solutes; some are also able to excrete excess salt.

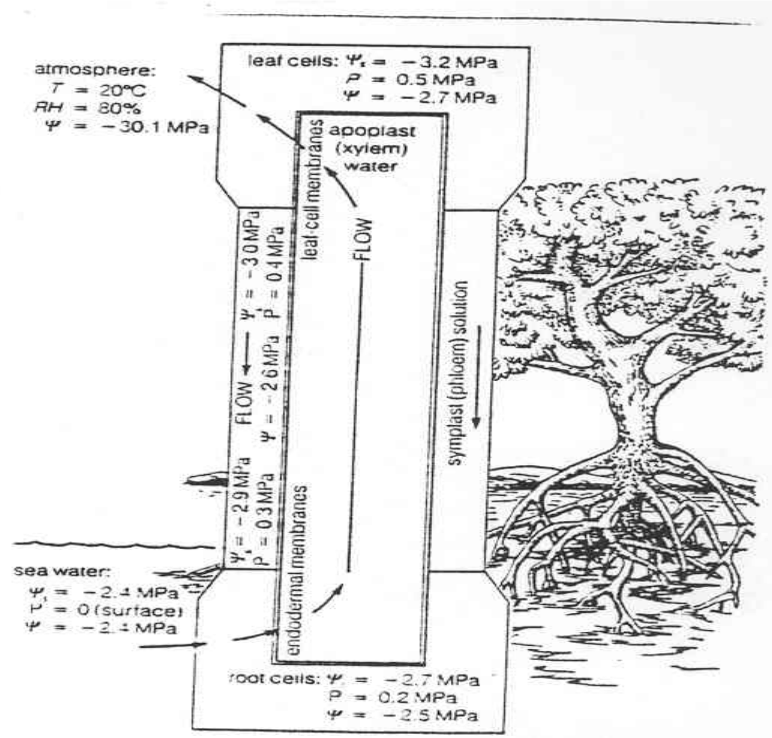


Figure 5-17 Water relations of a mangrove tree growing with its roots immersed in sea water. The diagram indicates the "essential" parts of the mangrove tree in this context. The endodermal (and exodermal?) membranes keep all but negligible amounts of salt out of the xylem, and the leaf-cell membranes maintain a high solute concentration in the cells. The result is that water in the xylem must be under considerable tension both day and night to remain in equilibrium with sea water, and leaf cells have such a negative osmotic potential that they absorb water from the xylem in spite of its tension and low water potential. Only osmosis keeps the leaf cells from collapsing. (Data based on Scholander et al., 1965, but their hypothetical numbers have been modified to better match the discussions in this chapter and in Chapter 8.)

Transpiration

- T α $e_{leaf} - e_{air}$
- Resistance due to stomatal factors

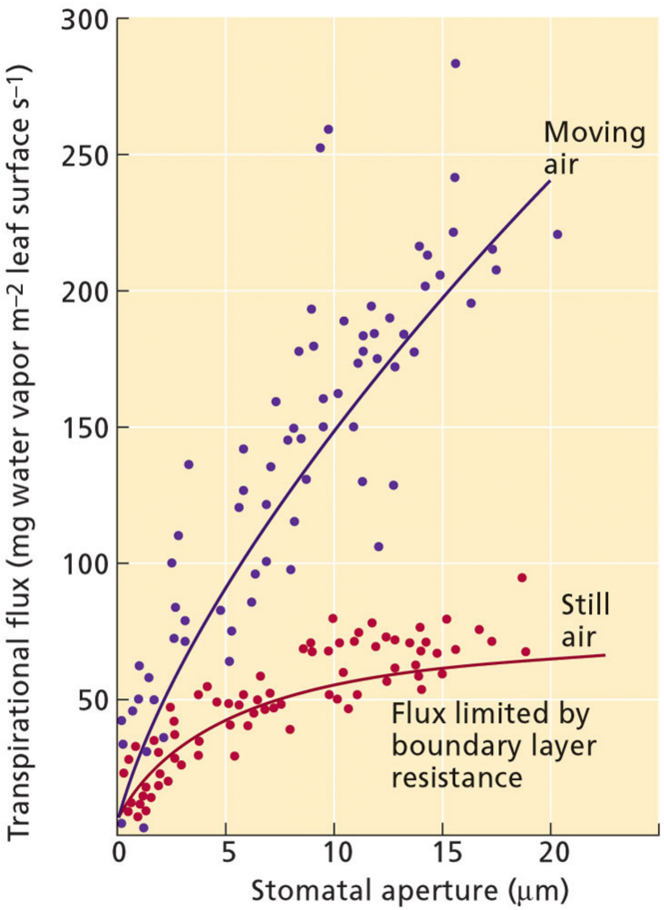
The energy budget for a typical mesophyte leaf.

Energy gain	$W\ m^{-2}$
a. Absorbed solar radiation	+605
b. Net infrared exchange	−235
c. Net radiation balance (a + b)	+370
Energy loss	
d. Loss by transpiration	−176
e. Loss by convection	−194
	−370

Data from Nobel, 1991.

Environmental factors

- Relative humidity of air
- Wind
- CO_2
- Leaf size and boundary layer
- Stomatal factors
- Light



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Boundary layer

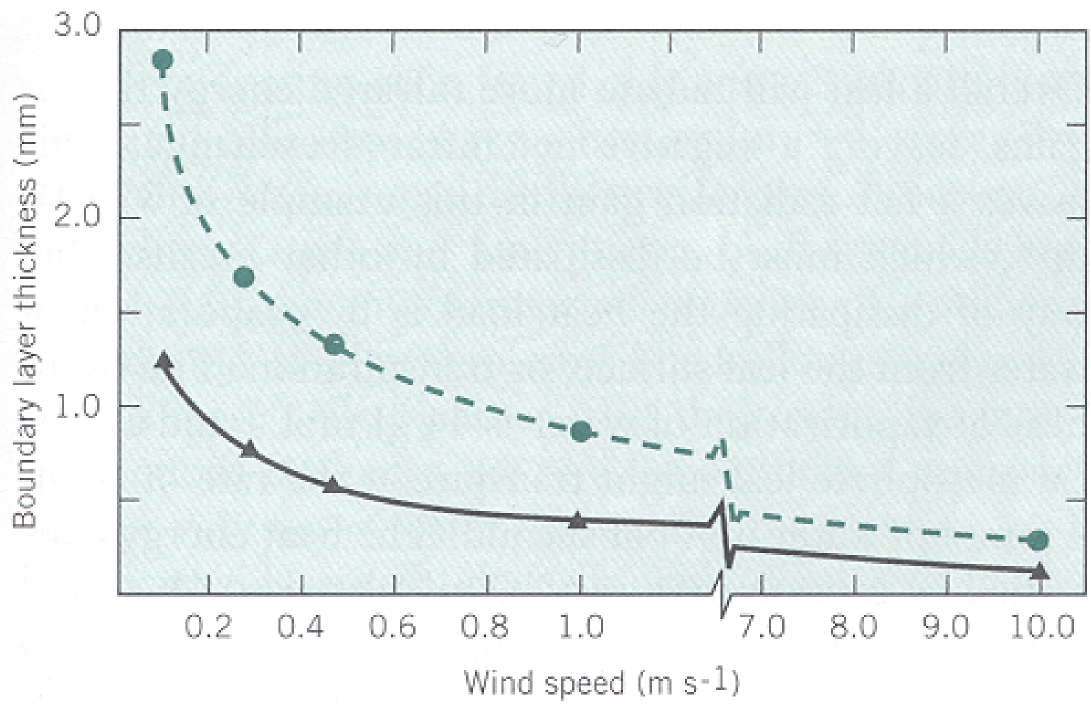

FIGURE 11.4 The impact of wind speed on calculated boundary layer thickness for leaves 1.0 cm (triangles) or 5.0 cm (circles) wide. A wind speed of 0.28 m s^{-1} = 1 km hr^{-1}. (Plotted from the data of Nobel, 1991.)