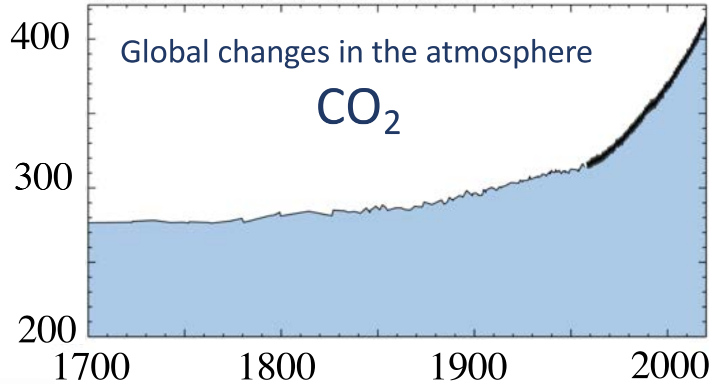


Topic 9

Leaf energy Budgets

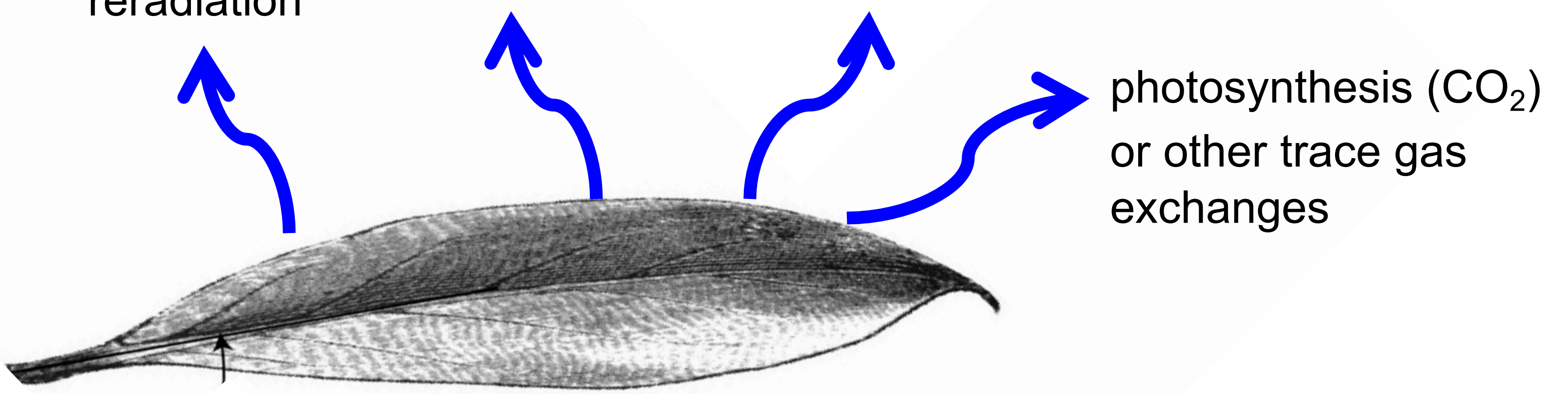
(5 parts)

Plant Ecology in a Changing World

Jim Ehleringer, University of Utah
http://plantecology.net

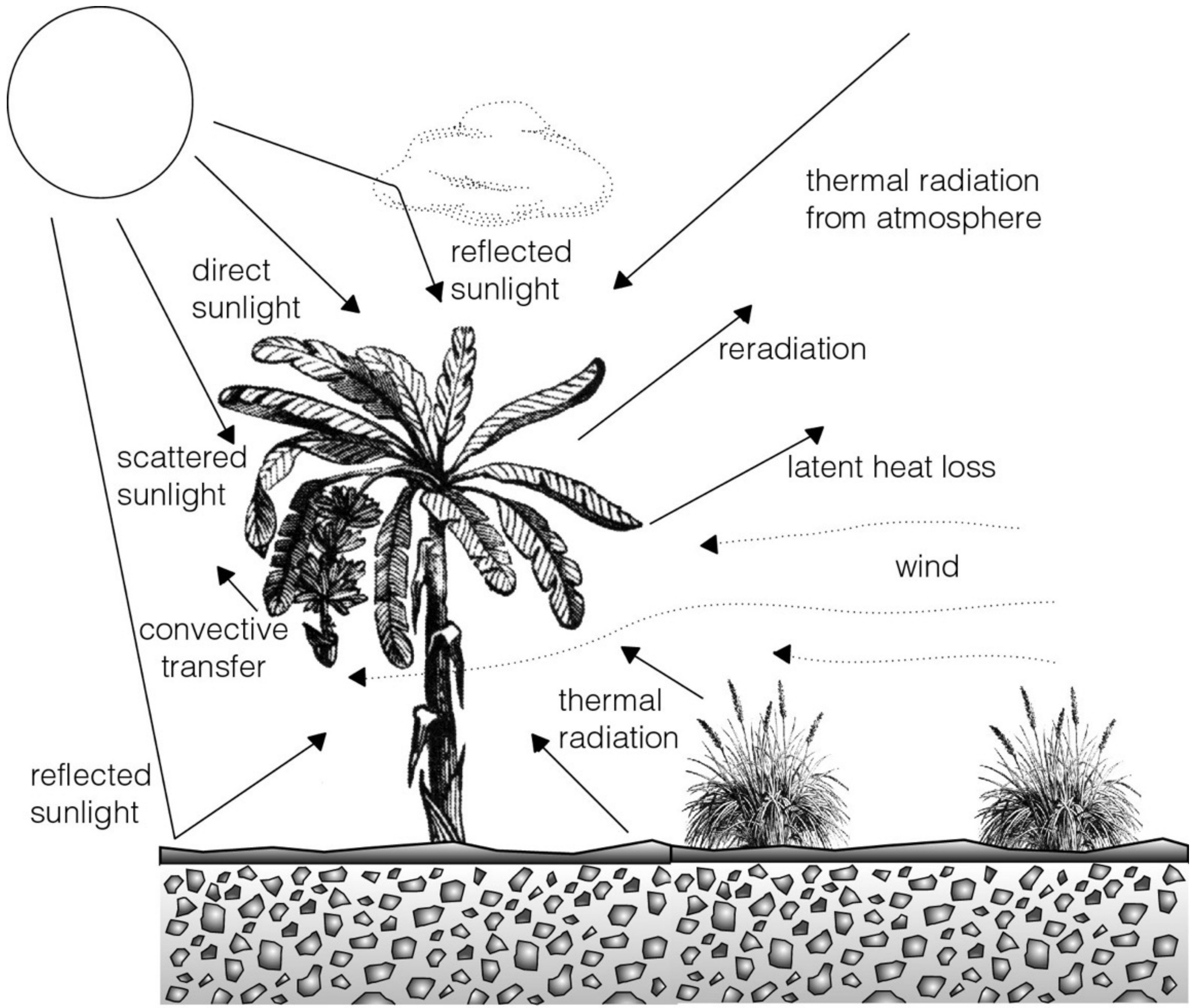
Part 1
The energy budget equation

Leaves interact with their physical environment through



energy exchange (radiation absorption heat transfer, reradiation)

mass exchange (transpiration, photosynthesis, trace gas)



There are many relevant components of the physical environment

Energy budget equation

The XLSX file calculates leaf temperatures for you.

energy in = energy out

energy absorbed = reradiation + convection + transpiration

$$a \bullet \cos(i) \bullet S_{direct} + a \bullet S_{diffuse} + \varepsilon \bullet R$$

solar direct   solar diffuse   infrared

Energy budget equation

The XLSX file calculates leaf temperatures for you.

energy in = energy out

energy absorbed = reradiation + convection + transpiration

$$\downarrow$$

$$\varepsilon \bullet \sigma \bullet (T_{leaf} + 273)^4$$

$$\downarrow$$

°C

The XLSX file calculates leaf temperatures for you.

Energy budget equation

energy in = energy out

energy absorbed = reradiation + convection + transpiration

$h_c \bullet (T_{leaf} - T_{air})$

convection coefficient

Energy budget equation

The XLSX file calculates leaf temperatures for you.

energy in = energy out

energy absorbed = reradiation + convection + transpiration

$k \bullet \lambda \bullet (e_{leaf} - e_{air}) \bullet g_{leaf}$

constant for converting vapor pressure to vapor density, 216.68

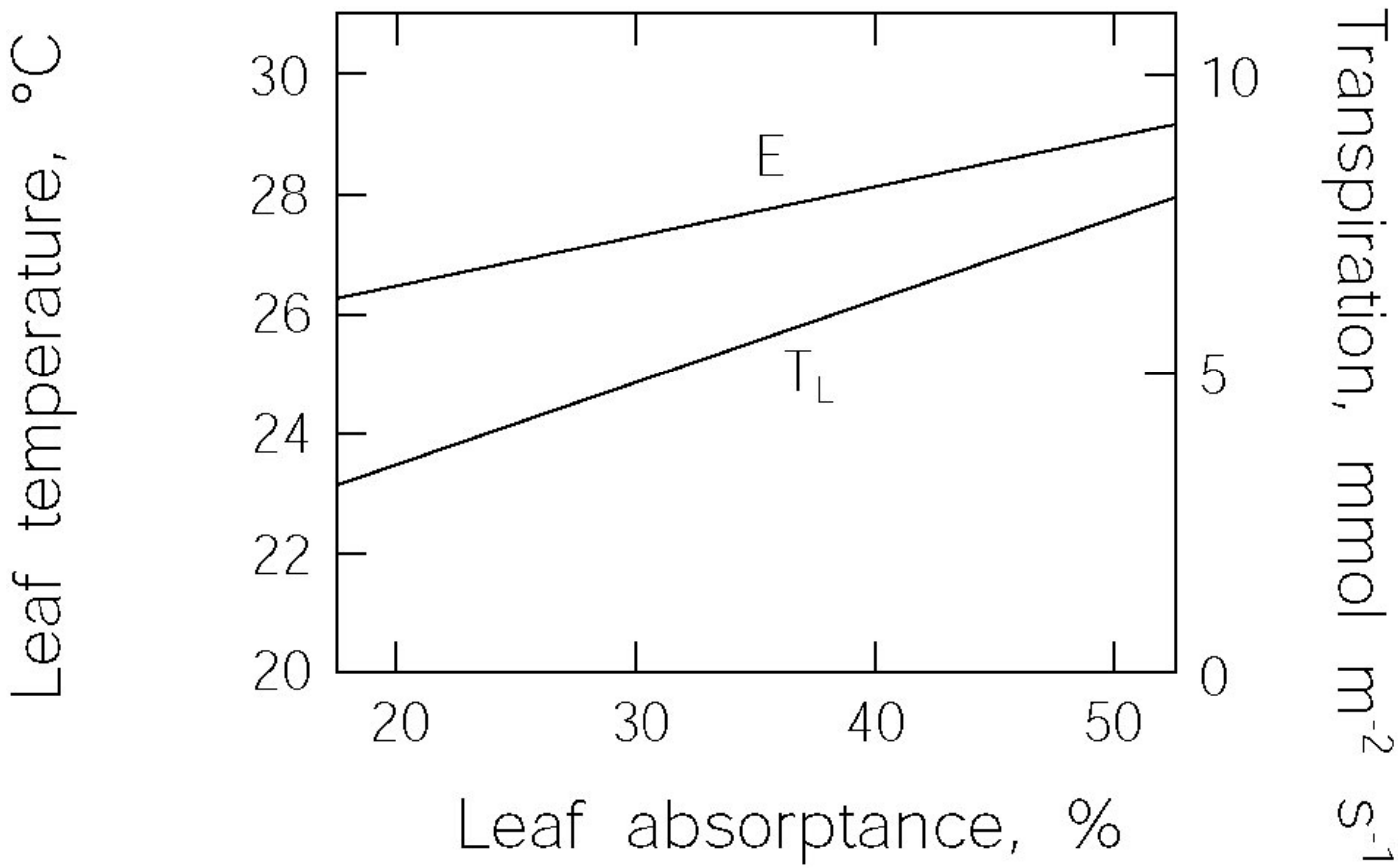
vapor pressures of leaf and air

leaf conductance

Part 2
Leaf coupling factors

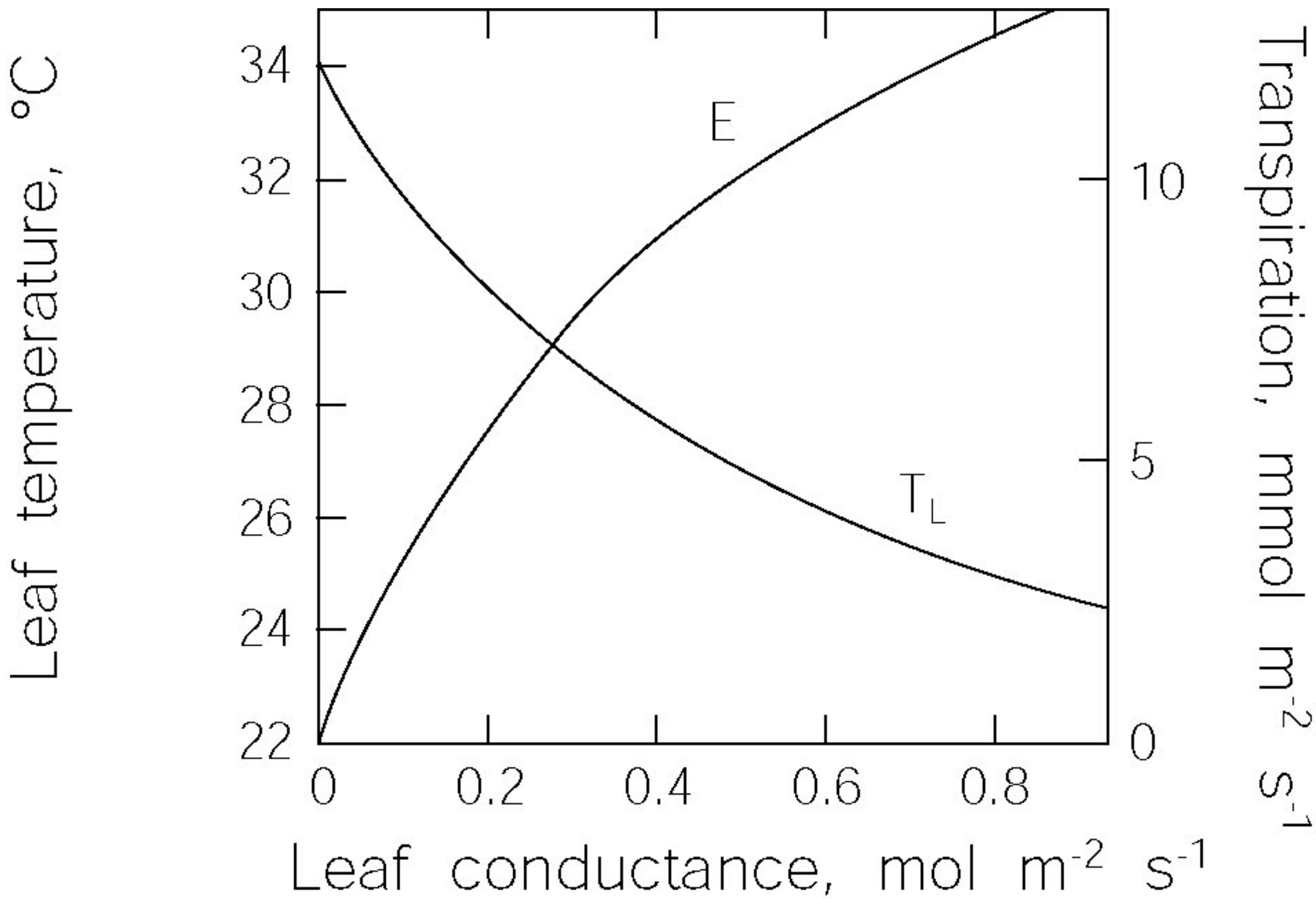
Leaf temperature is predictable when energy budget parameters are known

Parameters that plants can influence are known as **leaf coupling factors**.
Leaf absorptance is a coupling factor,



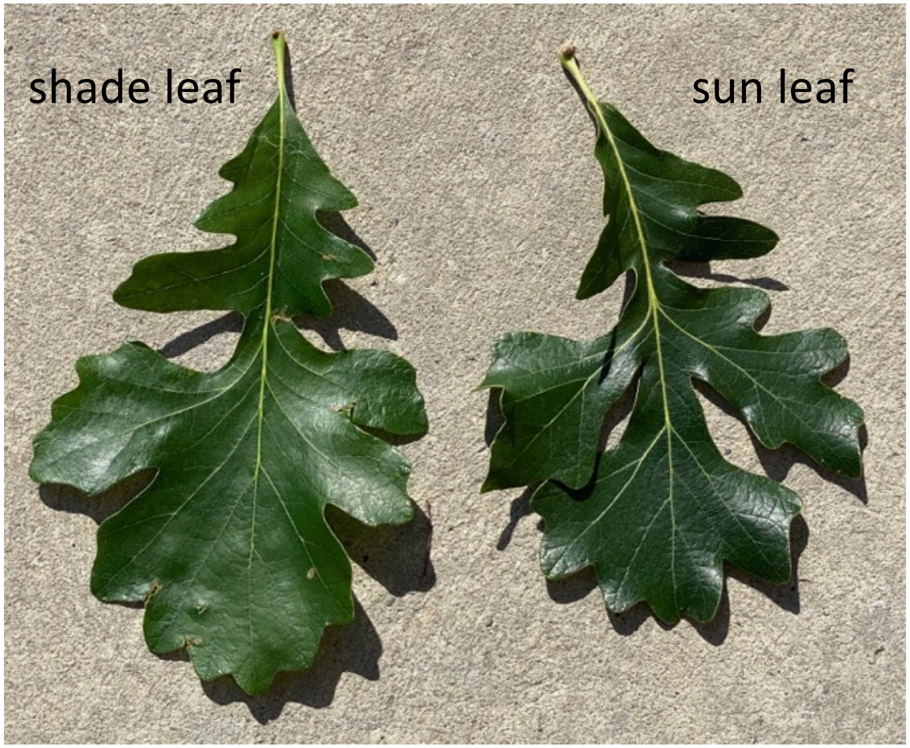
Leaf temperature is predictable when energy budget parameters are known

Parameters that plants can influence are known as **leaf coupling factors**.
Leaf conductance is a coupling factor.



Leaf coupling factors influence energy exchange between leaf and air

- leaf orientation
- leaf absorptance
- transpiration
- leaf size
- leaf shape



Leaf conductance values

open stomata	0.5 mol m^{-2} s^{-1}
closed stomata	0.05 mol m^{-2} s^{-1}

Leaf absorptance values (400-4000 nm)

typical green leaf	50 %
white leaf	30 %

Leaf coupling factors influence energy exchange between leaf and air

- leaf orientation
- leaf absorptance
- transpiration
- leaf size
- leaf shape

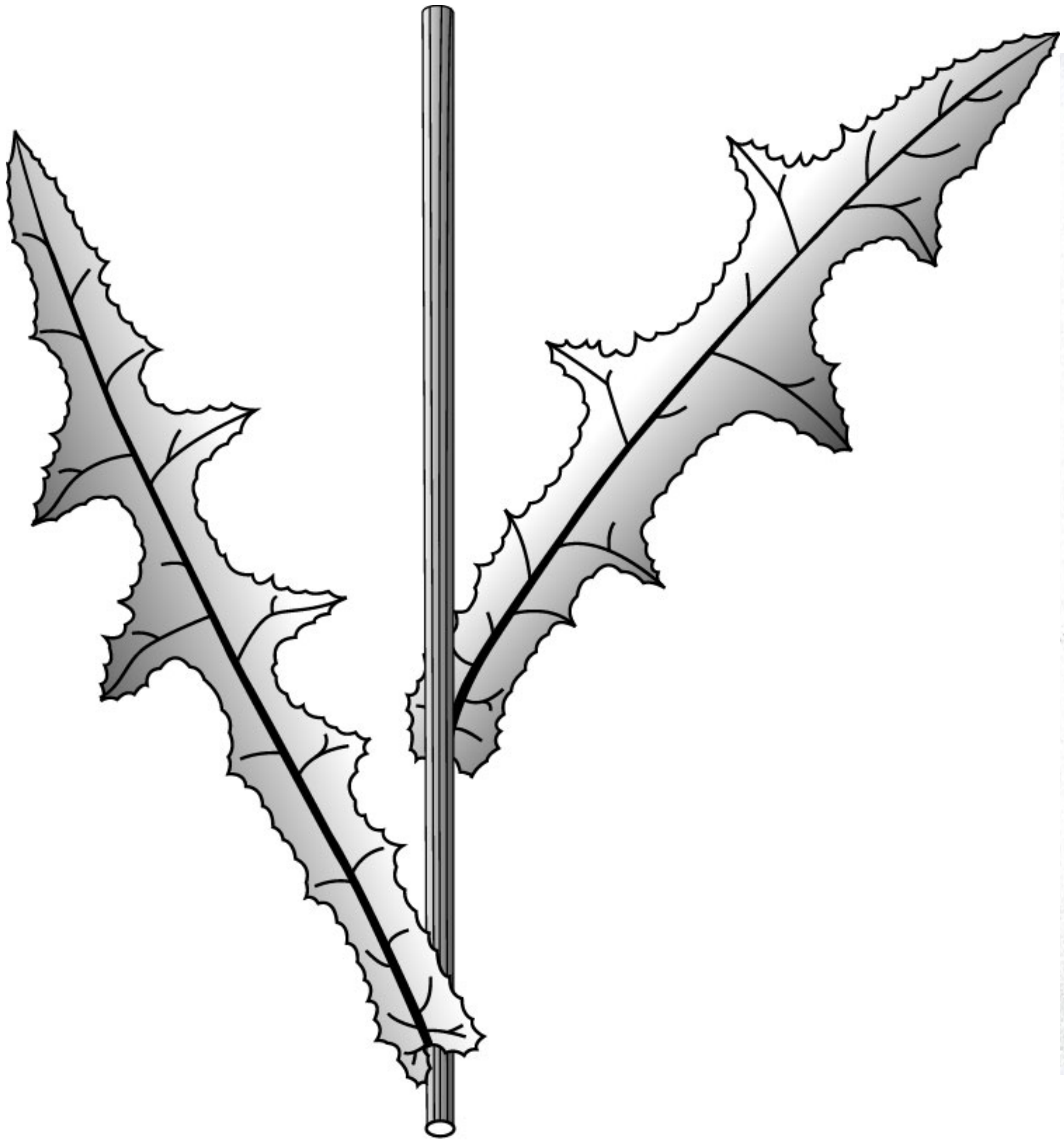
Leaf orientation includes

- changes in the orientation of the leaf relative to the sun [cos(i)]
- leaf absorptance between 400 - 700 nm
- leaf absorptance between 700 - 4,000 nm

Leaf orientation includes changes in cos(i) such as

- steep leaf angles (*Arctostaphylos*, *Eucalyptus*)
- steeper angles in sun leaves than shade leaves
- wilting to a vertical position
- leaf concavity (*Ceanothus*)
- leaf curling (many grasses)
- stem orientation (barrel cactus)

steep leaf angles in *Lactuca serriola*

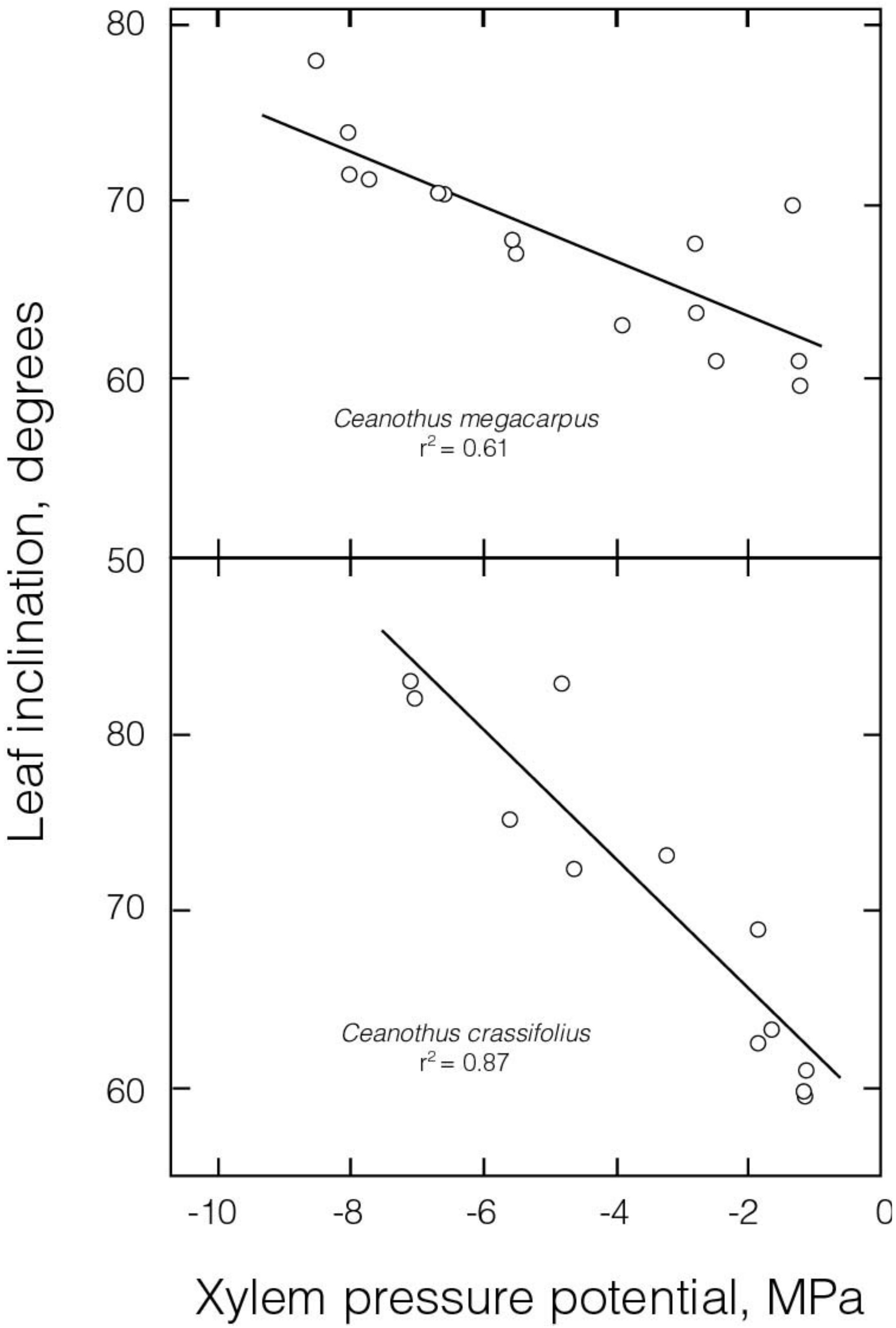


Many leaf orientation characteristics change under drought stress (= low transpiration)

• energy absorbed is reduced to offset reduced capacity to evaporatively cool

• increased leaf angle with drought stress (*Ceanothus* in the chaparral)

• paraheliotrophic leaf movements (e.g., *Lupinus, Medicago, Macroptilium*)



These *Ceanothus* species have evergreen leaves and are common shrub species within the chaparral, a vegetation type which occurs throughout the Mediterranean climate regions of southern California

Copiapoa columna-alba cacti orient due north in the Atacama Desert at an angle that minimizes solar radiation incident on cactus sides. Upper portions of the cactus have a waxy surface.

Part 3
Leaf absorptance

Photons are either absorbed, reflected or transmitted

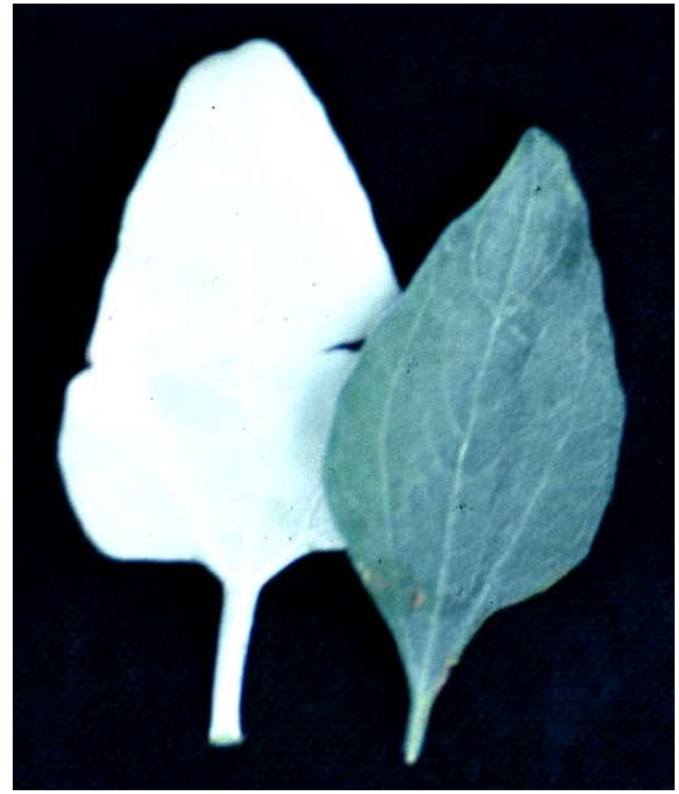
absorptance + reflectance + transmittance = 100%

Under drought stress, a frequent pattern is to reduce absorptance by increasing reflectance

Encelia farinosa
(North America)

Encelia canescens
(South America)

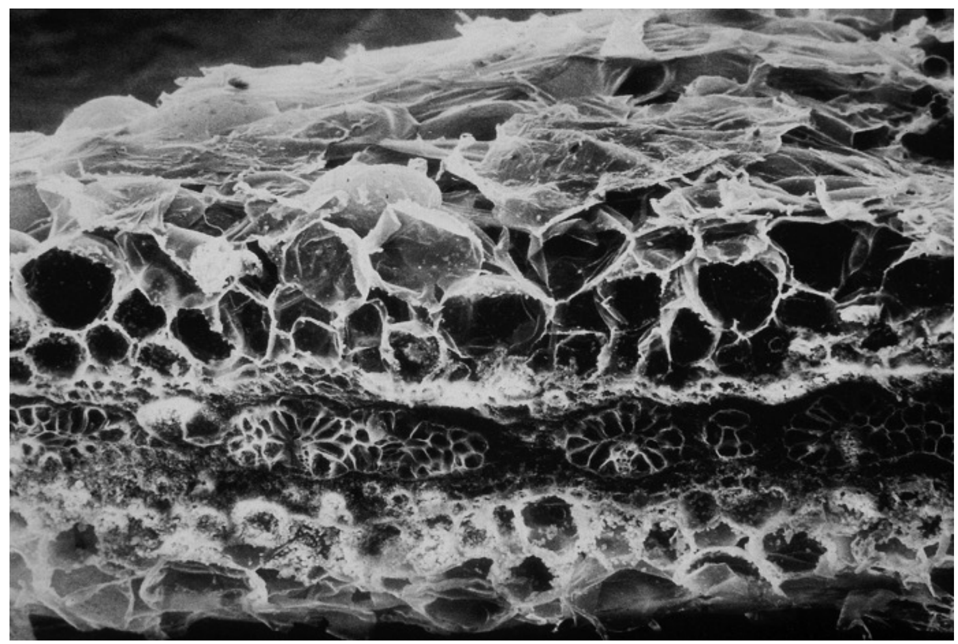
Mechanisms to reduce leaf absorptance include

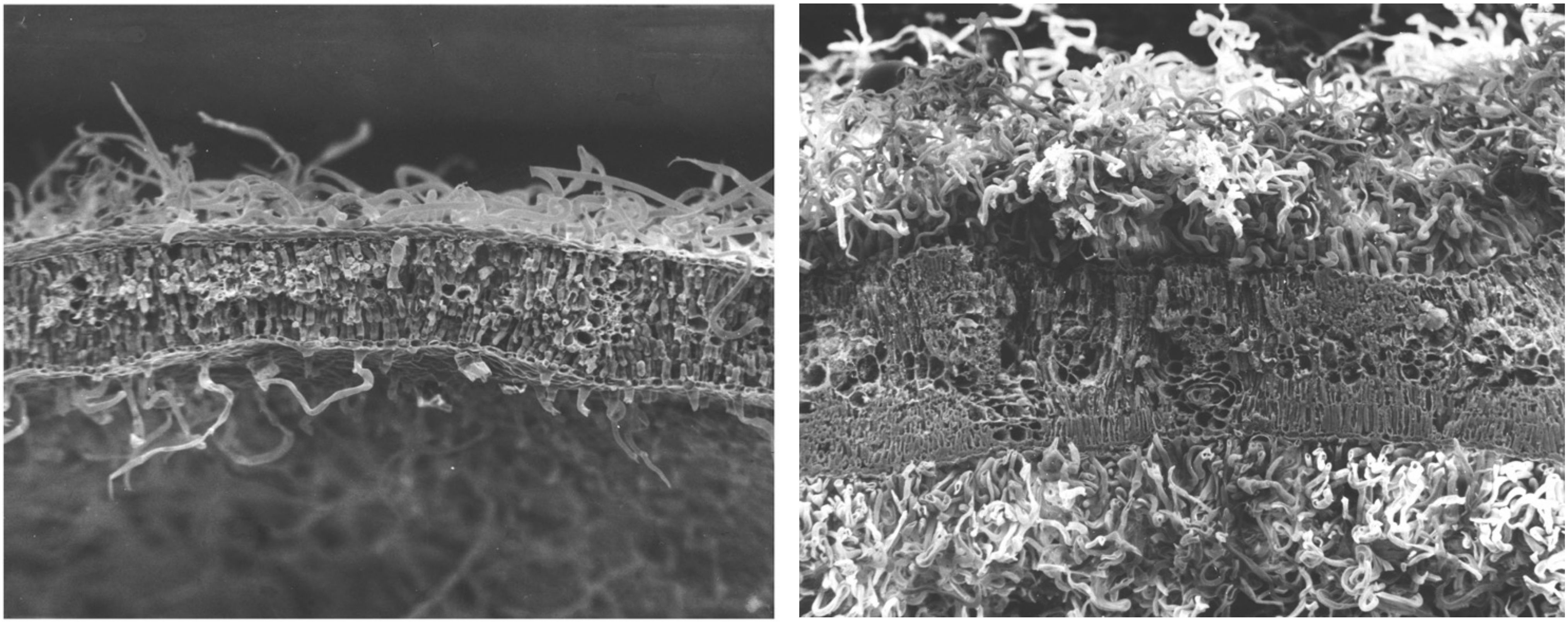


• dead, air-filled epidermal hairs
(*Artemisia, Encelia, Salvia*)

• cuticular waxes
(*Eucalyptus, Dudleya*)

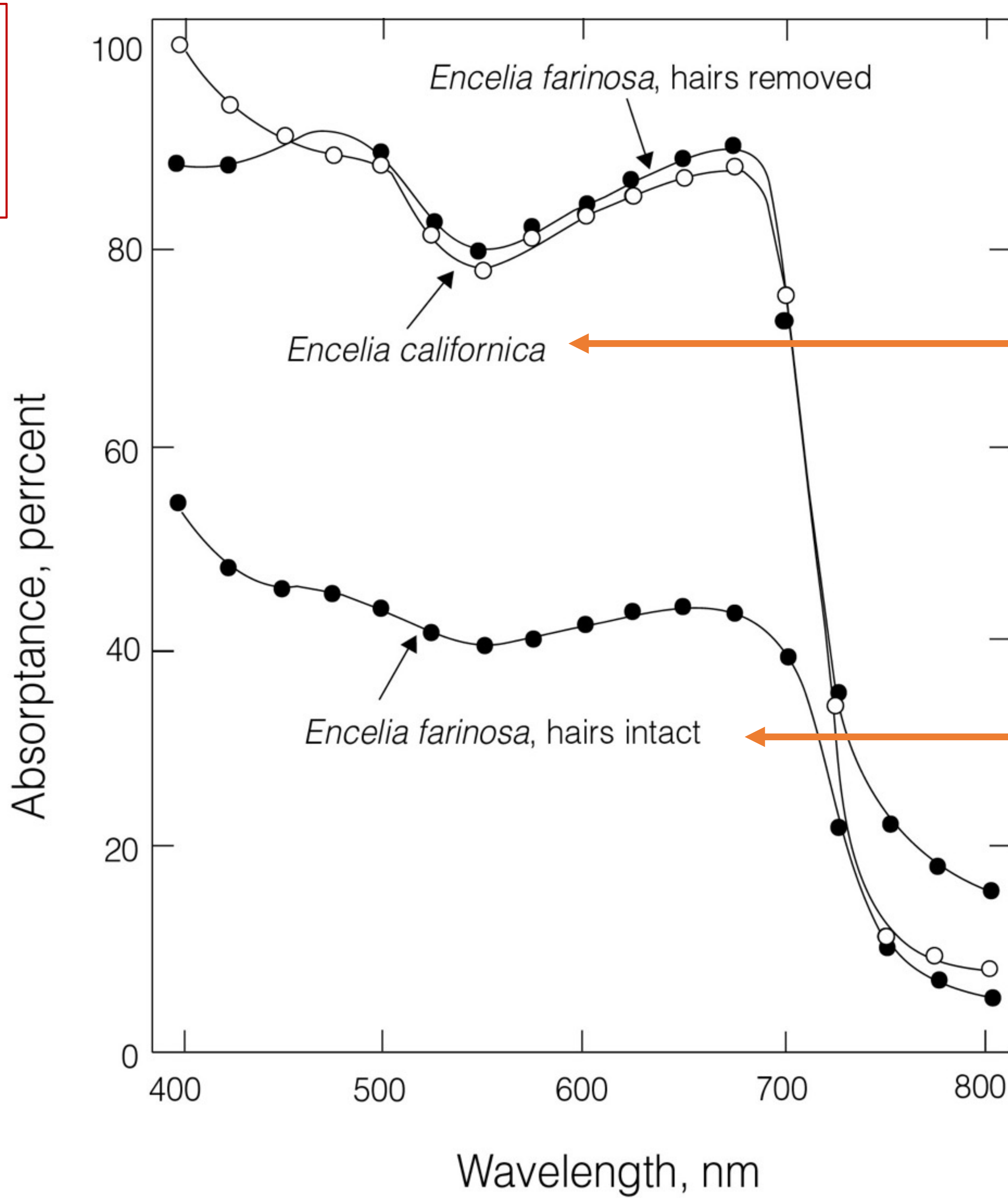
• epidermal salt bladders
(*Atriplex*)





Leaf cross sections of *Encelia farinosa*
(North America)

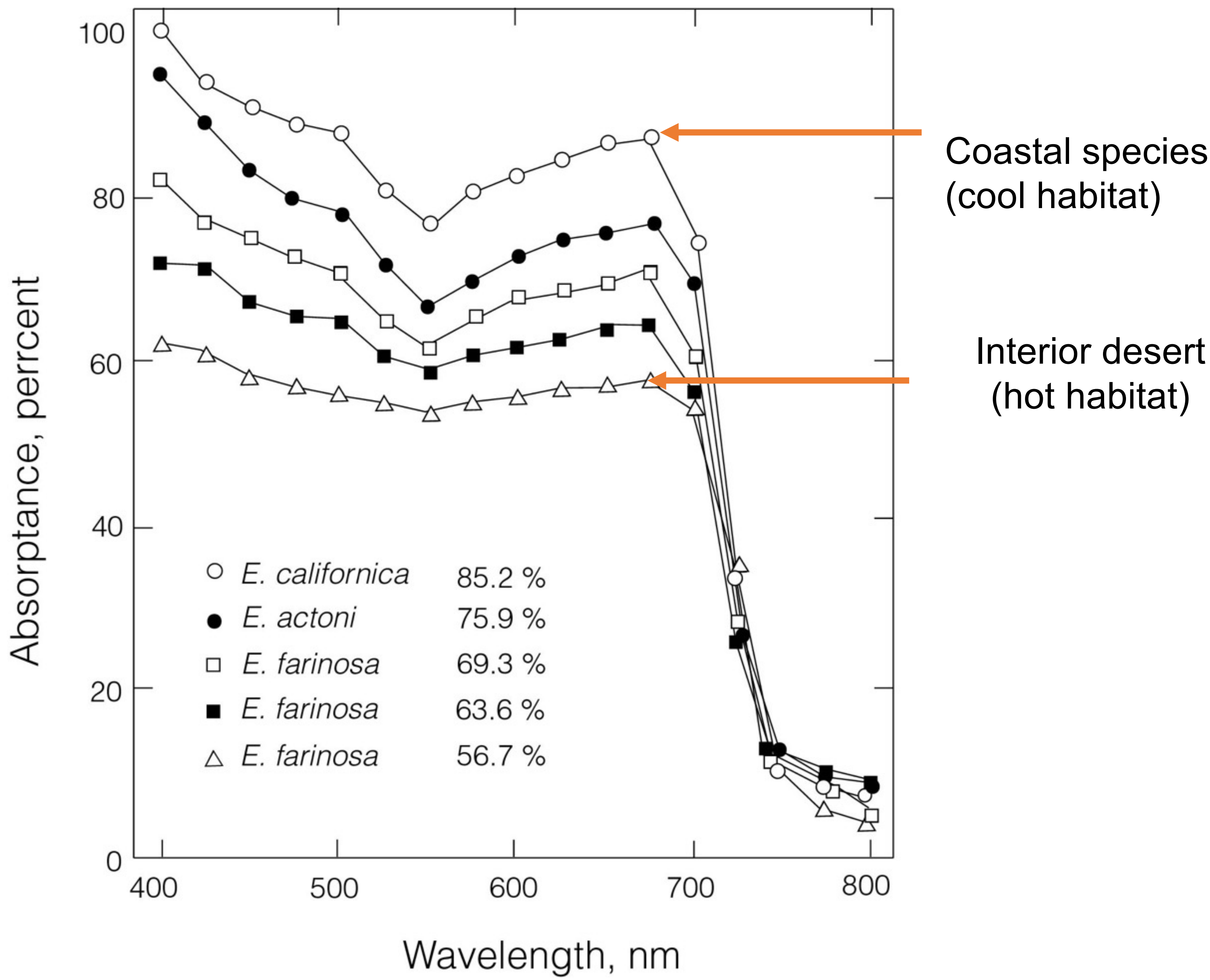
Hairs are typically a blanket reflector



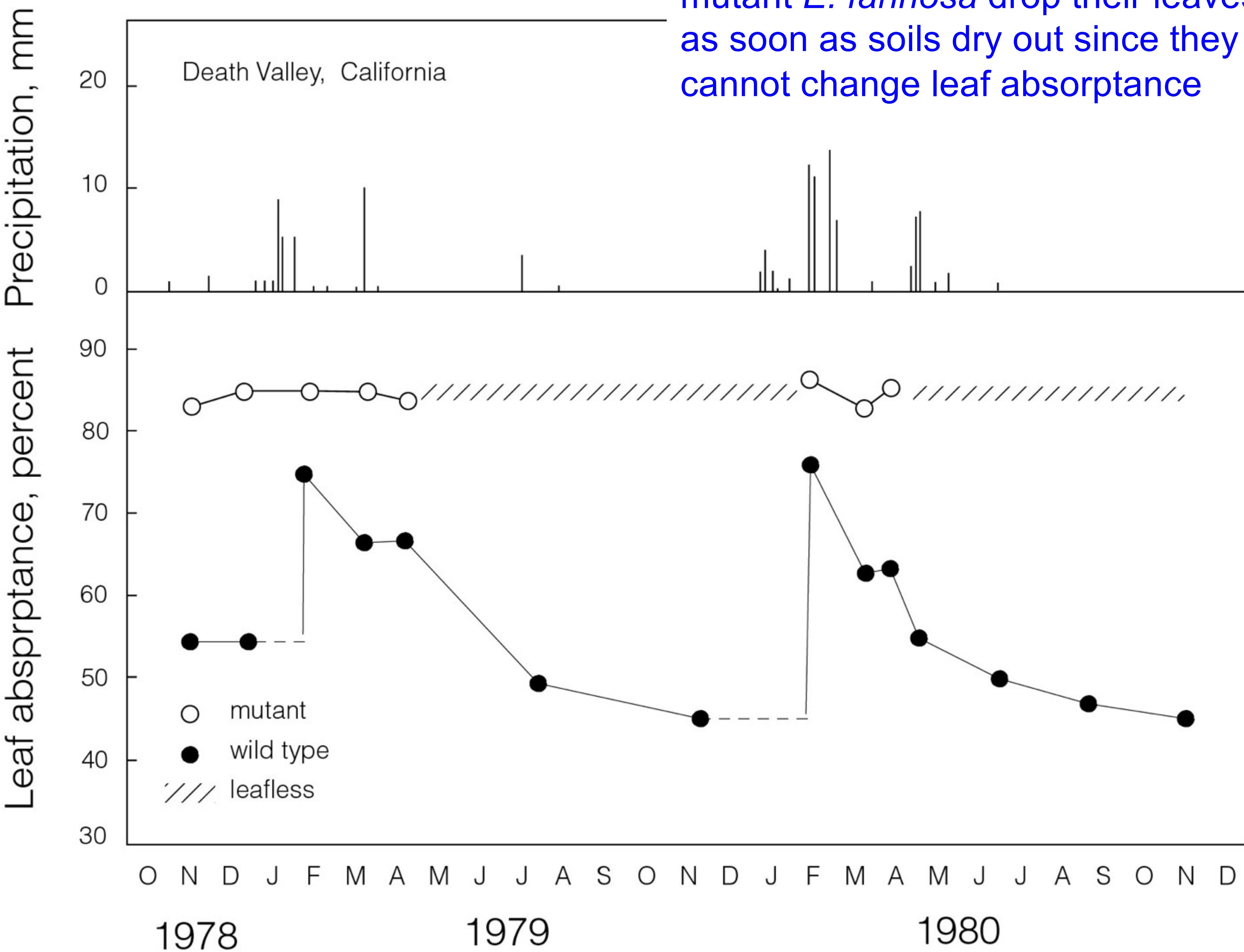
coastal

interior desert

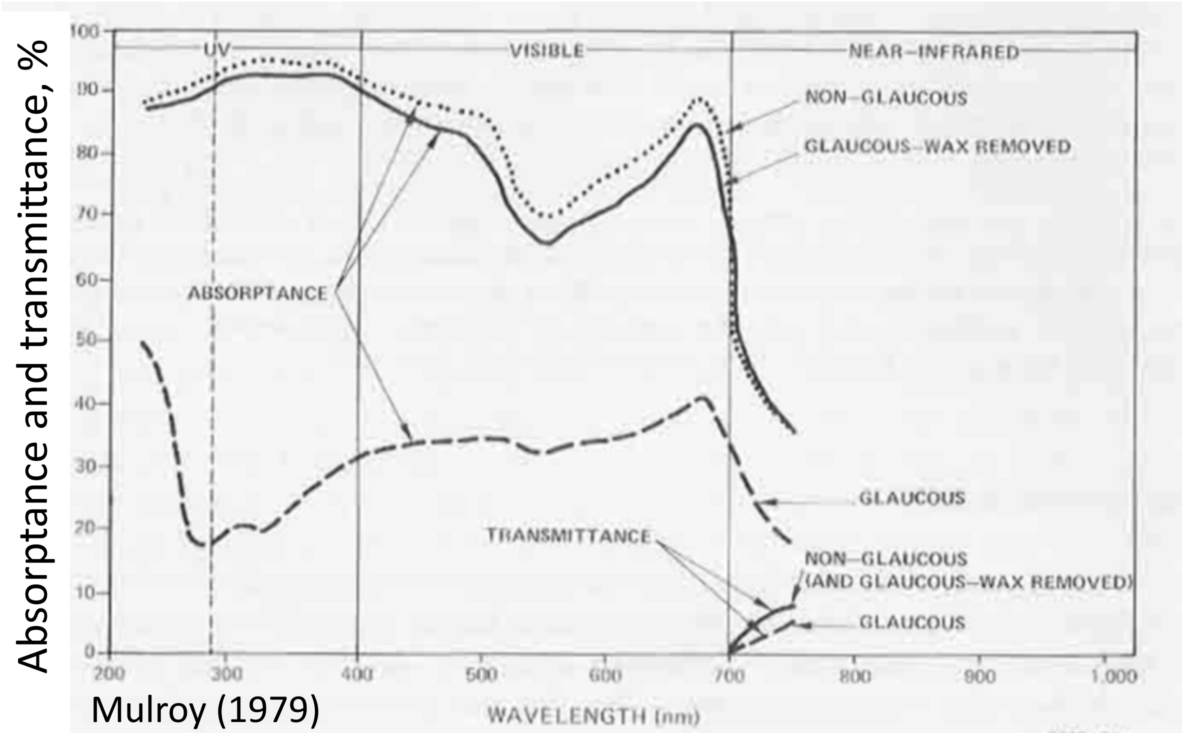
Changes in absorptance in *Encelia*, a genus of shrubs common to the western US



mutant *E. farinosa* drop their leaves as soon as soils dry out since they cannot change leaf absorptance



A waxy reflective surface is common among many CAM succulents in the Crasslulaceae, such as the *Dudleya* species shown here

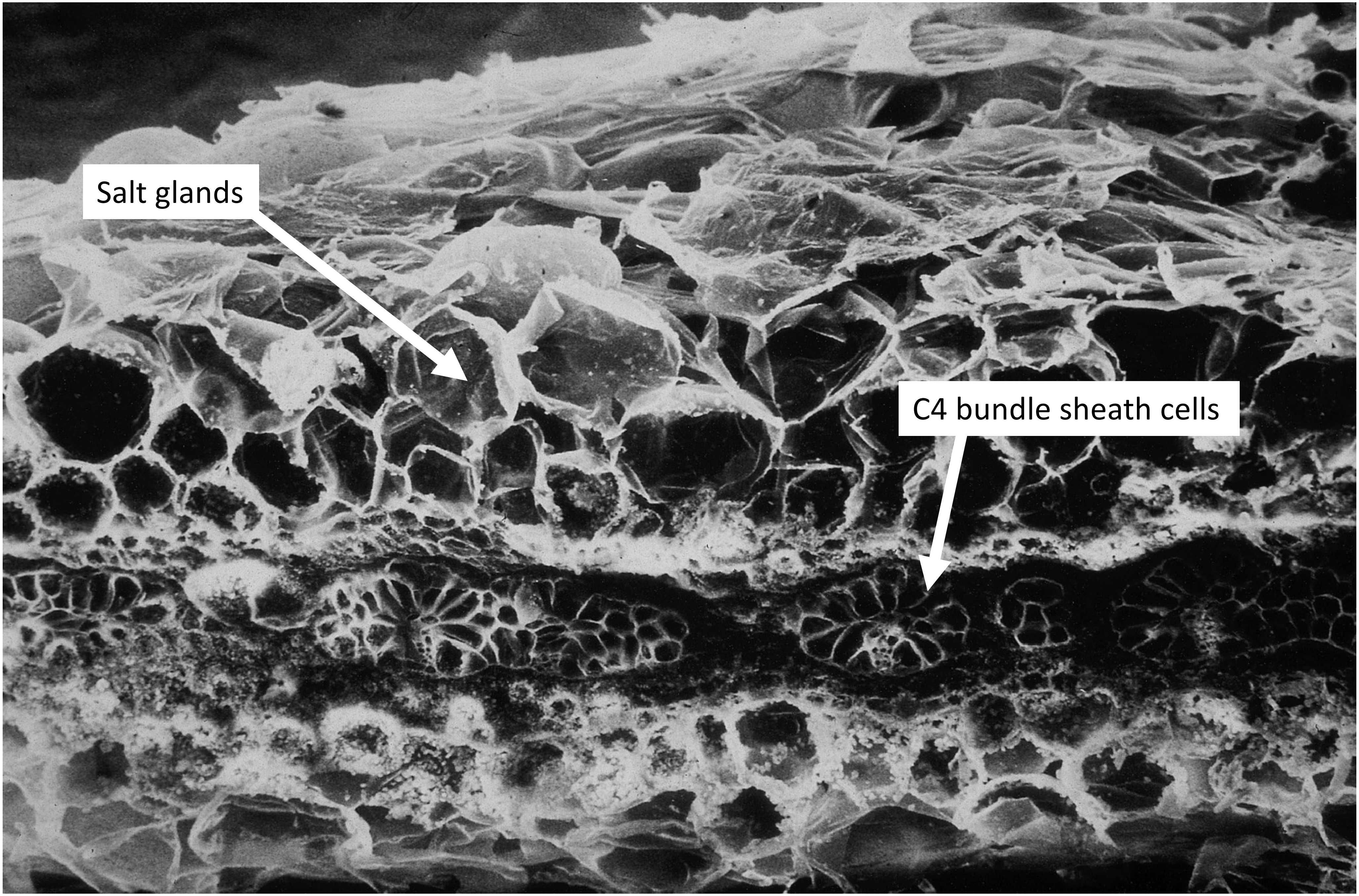


Mulroy (1979)

Dudleya brittonii, is a CAM succulent occurring in the coastal deserts of southern California and northern Baja California

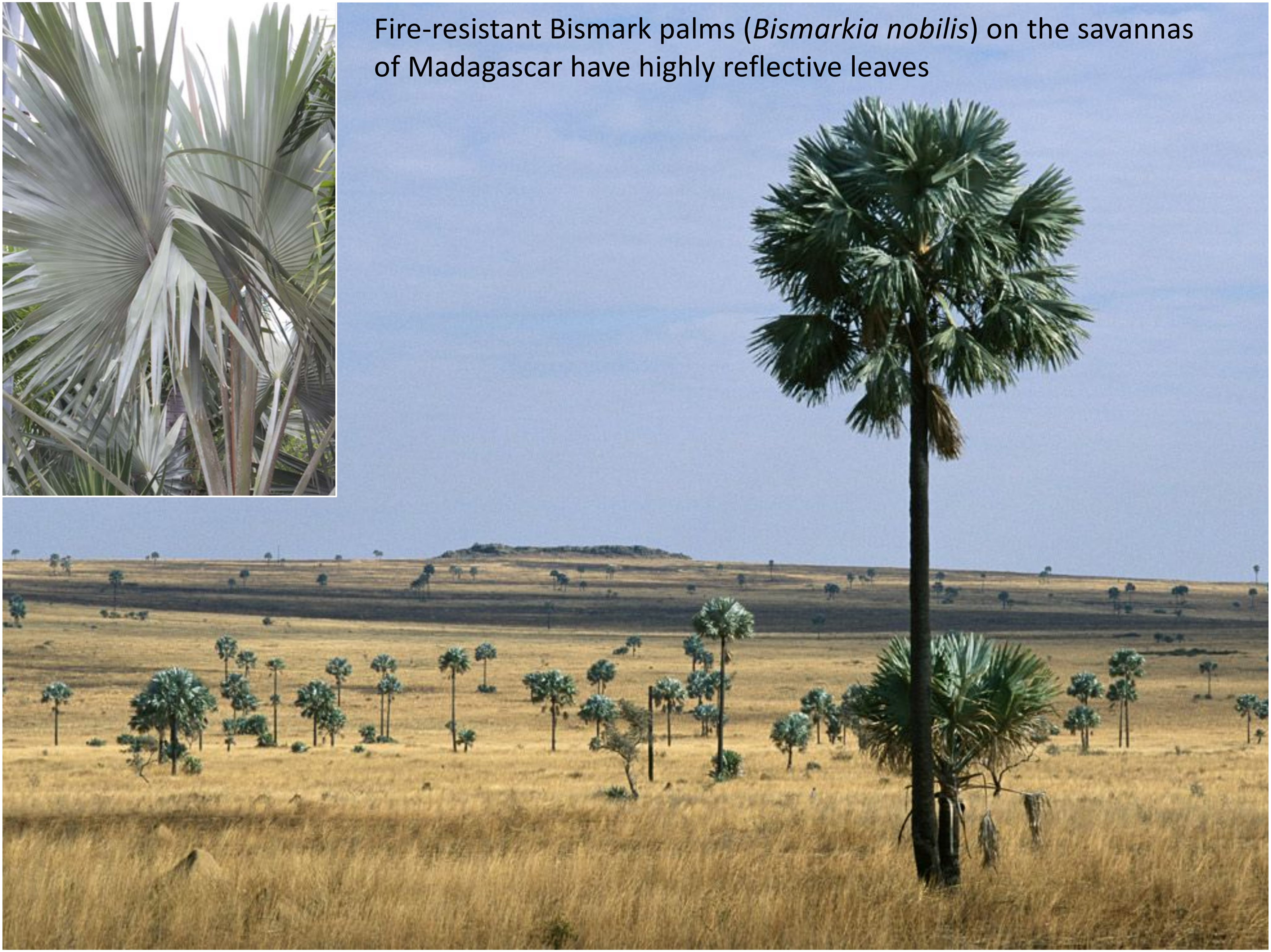
Atriplex hymenelytra has reflective leaves (salt glands)

Atriplex hymenelytra leaf cross section



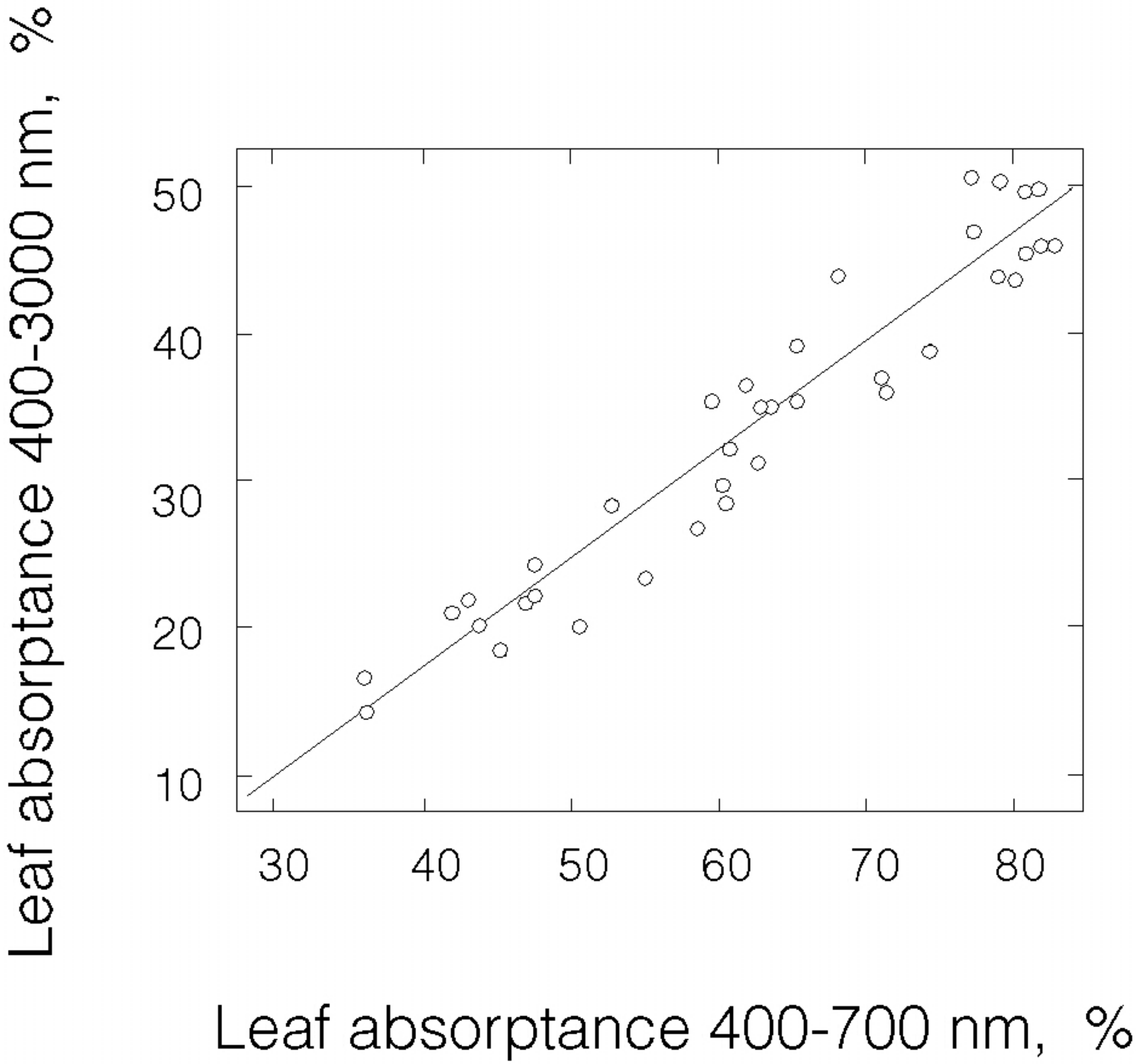
Predicted leaf temperatures for *Atriplex hymenelytra* leaves of different color and leaf angle during a mid-summer day with a leaf conductance of 0.02 mol m^{-2} s^{-1}

	Leaf temperature (°C)	Transpiration (mmol $m^{-2}s^{-1}$)
	50	1.9
wet salt bladders 	47	1.7
dry salt bladders 	43	1.4



Fire-resistant Bismark palms (*Bismarkia nobilis*) on the savannas of Madagascar have highly reflective leaves

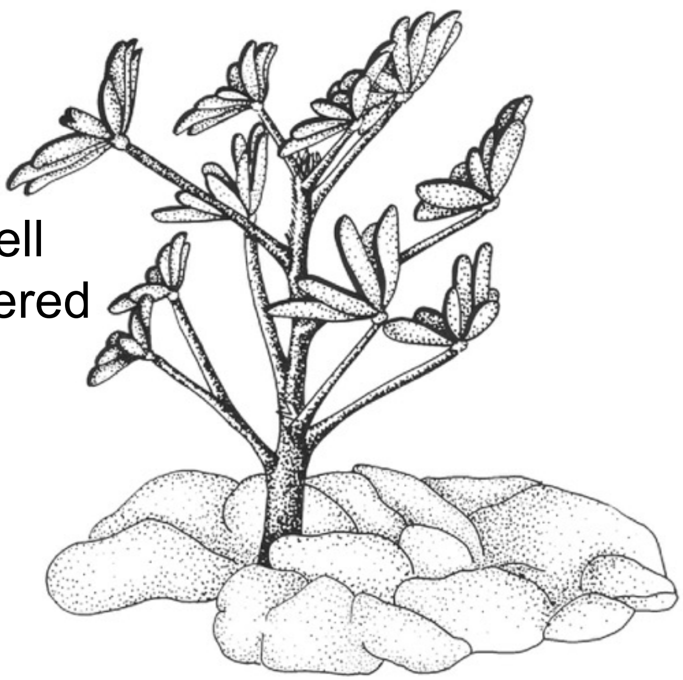
Absorptance of visible wavelengths is tightly correlated with absorptance over the entire solar spectrum



Part 4
Leaf movements

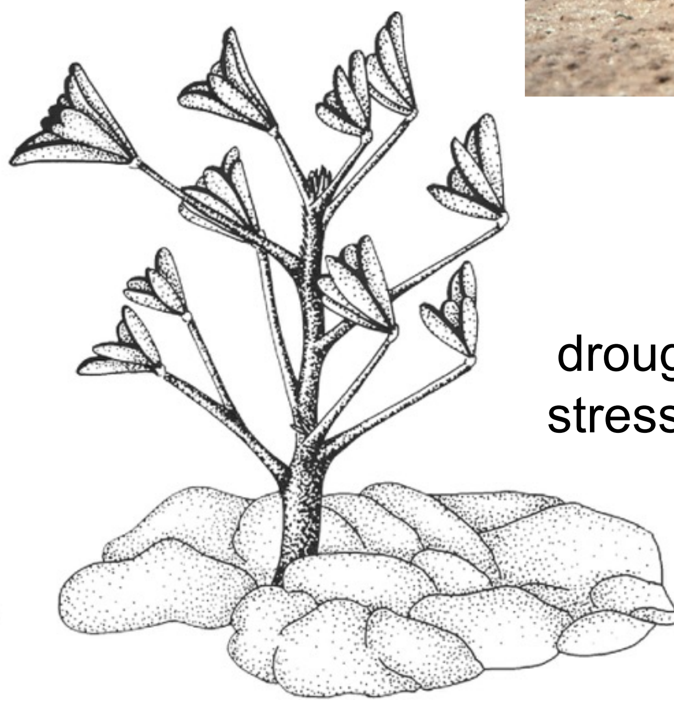
Lupinus arizonicus

Lupinus arizonicus,
C_3 annual of the Sonoran Desert



well watered

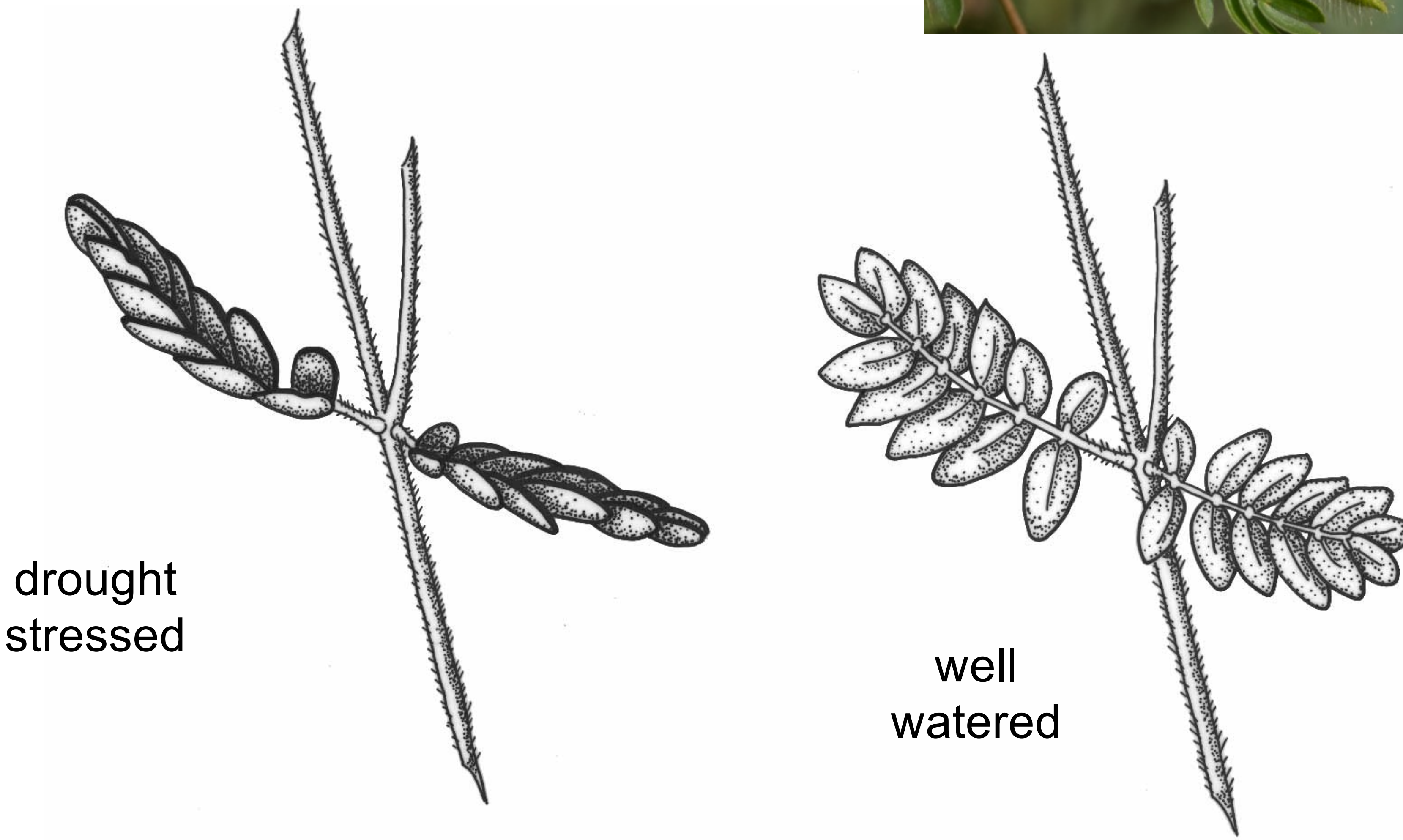
diaheliotropic



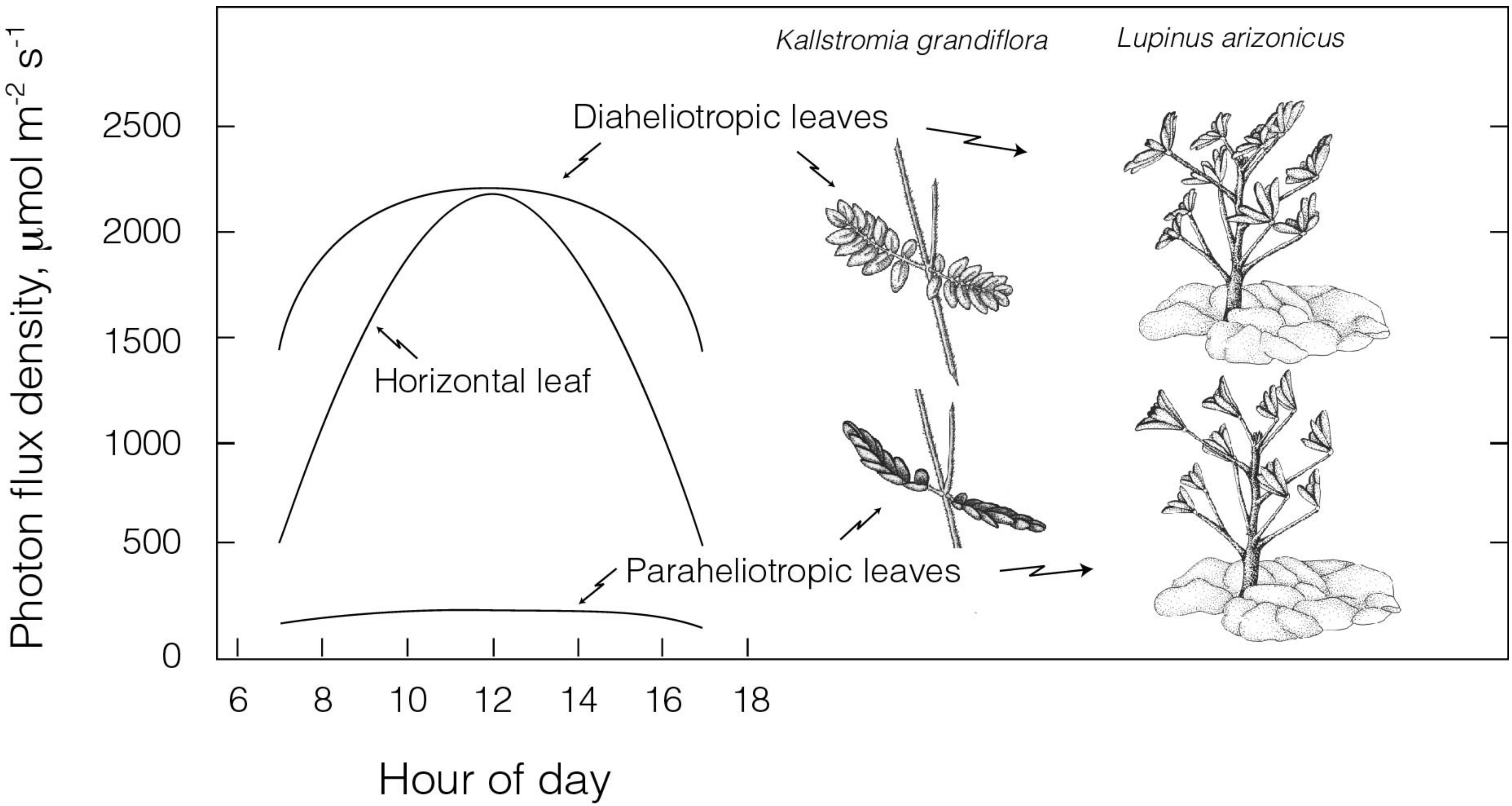
drought stressed

paraheliotropic

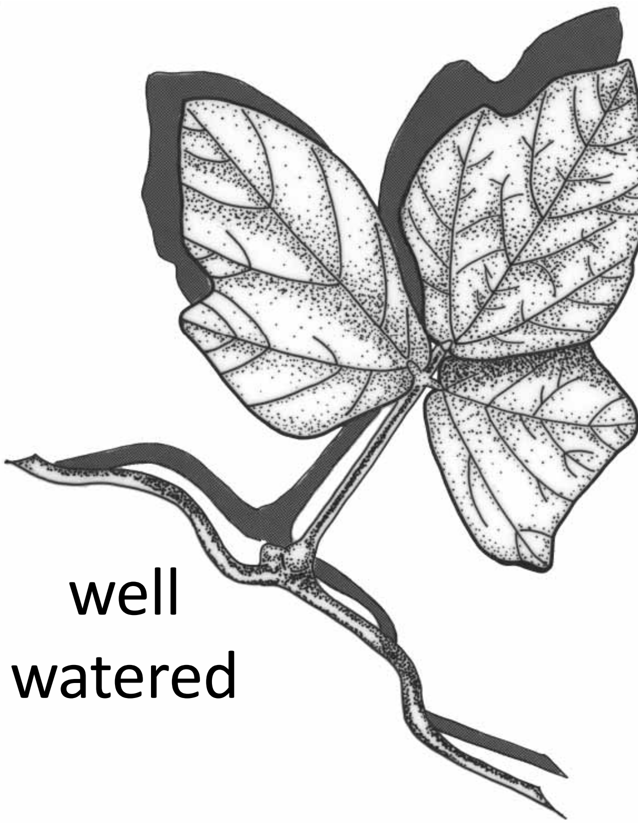
Kallstromia grandiflora,
C_4 annual in the Sonoran Desert



By controlling leaf orientation to the sun. photon fluxes are regulated



Macroptillium atropurpureum, a C_3 herb found in subtropical regions



well watered

drought stressed

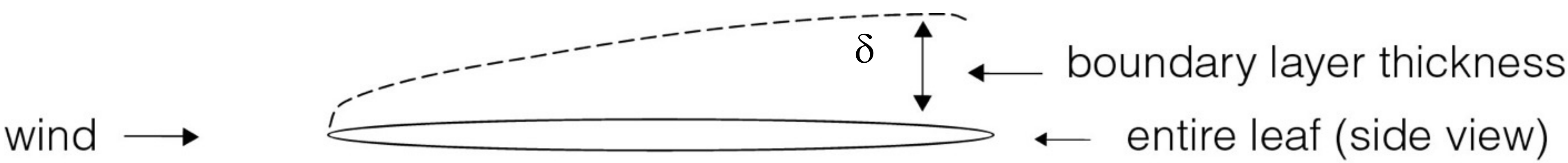
leaf solar tracking by
Amaranthus palmeri,
a C_4 summer annual
of the Sonoran Desert

Part 5
Convection

Leaf temperature is predictable when energy budget parameters are known

Parameters that plants can influence are known as leaf coupling factors.
Leaf convection parameters are coupling factors.

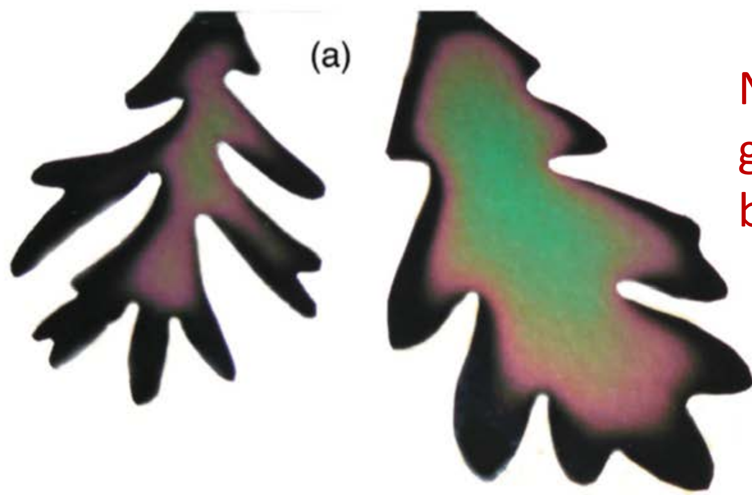
A boundary layer develops as air flows across a leaf



This boundary layer (d) retards the transfer of heat, CO_2, and H_2O from the leaf to the surrounding air

Leaf serrations tend to increase turbulence and disrupt the boundary layer

Fig. 2 (a) Horizontally held models of sun leaf and shade leaf made of liquid crystal sheet with a temperature range of 30°C (black) to 35°C (blue) (www.edmundscientific.com) glued to posterboard; the two models have been subjected to the same mild radiant heating from above with negligible air flow at an ambient temperature of 21°C. (b) Rectangles of the same liquid crystal sheet on copper plate (above) and posterboard (below); note the greater temperature uniformity of copper.



Note temperature gradients related to boundary layer height

The convection coefficient (h_c) and boundary layer resistance (r_a) depend on

- wind speed (u)
- leaf width (d)
- leaf shape constant (k)

$$h_c = c_p\rho / r_a$$

$$r_a = k \bullet (d/u)^{0.5}$$

r_a = boundary layer
c_p = heat capacity
ρ = density of air

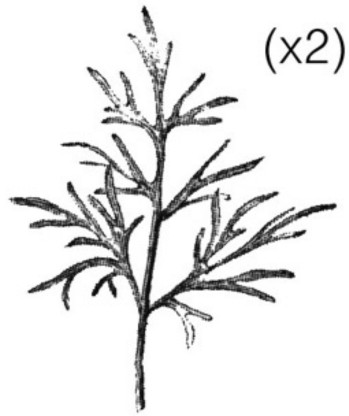
$$h_c = c_p\rho\, k^{-1}(u/d)^{0.5}$$

The thickness of the boundary layer (δ) over a leaf in mm can be described as

$$\delta = 4(d/u)^{0.5}$$

d is the mean leaf length (m)
u is the wind speed (m s^{-1})

Leaf lobing and compound leaves are quite common in plants of arid regions

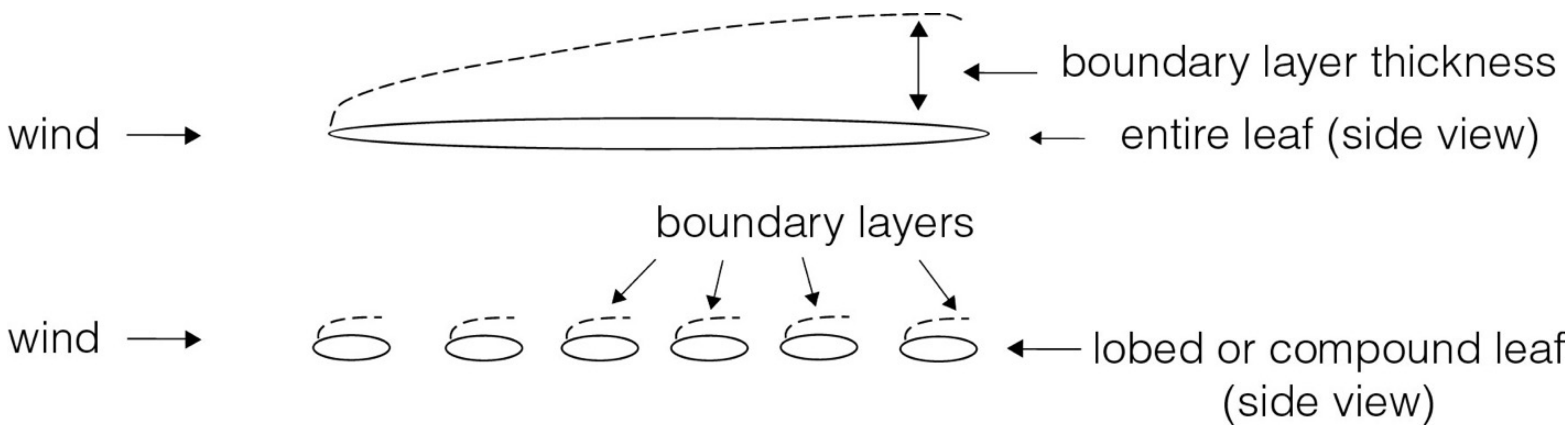


(x2)

(x2)

lobing is usually more deeply developed in sun leaves than in shade leaves

Leaf lobing interrupts the developing boundary layer

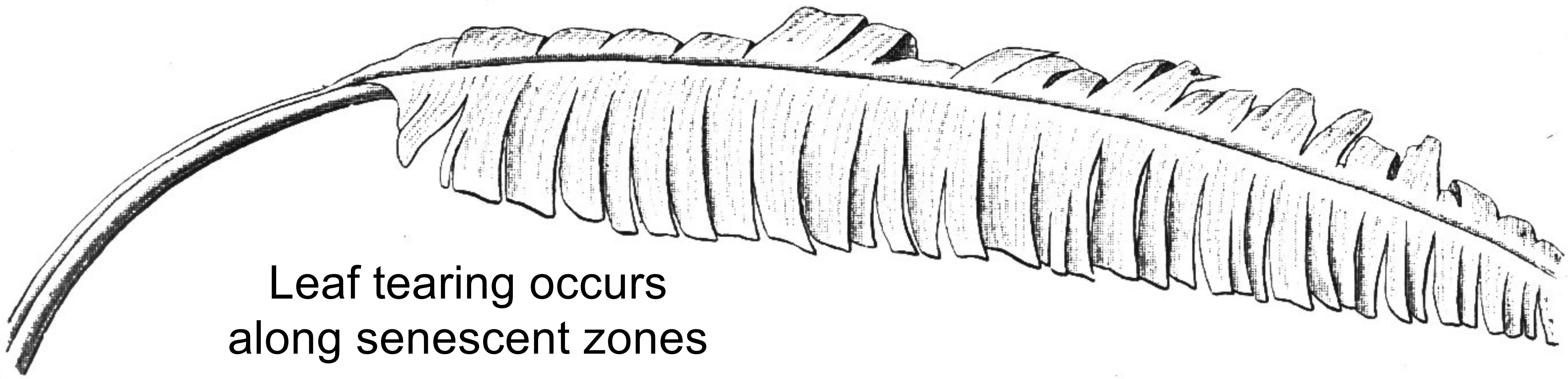


Philodendron species live in both sun and shade habitats. Large-leaved species in the sun tend to have dissected leaves, reducing the boundary layer.

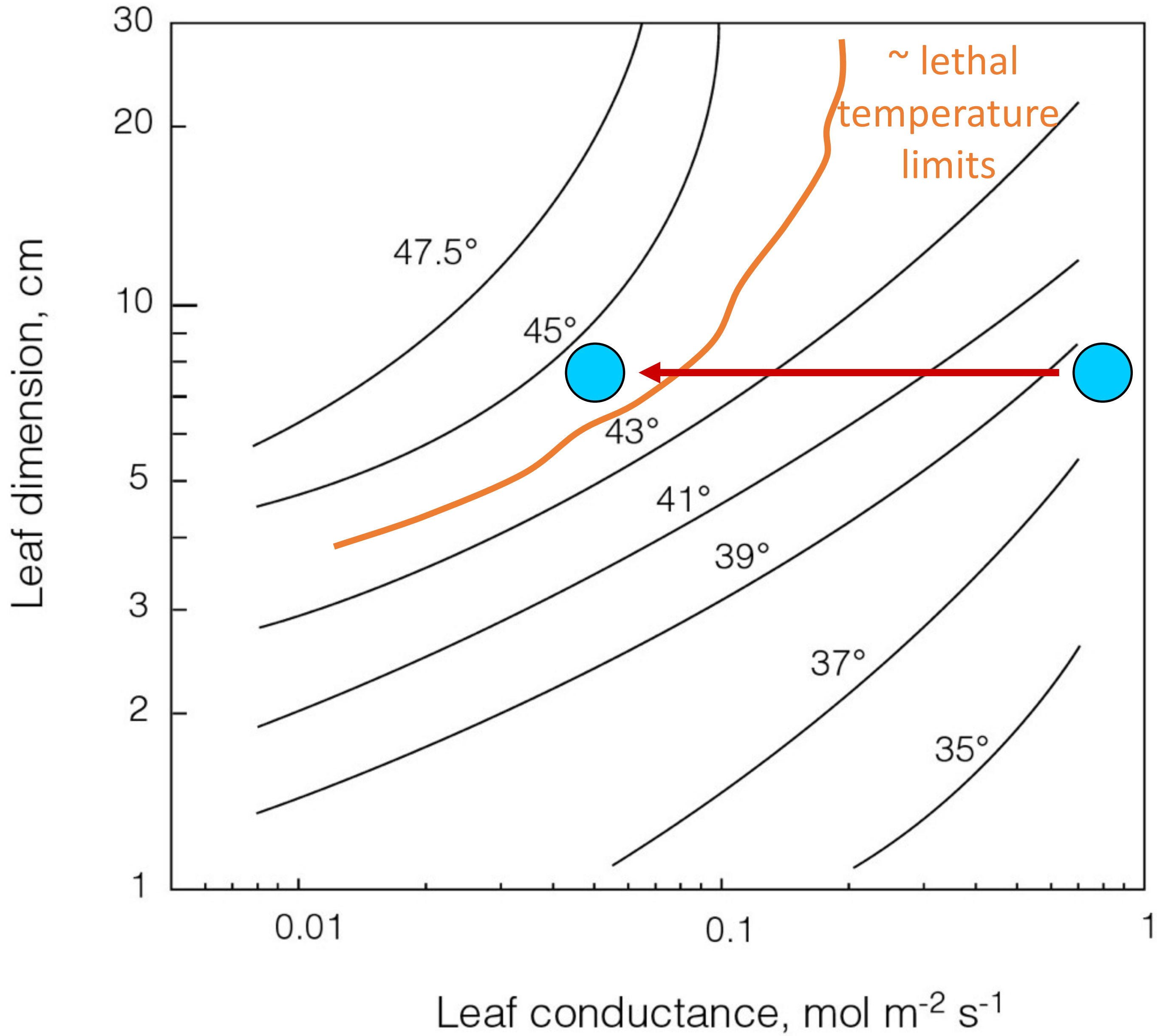
How to effectively reduce leaf size in order to increase leaf-to-air coupling?

Consider the challenges of avoiding high leaf temperatures in a banana leaf exposed to water stress

Banana leaves tear during water stress periods throughout the dry season



Banana leaf temperatures depend on both how large the leaf is and how wide open the stomata are



… if the stomata closed and leaf size remained large

Leaf coupling factors

- leaf orientation
- leaf absorptance
- transpiration
- leaf size
- leaf shape

Colorado blue spruce on campus