I. Transpiration and its Physiological Significance and Transpiration Area

(I) Definition

The transpiration refers to the water dissipation from the inside of the plant to outside via the surface of the plant in the form of gas.

(II) Transpiration Area

1. Lenticular transpiration: the transpiration from the lenticel on the stem and twig.
2. Leaf transpiration: the main method (accounting for 99.9%).

①. Cuticular transpiration: the transpiration from the cuticle of the leaf (with pectin substance and pores), accounting for 5%~10%;

②. Stomatal transpiration: the transpiration from the stomata, the mean method (accounting for 90%~95%);

(III) Physiological significance

1. The main impetus for plant absorption and water transport;
2. It facilitates the absorption and transport of mineral matter and inorganic matter;
3. It reduces the temperature of leaf blade.

II. Stomatal Transpiration

(I) Stomatal movement

The stomatal movement is caused due to different thickness of cell wall of stomatal guard cell, in addition to the connection between the fibril of cellulose and cell wall.

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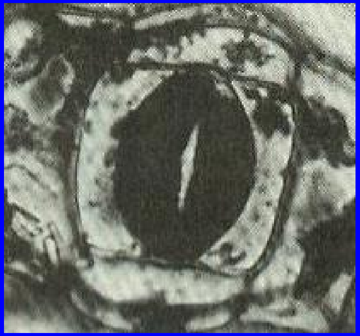
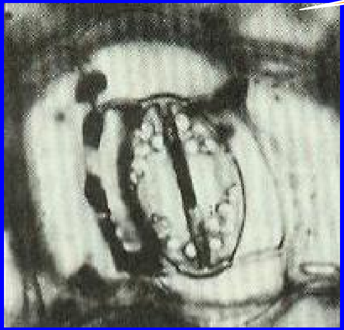
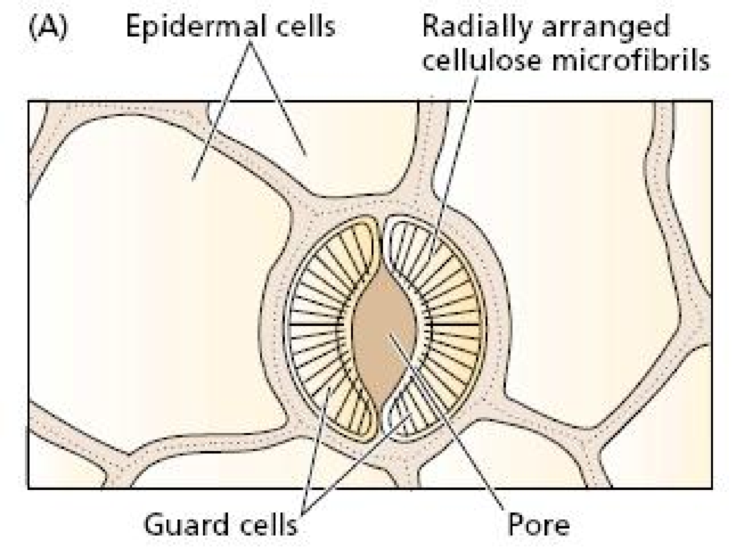
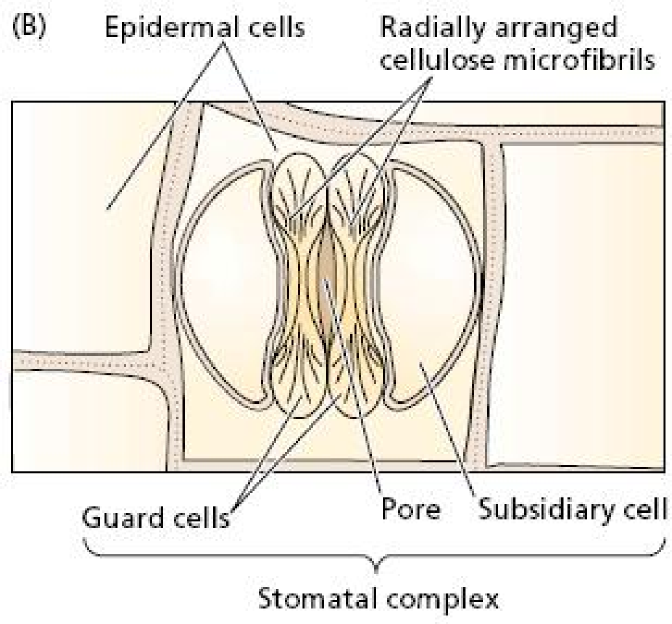
Reniform guard cell

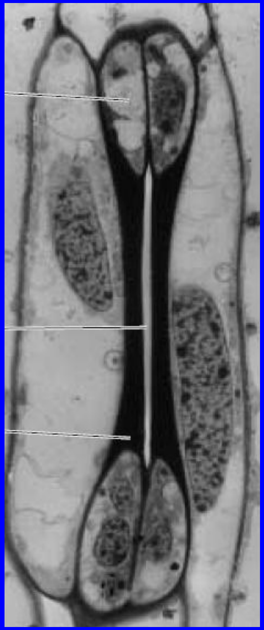




Dumbbell form guard cell







(II) Movement mechanism

1. Sucrose

Photosynthesis of chloroplast in stomatal guard cell under sunlight →CO_2↓ →pH↑→ Activity of amylophosphorylase ↑→ Transformation of starch to G-1-P→ Sucrose → Water potential ↓→ Entrance of water from subsidiary cell and peripheral epidermal cell to stomatal guard cell → Opening of stoma (Opens in daylight and closes at night)

2. K^+ absorption theory

There is photoactivated H^+ pump ATP enzyme on the cytomembrane of stomatal guard cell→The enzyme decomposes ATP→Extracellular secretion of H^+ to stomatal guard cell →Cytomembrane hyperpolarization →Absorption of extracellular K^+→$[K^+]_{intracellular}$↑→$[Cl^-]_{extracellular}$↑→Water potential↓→The water enters the guard cell→The stoma opens

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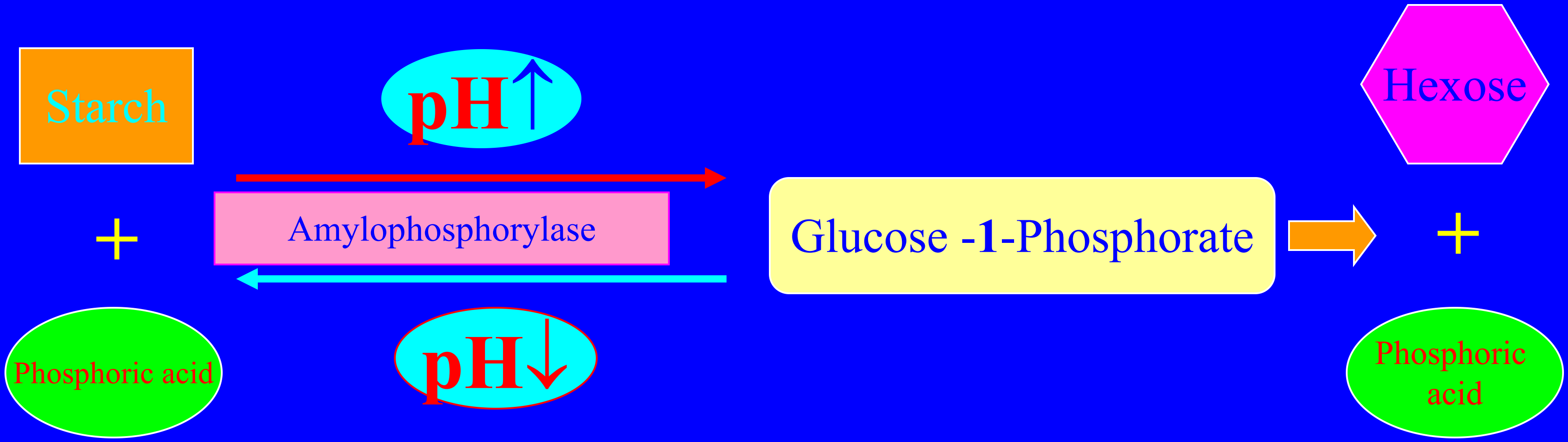


Starch

+

Phosphoric acid

pH↑

Amylophosphorylase

pH↓

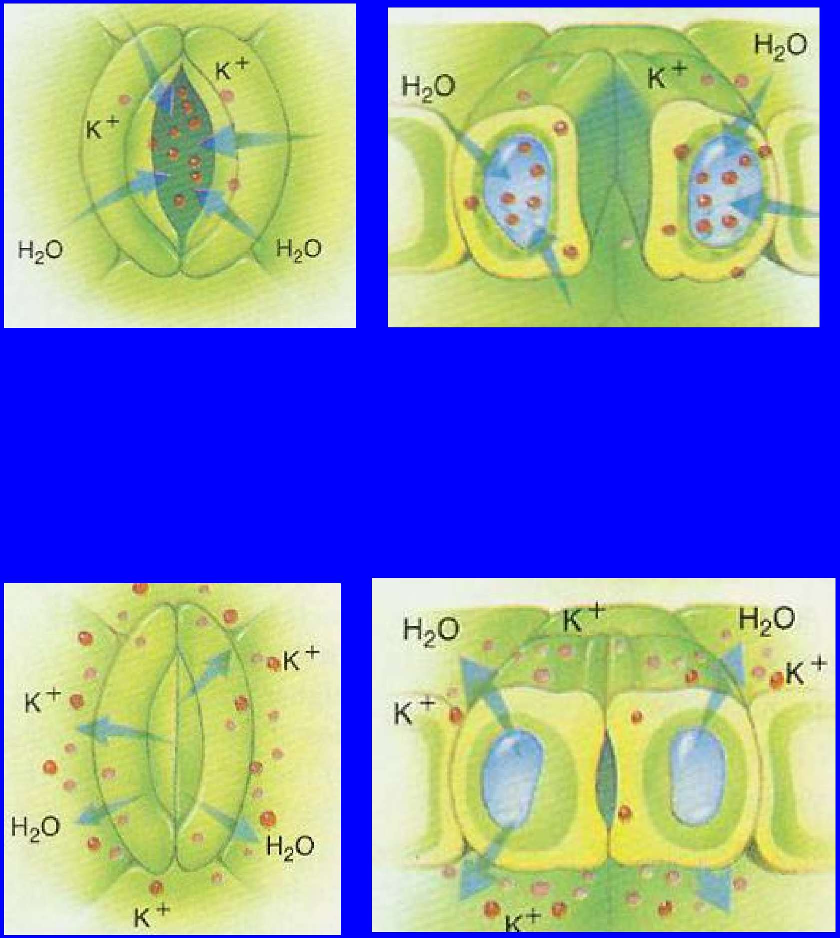
Glucose -1-Phosphorate

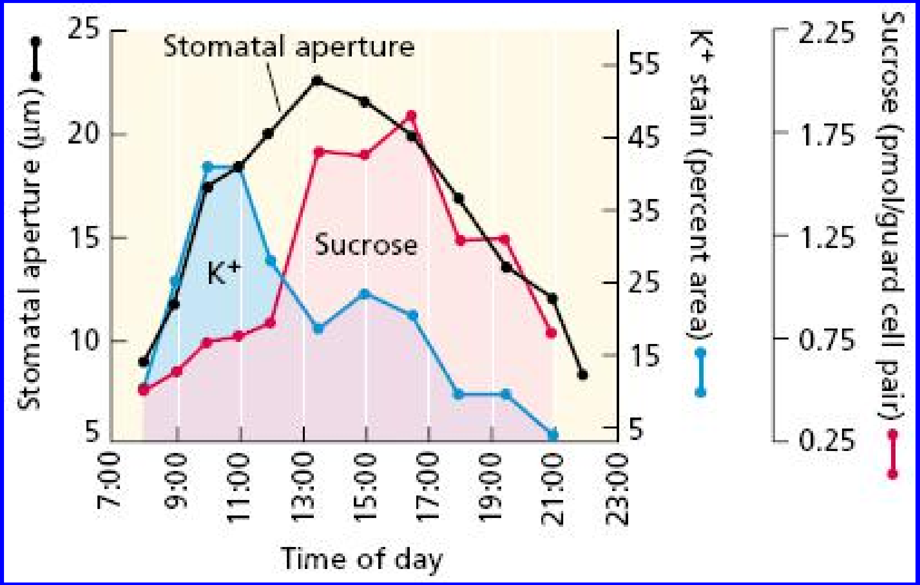
Hexose

+

Phosphoric acid

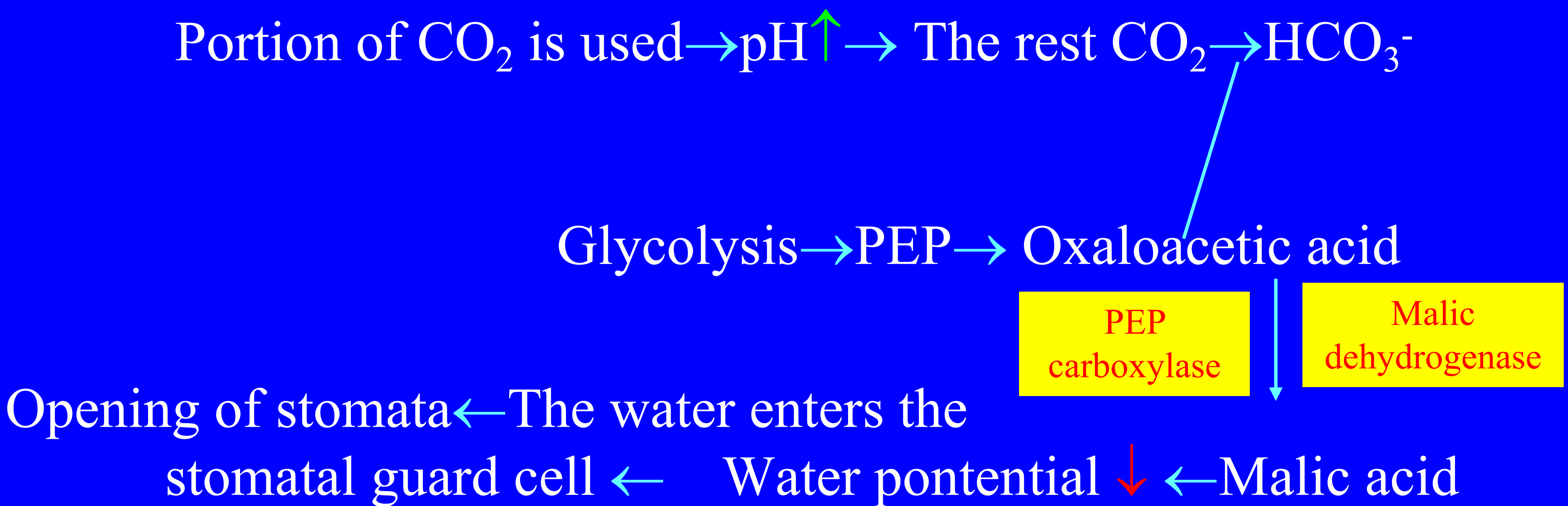
Chapter V Water Metabolism - Transpiration





Daily course of changes in stomatal aperture, and in potassium and sucrose content, of guard cells from intact leaves of broad bean (*Vicia faba*). (Talbott & Zeiger 1998)

3. Malic acid generation theory



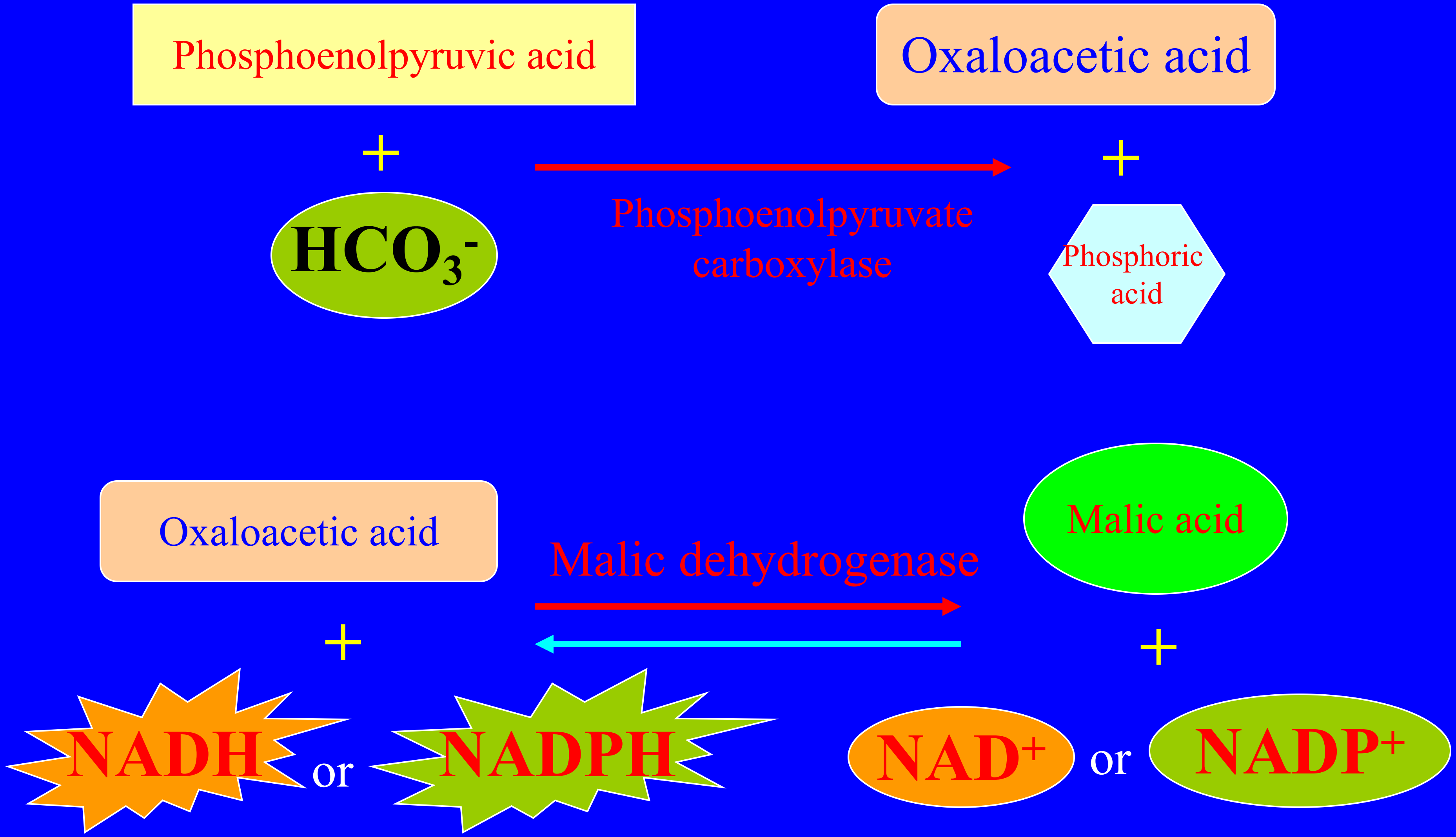
Portion of CO_2 is used→pH↑→ The rest CO_2→HCO_3^-

Glycolysis→PEP→ Oxaloacetic acid

PEP carboxylase

Malic dehydrogenase

Opening of stomata←The water enters the stomatal guard cell ← Water pontential ↓ ←Malic acid



Phosphoenolpyruvic acid

+

HCO_3^-

Phosphoenolpyruvate carboxylase

Oxaloacetic acid

+

Phosphoric acid

Oxaloacetic acid

+

NADH or NADPH

Malic dehydrogenase

Malic acid

+

NAD^+ or $NADP^+$

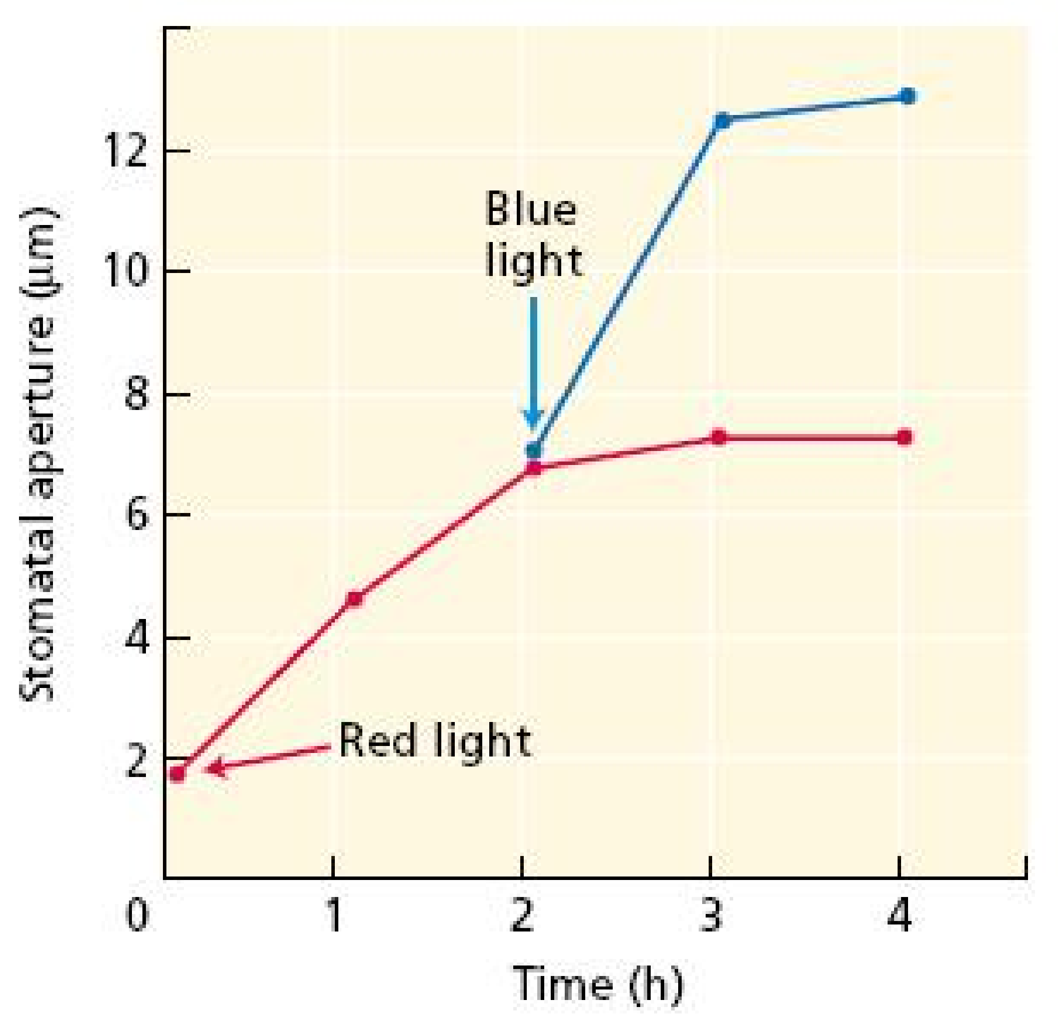
(III) Factors affecting stomatal movement

1. Sunlight: main influential factor that promotes the formation of sugar and malic acid and accumulation of K^+ and Cl^-; the stoma generally closes at the light intensity lower than light compensation point.

   Red light→Photosynthesis↑→Starch↑→Soluble sugar↑→Water potential of guard cell↓→Opening of stomata

   Blue light→Activation of H^+-ATP enzyme on the cytomembrane of stomatal guard cell→Release of H^+ to outside of cytomembrane→Potential of the internal side of membrane↓→Ion absorption, etc→ Opening of stomata.
2. Temperature: the degree of stomatal opening generally increases with the rise of temperature, reaching maximum at 30°C and decreasing after 35 °C, and the opening of stoma is not large at low temperature.
3. CO_2: low concentration promotes the opening of the stoma regardless of the presence of light.
4. Abscisic acid: ABA→Cytoplasmic Ca^{2+} and pH↑→Activity of outlet K^+ and Cl^- channel↑→$[K^+]$ and $[Cl^-]$ of stomatal guard cell↓→Water potential↑→ Close

The response of stoma to blue light under a red-light background. stoma from detached epidermis of *Commelina communis* (common dayflower) were treated with saturating photon fluxes of red light (red trace). (Schwartz & Zeiger 1984)



III. Internal and External Conditions Affecting Transpiration

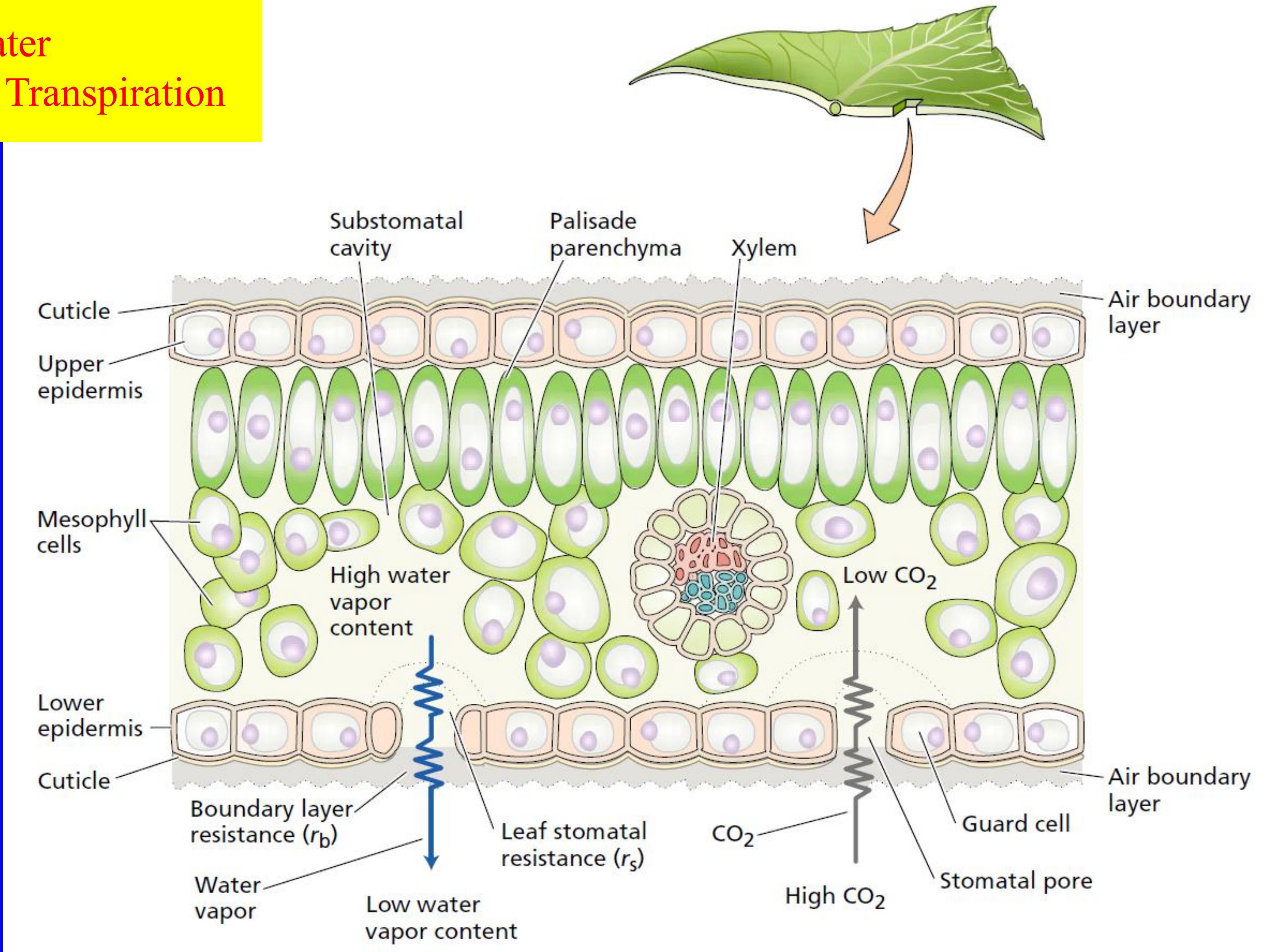
I. Process of stomatal transpiration and diffusion:

The cell wall of mesophyll cell in substomatic cavity becomes wet→The water turns into vapor→ Substomatic cavity →Stomata→The diffusion layer on leaf surface→ The air

II. Transpiration speed:

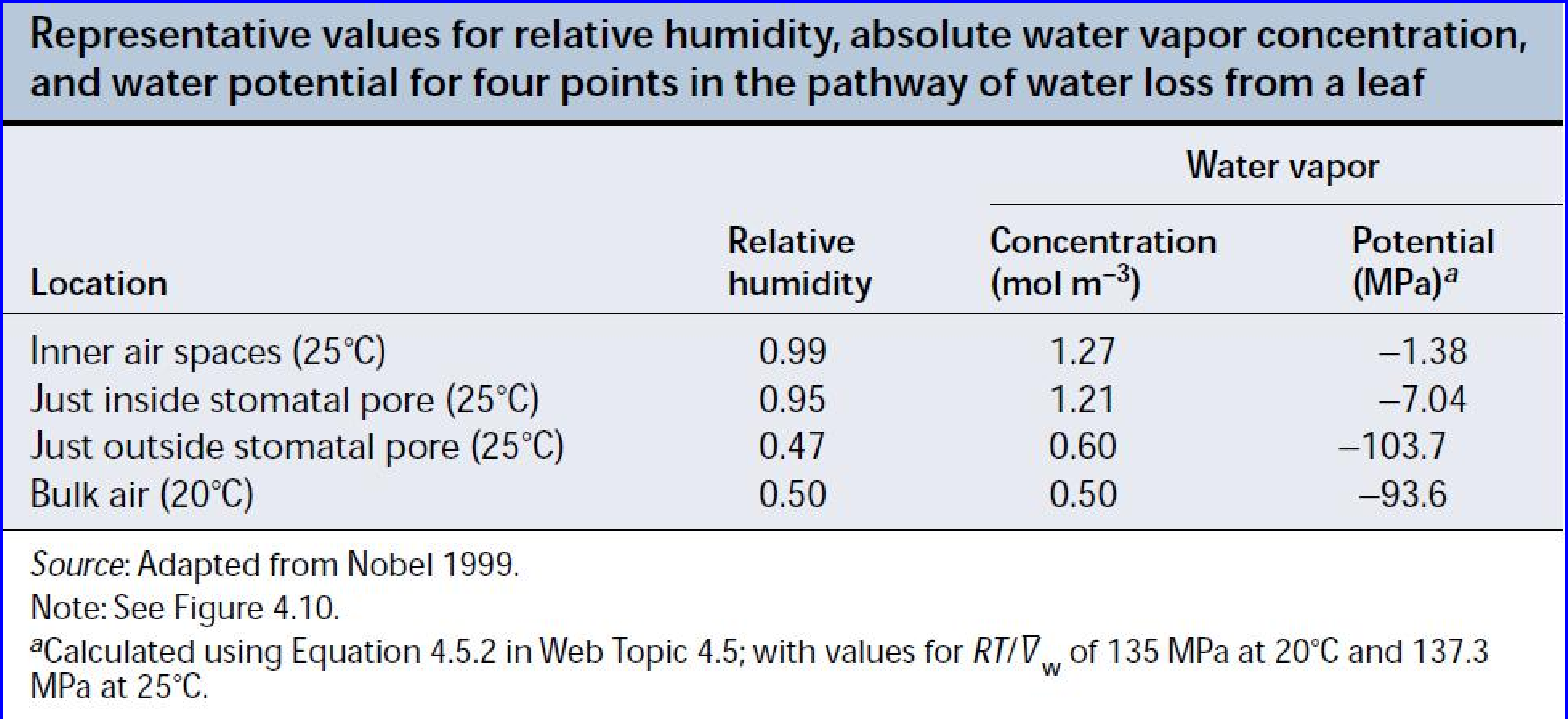
$$= \frac{\text{Diffusion}}{\text{Resistance from diffusion process}} = \frac{\text{Vapor pressure in substomatic cavity-vapor pressure outside the leaf}}{\text{Stomatal resistance +Resistance from diffusion layer}}$$

Chapter V Water Metabolism - Transpiration



Water pathway through the leaf. Water is pulled from the xylem into the cell walls of the mesophyll, where it evaporates into the air spaces within the leaf. Water vapor then diffuses through the leaf air space, through the stomatal pore, and across the boundary layer of still air found next to the leaf surface. CO_2 diffuses in the opposite direction along its concentration gradient (low inside, higher outside).

Chapter V Water Metabolism - Transpiration



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

		Water vapor	
Location	Relative humidity	Concentration (mol m^{-3})	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.

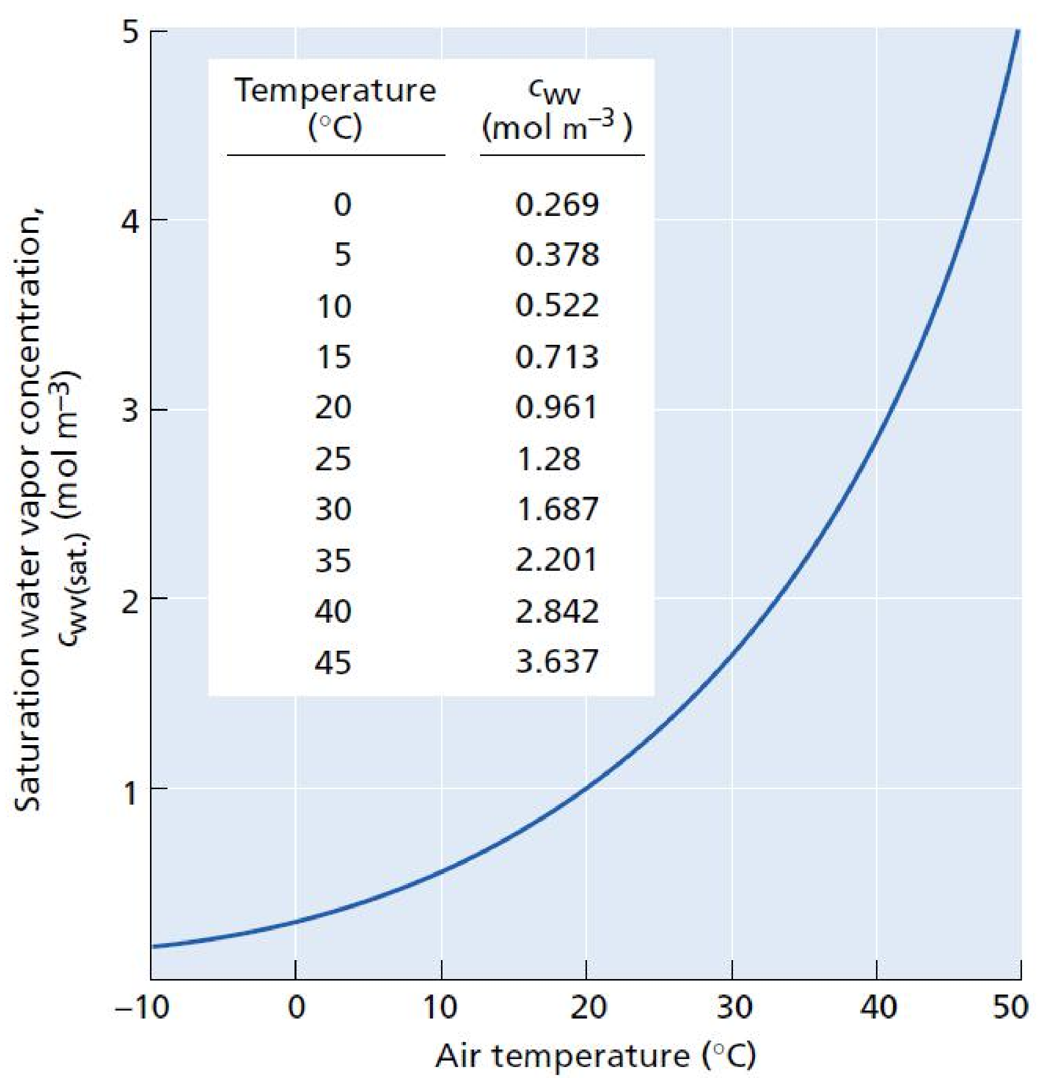
[a] Calculated using Equation 4.5.2 in Web Topic 4.5; with values for $RT/\bar{V}_w$ of 135 MPa at 20°C and 137.3 MPa at 25°C.

(III) Effects of external conditions on transpiration

1. Lighting: Light→ Air temperature and leaf temperature↑→ But leaf temperature > Air temperature→The difference of vapor pressure between inside and outside of the leaf↑→Transpiration↑; → Stomata↑→Internal resistance↓→Transpiration↑.
2. Air relative humidity: ↑→Vapor pressure of the air↑→The difference of the vapor pressure between inside and outside of the leaf↓→Transpiration↓.
3. Temperature: Temperature ↑→The increase of the vapor pressure in substomatic cavity > The increase of vapor pressure of the air→ The difference of the vapor pressure between inside and outside of the leaf ↑→Transpiration↑.
4. Wind: The breeze promotes the transpiration; the strong wind →The stoma closes→Transpiration↓.
5. Change between daylight and night: in a fine weather,

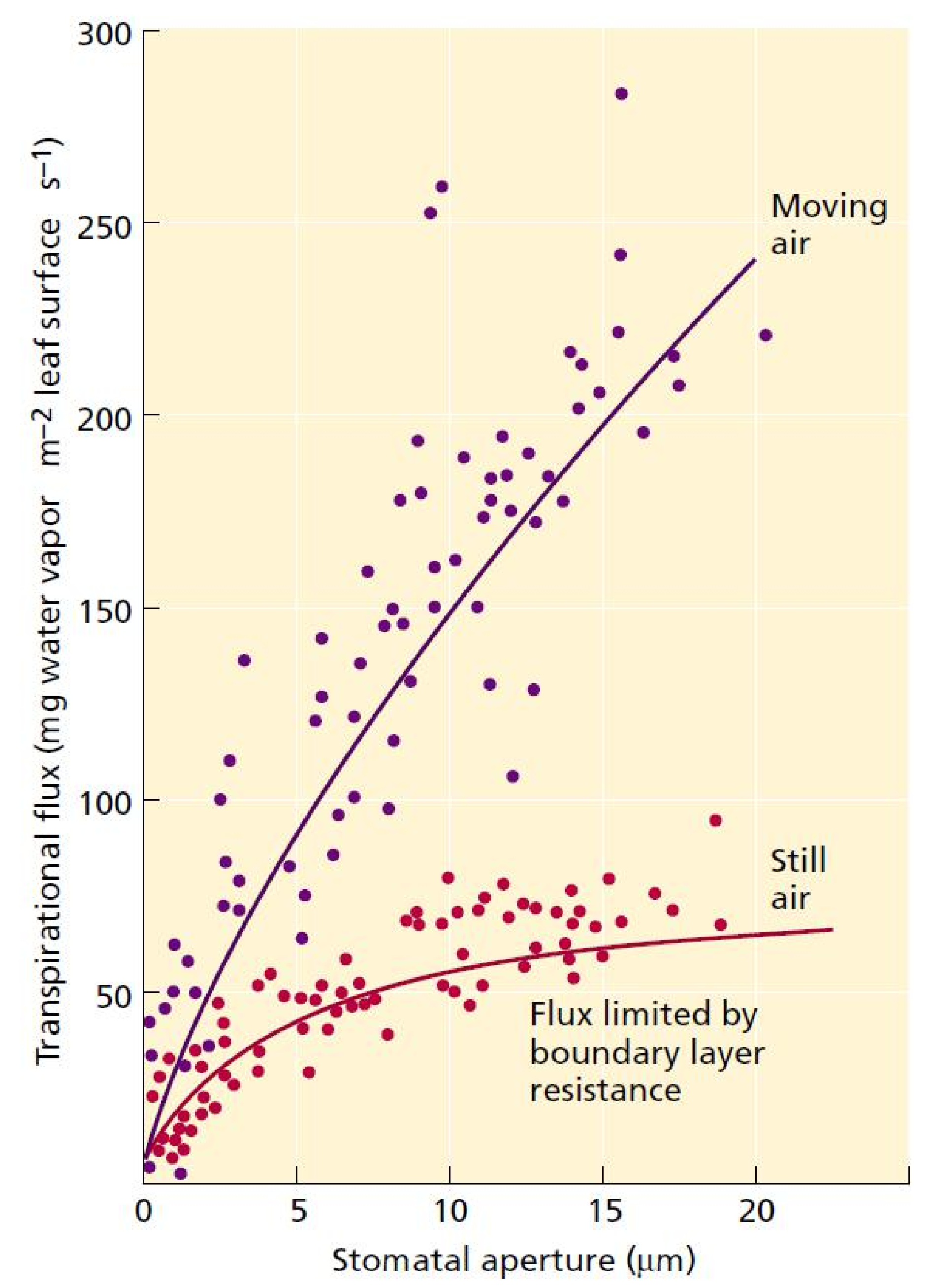
The sun rises ——→ The stoma opens ——→ Transpiration↑.
└→The temperature rises→The inside-outside vapor pressure↑ ┘

Concentration of water vapor in saturated air as a function of air temperature.



Temperature (°C)	c_{wv} (mol m^{-3})
0	0.269
5	0.378
10	0.522
15	0.713
20	0.961
25	1.28
30	1.687
35	2.201
40	2.842
45	3.637

Dependence of transpiration flux on the stomatal aperture of zebra plant (*Zebrina pendula*) in still air and in moving air.



(IV) Effects of internal factors on transpiration

1. The stoma opens frequently and in large degree→The internal resistance↓→Transpiration↑;
2. The volume of substomatic cavity↑→The wall area of wet cell↑→The vapor is supplemented continuously→Relative humidity inside the cavity↑→Inside-outside humidity difference↑→ Transpiration↑;
3. Internal area of leaf blade (area of intracellular space) ↑→ Water evaporation area ↑→Inside-outside difference↑→ Transpiration↑.

(IV) The approach to reduce transpiration speed

1. Promoting robust root growth to increase water absorption capability;
2. Reducing transpiration to avoid withering due to over transpiration and under water supply;
3. Specific method: Protecting young root and removing some branches and leaves as appropriate; selecting proper time for transplant.

(VI) Indexes of transpiration

1. Transpiration speed: the water amount evaporated from unit area of leaf surface in certain period of time ($g/m^2/h$).
2. Transpiration ratio: the ratio of the amount (mol) of H_2O lost in plant transpiration against that of CO_2 assimilated in photosynthesis.
3. Water utilization rate: the mole number of CO_2 assimilated per mole of H_2O lost in plant transpiration.

I. Water Transport Route

1. Entire route: the water enters the apical epidermal cells from soil solution→ Cortical parenchyma cells→Vessel and tracheid→Transport upward to the xylem of stem and leaf→Mesophyll cell in substomatic cavity →Stomata→Evaporate to the air
2. Two routes

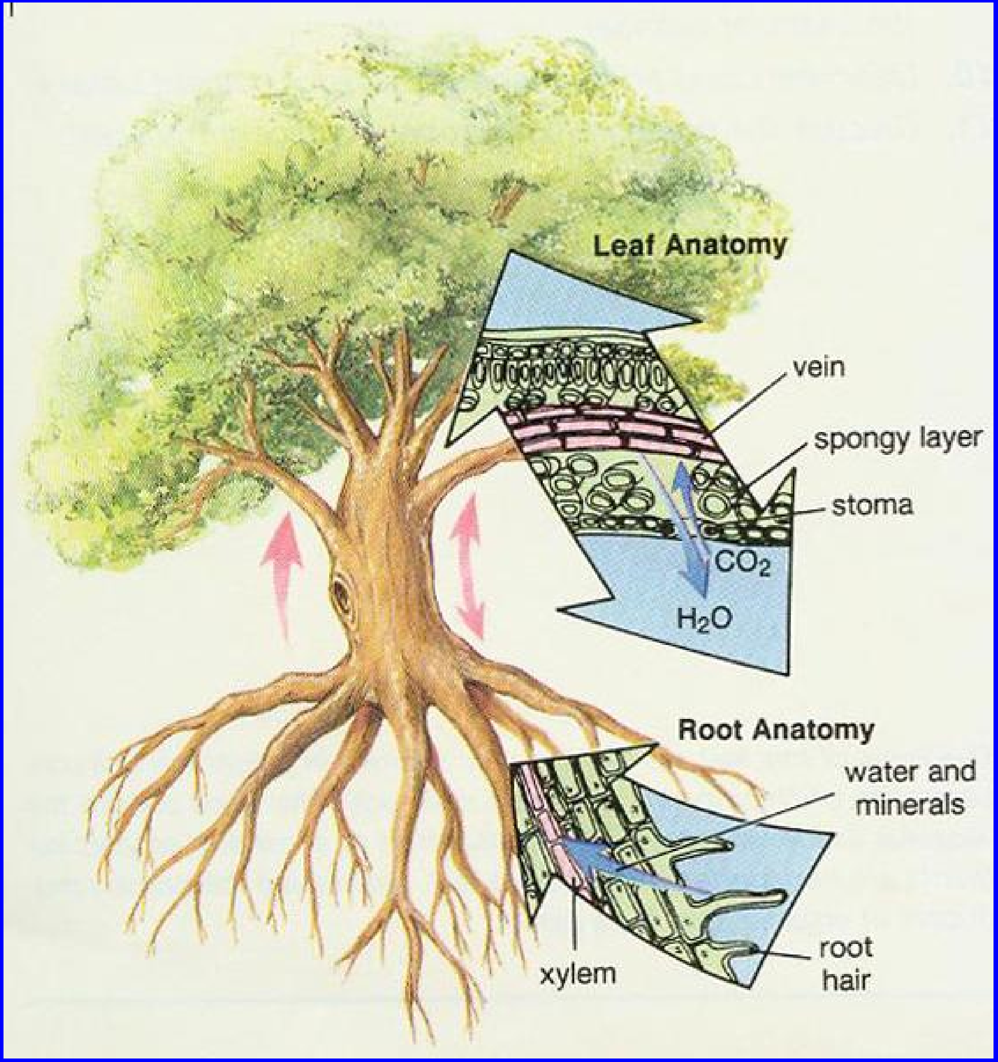
① Through dead cells: elongated dead cells of vessel and tracheid, with little resistance, suited for long-distance transport;

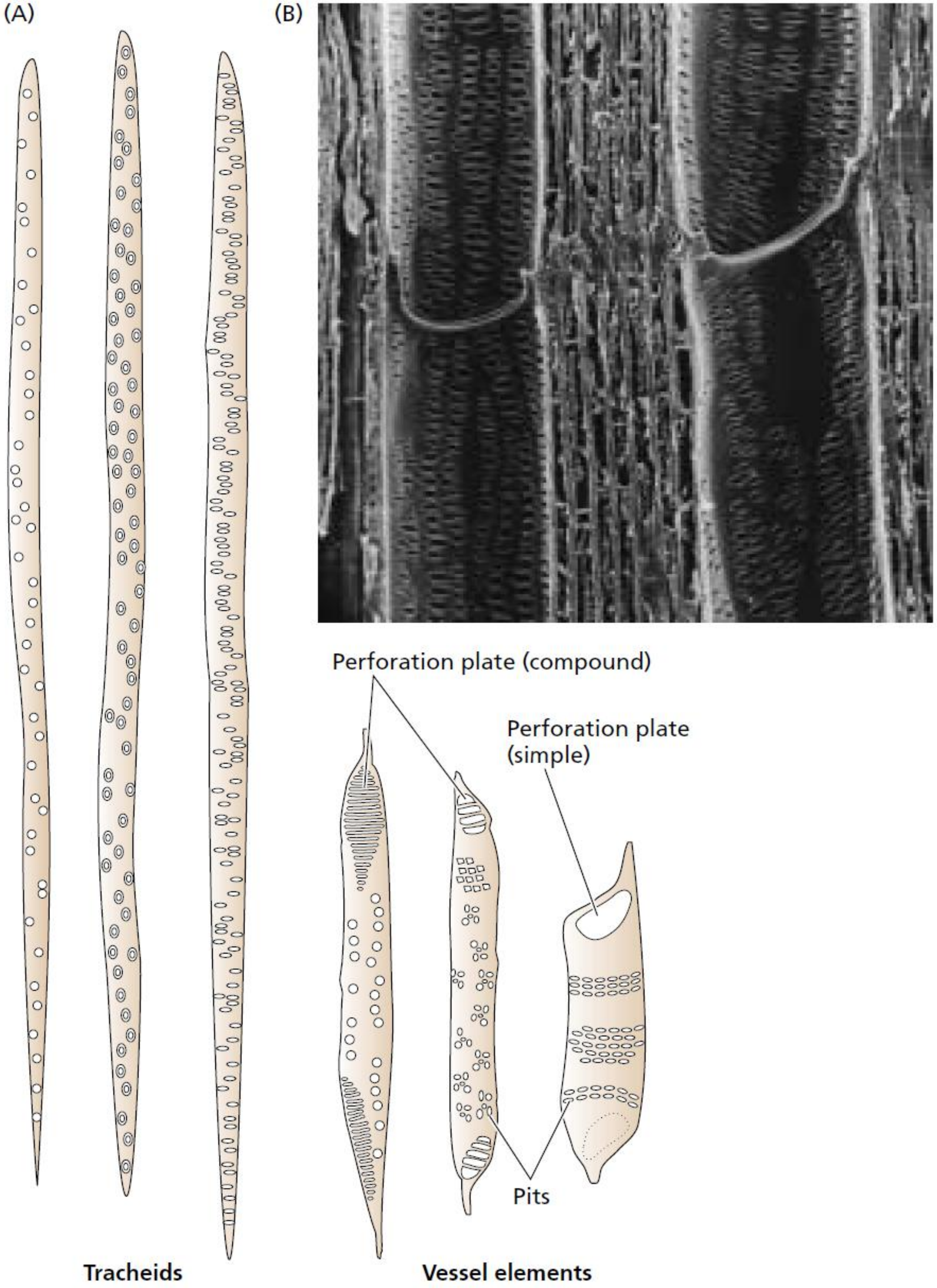
② Through living cells: from leaf vein to mesophyll cells near substomatic cavity, and transport by means of penetration, with large resistance, unsuited for long-distance transport.

II. Water Transport Speed

The water transport speed is subject to the influence of transfusion tissue and environment conditions, and the speed of water flow through the protoplasm is merely 10^{-3} cm/h, and that through xylem is 3-45 cm/h.

Leaves and roots are regions of a flowering plant body that are specialized to interact with environment. The roots take up water and minerals. The leaves carry on gas exchange, but at the same time they lose water to the environment.





Tracheary elements and their interconnections. (A) Structural comparison of tracheids and vessel elements, two classes of tracheary elements involved in xylem water transport. (B) Scanning electron micrograph of oak wood showing two vessel elements that make up a portion of a vessel.

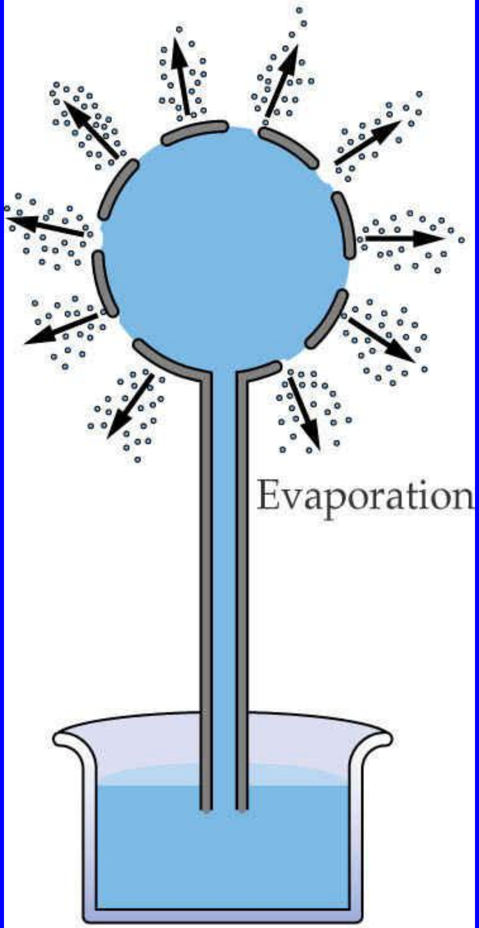
III. The impetus for water to rise in vessel and tracheid

1. Impetus for water to rise

① Root pressure: generally not higher than 0.2 MPa, which enables the water to rise by 20.4 m

② Pulling force from transpiration: main impetus

A working model of the cohension-tension mechanism of water movement in the xylem, represented as a porous ceramic cup atop a capillary tube.



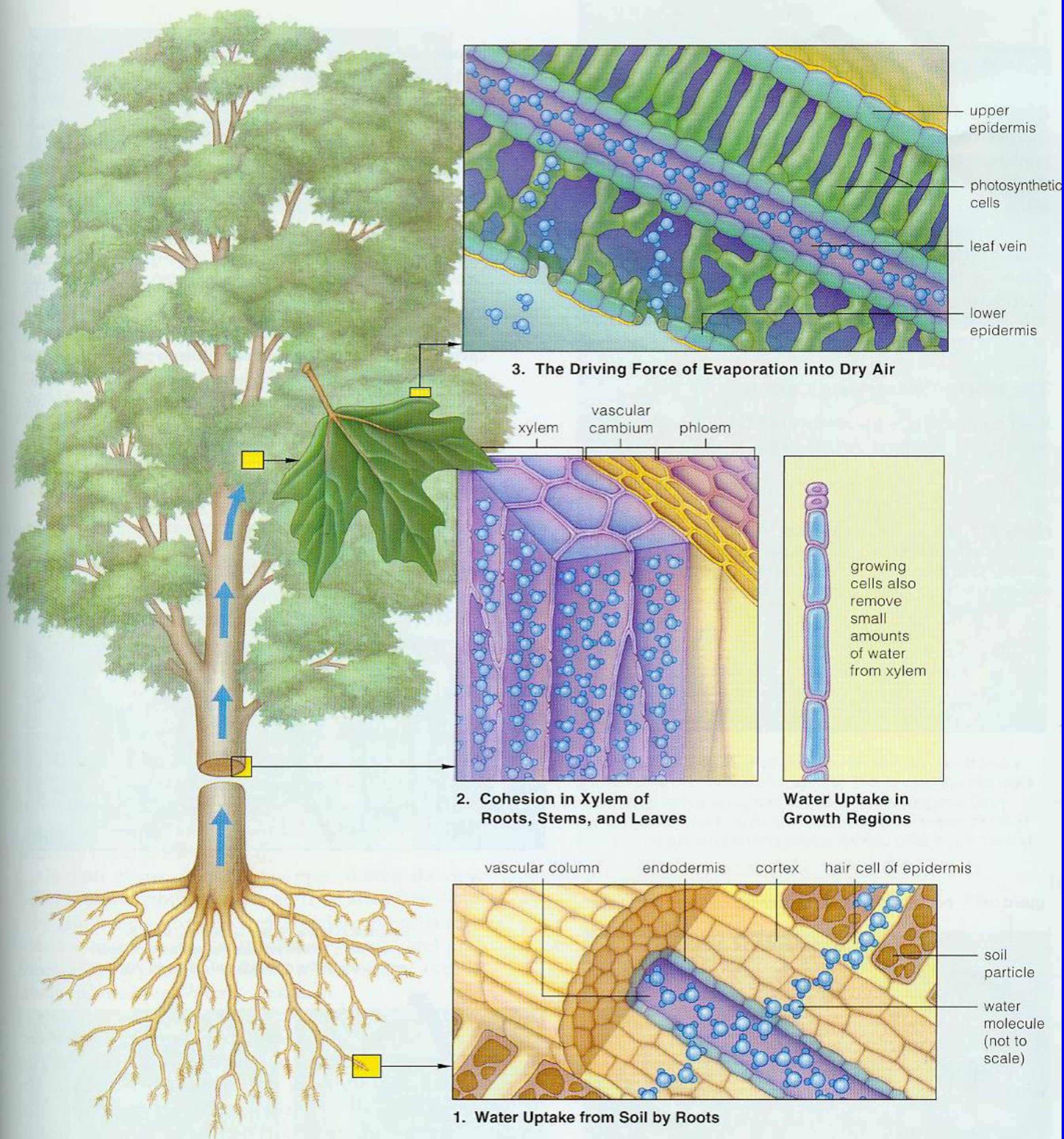
2. The pulling force from transpiration is the main impetus for the water to rise.

① Cohesion: the force among the molecules of the same kind to attract to each other, and the cohesion among the water molecules in plant cells can be as high as 20 MPa.

② Tension: the water column descends due to the effect of the pulling force of transpiration as well as gravity, which produces tension; the tension of water column in xylem is 0.5-3 MPa.

③ Cohesion theory: due to water loss from transpiration, the leaf blade takes in water from the vessel and tracheid, which produces tension in the water column in the vessel and tracheid; the cohesion among water molecules are greater than the tension of water column, which ensures continuous rise of water molecules.

④ Controversies in this theory: are living cells involved in the rise of water? The generation of bubbles interrupts the water colu, why the water continues to rise？



3. The Driving Force of Evaporation into Dry Air

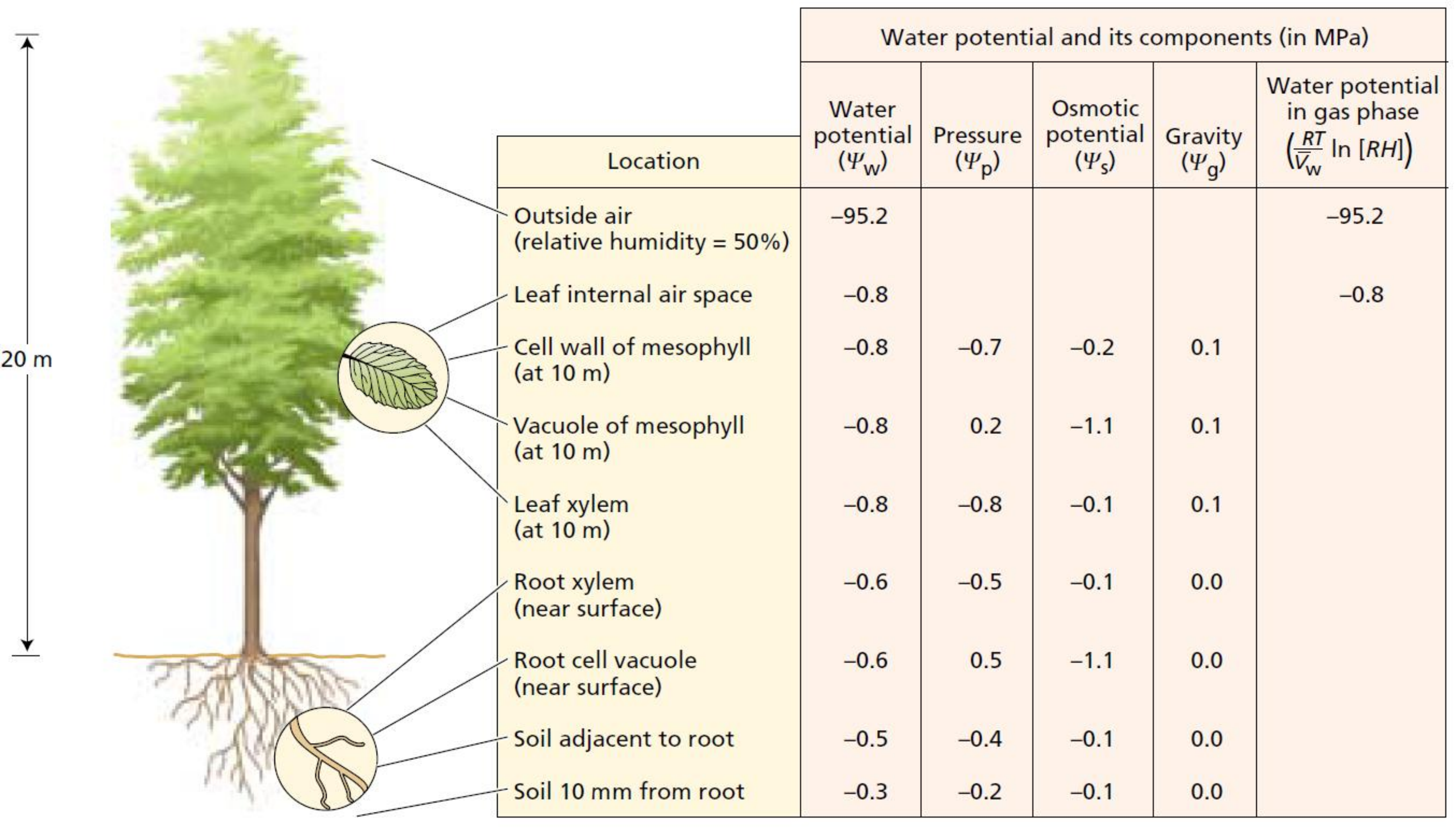
2. Cohesion in Xylem of Roots, Stems, and Leaves

Water Uptake in Growth Regions

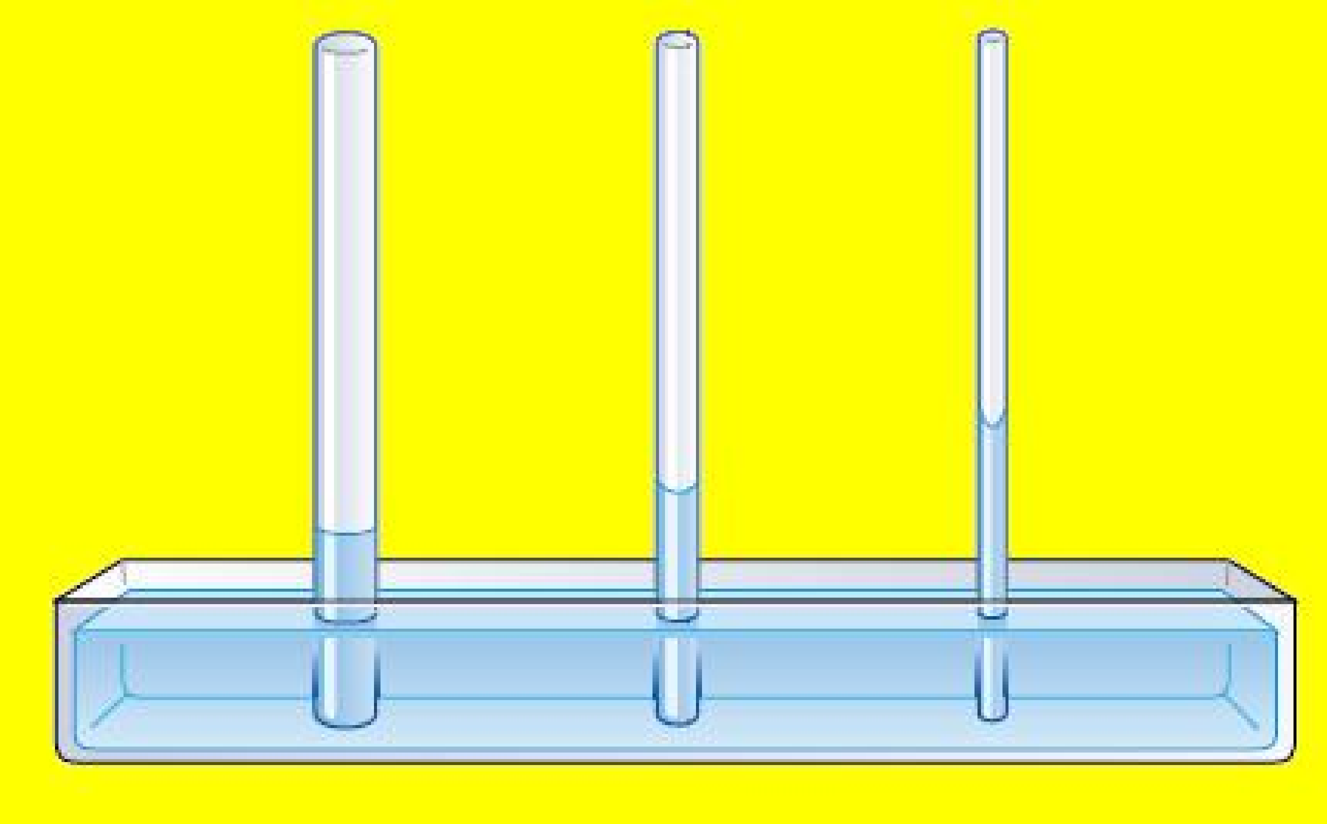
1. Water Uptake from Soil by Roots

Cohesion-tension model of water transport.

Representative overview of water potential and its components at various points in the transport pathway from the soil through the plant to the atmosphere.



Location	Water potential and its components (in MPa)				
	Water potential (Ψ_w)	Pressure (Ψ_p)	Osmotic potential (Ψ_s)	Gravity (Ψ_g)	Water potential in gas phase $\left(\frac{RT}{\bar{V}_w}\ln[RH]\right)$
Outside air (relative humidity = 50%)	–95.2				–95.2
Leaf internal air space	–0.8				–0.8
Cell wall of mesophyll (at 10 m)	–0.8	–0.7	–0.2	0.1	
Vacuole of mesophyll (at 10 m)	–0.8	0.2	–1.1	0.1	
Leaf xylem (at 10 m)	–0.8	–0.8	–0.1	0.1	
Root xylem (near surface)	–0.6	–0.5	–0.1	0.0	
Root cell vacuole (near surface)	–0.6	0.5	–1.1	0.0	
Soil adjacent to root	–0.5	–0.4	–0.1	0.0	
Soil 10 mm from root	–0.3	–0.2	–0.1	0.0	



Capillarity in narrow tubes. The smaller the diameter of the tube, the greater the rise of the fluid.

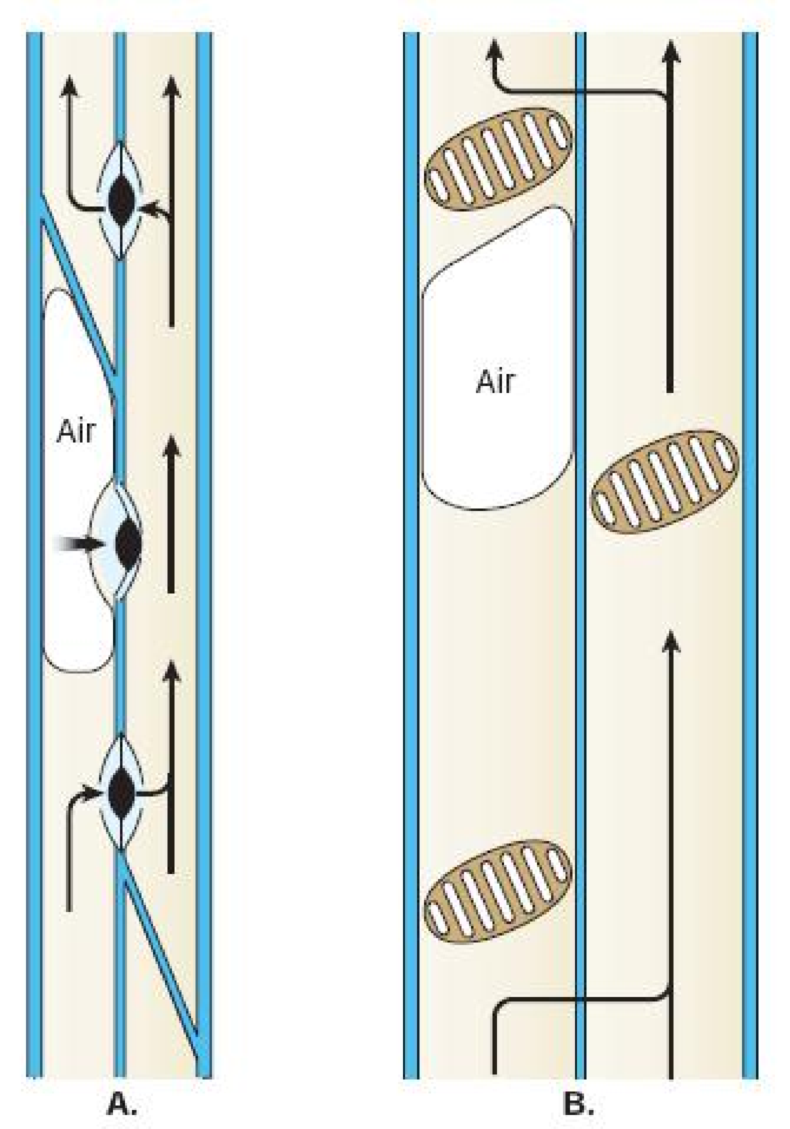
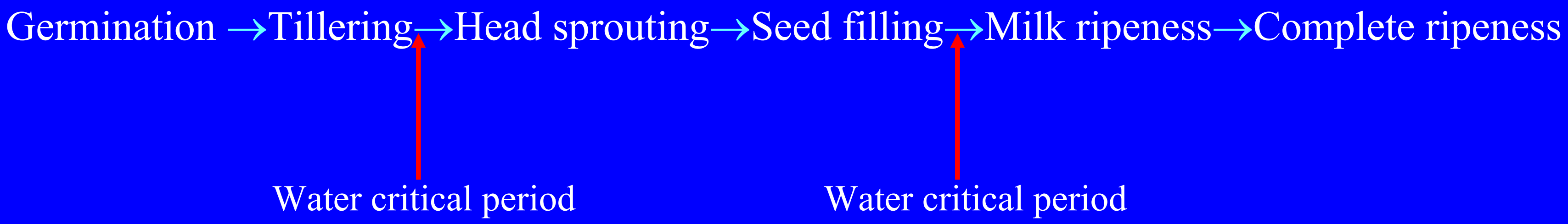


Diagram to illustrate how water flow bypasses embolisms in tracheids and vessels.

I. Water Demand in Crops

1. Water demand varies in different kinds of crops: soybean and rice > wheat and sugar cane > broomcorn and corn; C_3 plant > C_4 plant.
2. Water demand varies greatly even for the same crop in different development stages. Take the wheat for an example.



Germination →Tillering→Head sprouting→Seed filling→Milk ripeness→Complete ripeness

Water critical period

Water critical period

II. Indexes of Rational Irrigation

1. Morphological index

In water shortage, young and tender stem and leaves wither; the stem and leaves turn dark green or red; the growth rate slows down.

2. Physiological indexes

Water potential of leaf blade; cellular sap concentration; osmotic potential; stomatal aperture.

III. Method of water-saving irrigation

Ditch irrigation and drainage; sprinkling irrigation; trickle irrigation; regulated deficit irrigation; controlled root alternation irrigation

IV. Reasons for increased production by rational irrigation

1. Physiological water demand
   ① Preventing soil drought, and changing the climate conditions on the irrigated ground.
   ② Changing various physiological effects of the crops;
   ③ Changing the environment for the crops, and exerting indirect influence to the crops.
2. Ecological water demand
   ① Prior to the start of the cold-air outbreak in spring and the low temperature damage in autumn;
   ② The irrigation to saline and alkaline land exerts effects of salt-leaching and desalting;
   ③ The fertilization in dry land exerts effect of dissolving fertilizer.

Assignments

- Design an experiment device to prove the presence of transpiration in the plant.
- Design an experiment to measure water transport speed.