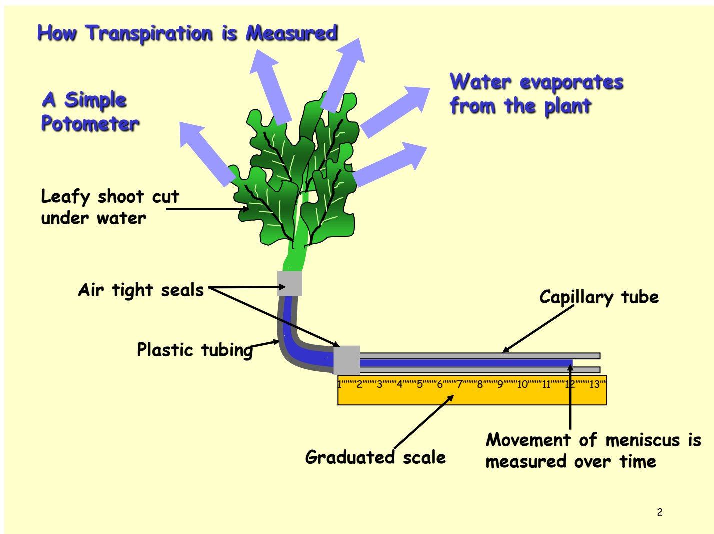
Transpiration

Transpiration: It is the process of water loss as a vapor through stomates. Part of the lost water goes out through the (cuticle), and another part through the lenticels. The roots also lose water if they came into contact with the air. Transpiration differs from natural evaporation because water vapor (in transpiration) does not evaporate from the free surface, but passes through the epidermis, which is covered by cuticles, or through leaf stomata.



Two stages in the process of transpiration are recognized:

1. Water evaporates from the walls of moist cells into the air chambers just behind the pore of stomates.

2. Water vapor diffuses from air chambers or spaces into the outside environment.

The water potential of the air (ψ_w) is always very negative (more negative than the plant). This is why there is a tendency to lose water by transpiration. The water lost by transpiration is replaced (or subsidized) by the absorption of water from the soil. This is why there is water flow (or what is called a transpiration stream from the root to the surfaces of water-losing – leaves (transpiration surfaces).

A very little amount of absorbed water, probably not more than 5%, remains in the plant for growth, and less ratio participates in a biochemical reaction, while the remaining water is lost to the air. The amount of water lost from the plant is very big and reaches hundreds of liters per season per plant.

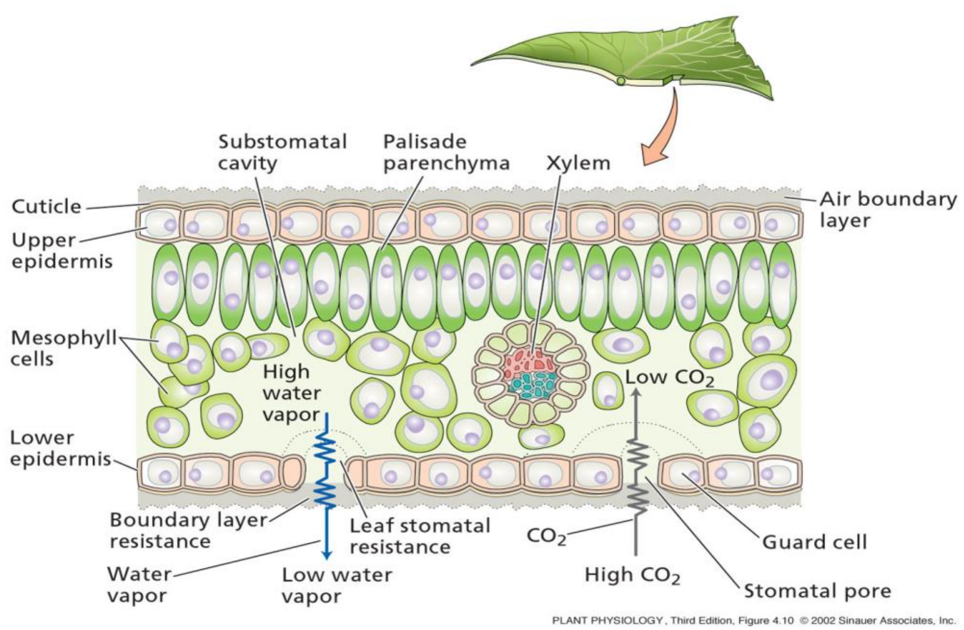
Distribution of stomates

Usually, the stomates are distributed on both upper and lower leaf surfaces, but generally, the number of stomates on the lower surface is greater than the upper. In some plants, e.g. apple and coleus, the stomates are present only on the lower surface. The number of stomates differs from species to species, and even in the leaves of the individual plant. Plants grown in the shadow usually contain less number of stomates in their leaves as compared to those grown in a sunny environment.

The average number of stomata is about 10,000 stomata /cm^2 in cotyledonary plants, and 1000-2000 in cereals, but may reach 100,000 stomata /cm^2 in some species. However, the stomates do not cover more than 3% of the leaf surface.

Anatomy of stomatal apparatus.

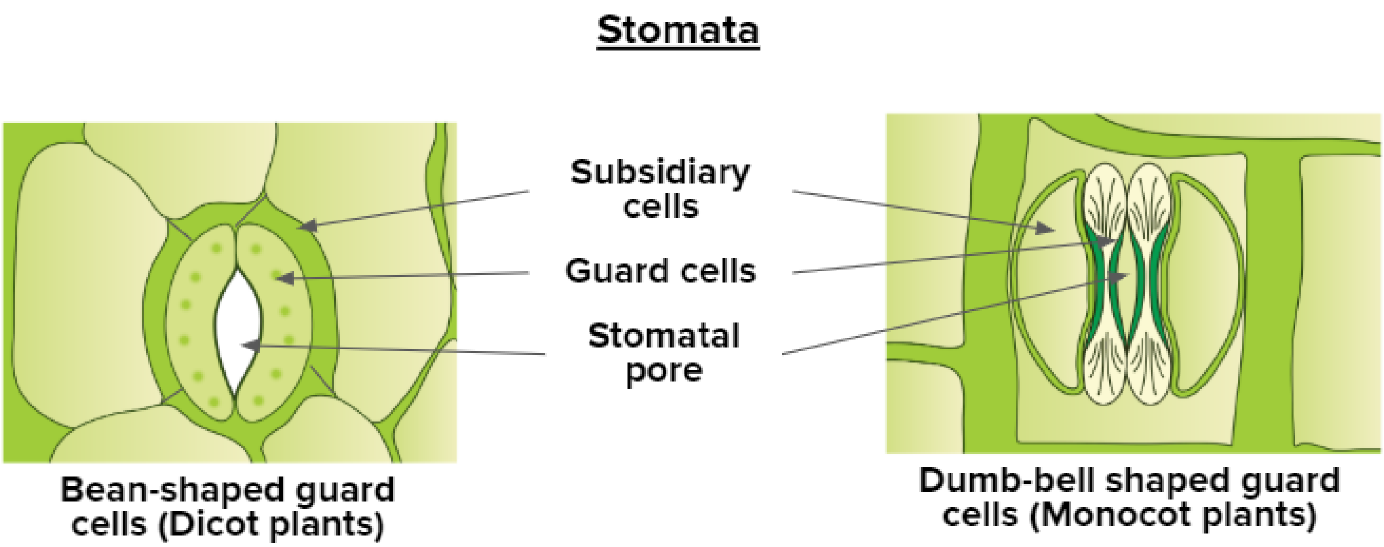
Fig. Water movement from leaf to atmosphere

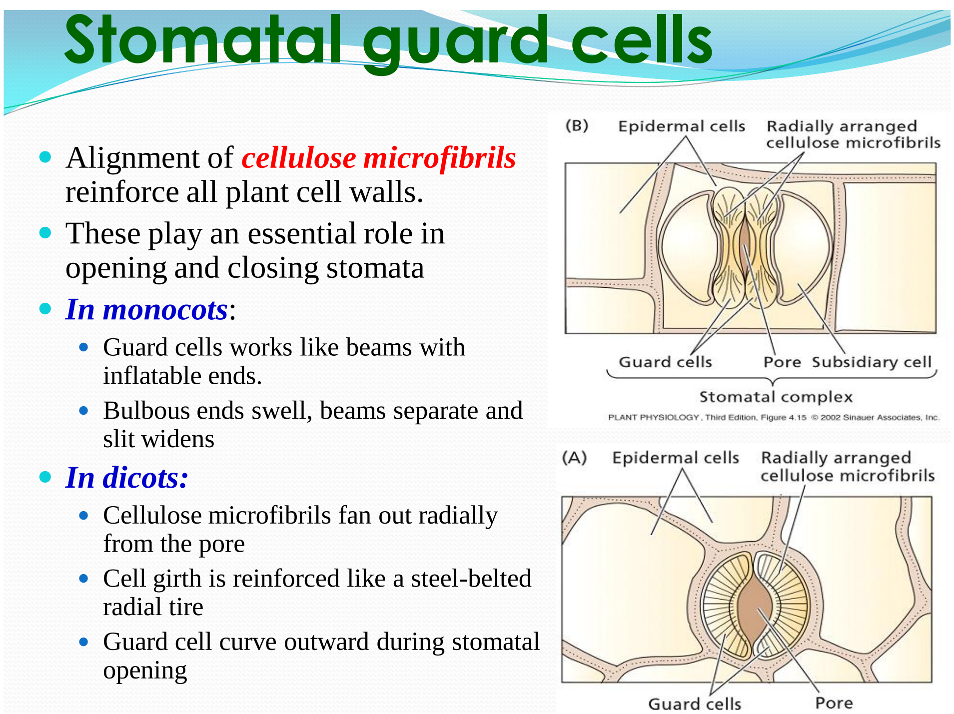


Leaf cross section

The principal component of the stomatal apparatus are:-

1. Guard cells.
2. Stomatal opening (pore).
3. Substomatal chamber.
4. Accessory cells or subsidiary cells.





Although the change in turgidity is the driving force for the opening and closing of stomates, the characteristic of uneven thickening in the cell walls next to the pore (or stomatal opening) and cells adjacent to the epidermis as well as the presence of radially arranged cellulose microfibrils, causes the opening of stomates when they are turgid.

Role of K^+ in opening and closing of stomates

It is known that the opening and closing of stomates are controlled by the turgidity of guard cells. The Turgidity of such cells depends basically on their contents of potassium (K+) salts.

During the night, the concentration of soluble substances in the vacuole of the guard cell is relatively low, causing Ψs of the cell to be low, which causes the cell to be in a flaccid shape, and closes the pore. In the morning, K+ is transferred to the vacuoles of guard cells, which subsequently increase the Ψs, and water moves into the guard cells which become turgid, and open the stomates.

In the **night** or during water stress → Exit of K^+ → low Ψs → Water exit → Flaccid guard cell → Pore closed

In the **morning** → K^+ moves into vacuoles → high Ψs → Water entrance of guard cells into guard cells → Turgid guard cells → Pore open.

Accessory cells, as well as other epidermal cells surrounding the guard cells stores K^+ at the night and also during the water stress period. Also when K^+ passes through the membranes, other negative ions such as Cl^- enter with it (i.e. with K^+) or positive ions (such as H^+) exit, which leads to an increase in the pH (when pores are open).

Ecological factors affecting transpiration:

1. Water stress: Water stress causes increased abscisic acid (ABA) levels in the vacuoles, which cause the exit of K^+, and subsequently lower the Ψs of the guard cell, followed by water exit from guard cells and closing the stomata.

2. **CO_2 concentration:** The CO_2 contents of chambers or air spaces under the stomates are a principal regulator of pore opening in several plant species. If CO_2 concentration in these chambers or spaces is reduced to lower than its concentration in the air (i.e. less than 0.03%), the guard cells become turgid and the pores open. This usually happens in the presence of light, which increases the rate of photosynthesis, which subsequently reduces CO_2 concentration in air chambers surrounding guard cells and opens the pore. This explains why the stomates open during the day and close at night.

3. Light:

Light → Transformation of light energy to thermal energy → Increased temperature → Increased transpiration

Light → Increase membrane permeability → Increased transpiration

Light → Photosynthesis → Transformation of solar energy to Chemical energy → Pump K^+ guard cells → increase Ψs → water entrance to guard cells → Transpiration

Photosynthesis → Increase sugar → increase Ψs → water entrance to guard cells

Photosynthesis → Reduce CO_2 concentration in air chamber → Stomate opening

** Observe that water stress, CO_2 concentration, and light affect transpiration by controlling stomates opening and closing.

4. Air humidity:

Since water is lost as a vapor, it is therefore more appropriate to consider vapor pressure rather than relative humidity. Water vapor diffuses usually from the high vapor pressure region to the lower region, i.e. towards decreasing vapor pressure gradient (ΔVP).

The air spaces or chambers in the leaf (substomatal) are usually saturated with water vapor, while the air surrounding the leaf is unsaturated or even low in water vapor. Therefore, there will be a vapor pressure gradient between air chambers in the leaf and the outside air. This difference or gradient is the actual driving force for transpiration.

5. Temperature:

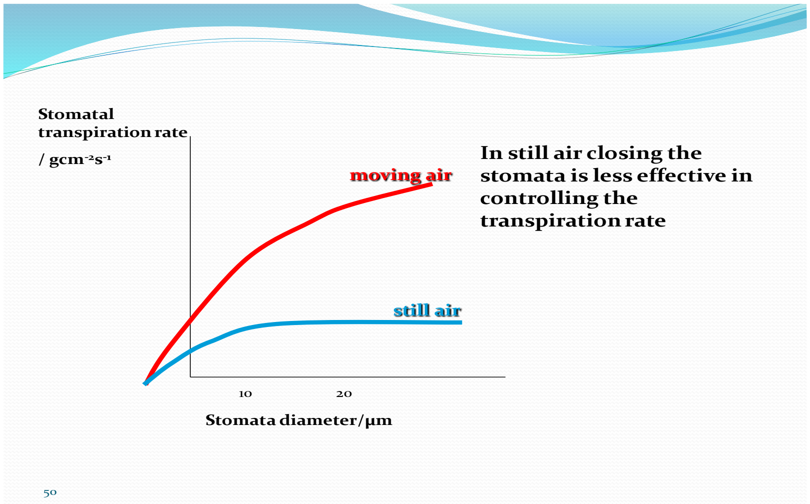
If other factors remain unchanged or constant, a rise in temperature, within the physiological limits, will increase the rate of transpiration. The effect of temperature comes actually from its effect on the vapor pressure.

6. Wind:

The exit of water vapor passes through the air chambers in the leaf then through the stomatal opening or pore, which resist the exit of the vapor, and then the boundary layer, (i.e. the stable air layer that increases the path of water vapor movement). All these factors reduce the rate of transpiration.

In the case of high-speed wind, the boundary layer is removed, and then the path of water vapor movement is changed, which leads to increased transpiration. In other cases, like storms or very high-speed wind, coupled with increased evaporation, this will lead to a reduction in temperature (cooling) with drought or dry condition sufficient to close the stomates, and reduces the rate of transpiration.

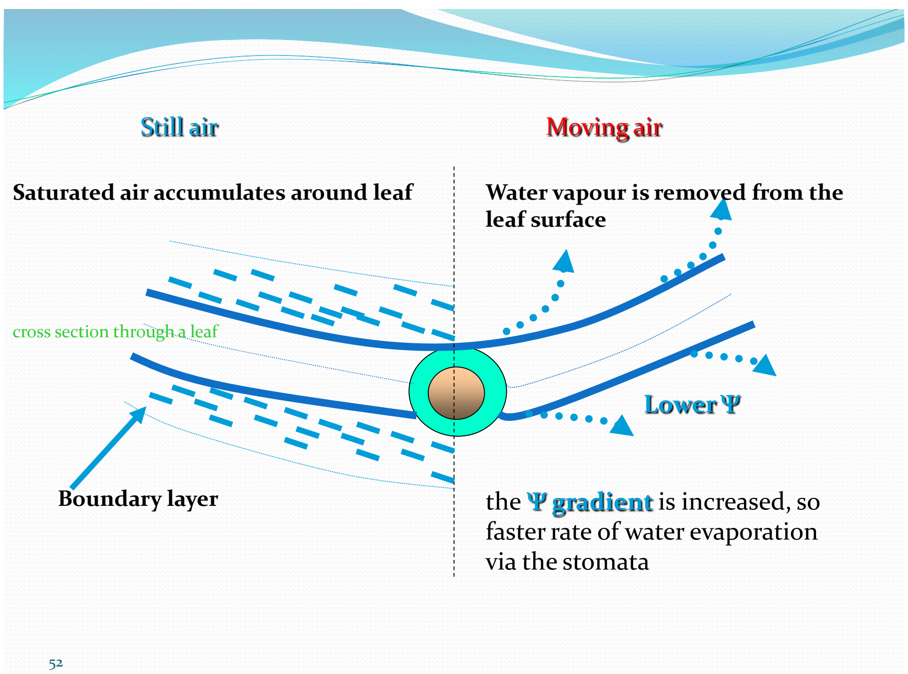
Fig. The Effect of Wind Speed on the Rate of Transpiration



7. plant hormones.

- ABA---close, ABA promotes Ca^{+2} increase in cytosol indirectly makes K+、Cl- flows out of GC and inhibits entrance of K^{+} into GC.
- IAA 、CTK result in stomata opening.

Fig. Moving Air Removes the Boundary Layer of Water Vapour From the Leaf



Botanical factors affecting transpiration

1. The ratio of root to the vegetative or aerial organ: Transpiration increases with an increased ratio.
2. Leaf area: Increased leaf area will increase the rate of transpiration.
3. Number of stomates per unit area
4. Distribution of stomates on leaf surfaces
5. Size of stomata opening or pore size.
6. Thickness of cuticle
7. Presence of trachoma (i.e. hairs) on leaf surface which affects wind movement.
8. Besides, closed stomata during the day. Leaf structure, e.g. adaptation of xerophytic plants

Adaption to reduce water loss in xerophytes

1. **Thick waxy cuticle** to reduce evaporation**.**
2. **Reduced leaf area e.g.** needles leaf.
3. **Hairy leaves,** the hairs trap a layer of saturated air.
4. **In sunken stomata,** the pits above the stomata become saturated.
5. **Rolled leaves**, reduces the area exposed to the air and keep the stomata on the inside so increasing the water vapor inside the roll.

Note:- Increasing the water vapor around the stomata reduces the water potential gradient so slows water loss.

While:- the adaptation to increasing water uptake in xerophytes

1. **Deep extensive root,** system to maximize water uptake.
2. **Accumulation of solutes in the root,** system to reduce the Ψ, so making Ψ gradient from the soil to root cell steeper.
3. **Some very shallow roots** absorb dew which condenses on the soil at night.

Starch-sugar conversion theory

The enzyme Starch phosphorylase (SPLase) plays an important role in stomata opening and closing.

pH>5.0 hydrolysis activity ↑,
pH<4.6 synthesis activity ↑

Light	**darkness**
Photosynthesis in guard cell (GC)	Respiration in GC
Consume CO_2, Cell pH↑	Produce CO_2, cell pH↓
SPLase hydrolysis activity↑	SPLase synthesis activity↑
Starch becomes G-1-P ↑	G-1-P to starch
Water potential↓	Water potential ↑
GC absorbs water and turgor↑	Loss of water and turgor↓
↓	↓
Stomata opening	Stomata closure

Light（dark）

↓

Guard cell (GC) photosynthesis（respiration）

↓

ATP and malate ↑

ATPase hydrolysis ATP, malate dissociates H+

↓

H^+ pump out of GC, K^+ pump into GC

↓

Water potential ↓

↓

GC absorbs water and turgor ↑

↓

Stomata opening

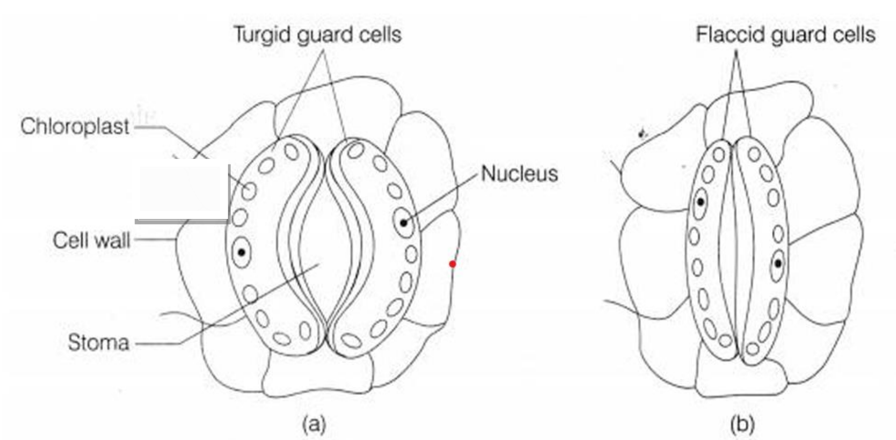


Fig. 1 (a) Stoma (open)
(b) Stoma (closed)

Role of transpiration

-1) It decreases leaf temperature.
-2) It is a power for water absorption and transportation.
-3) It enhances the transfer and distribution of mineral nutrition and other solutes in the plant body.

Transpiration rate: Water loss of plant through transpiration per unit leaf area and per unit time ($g/m^2.s$).

Daytime1.5-7.5 $g/m^2.s$， night<0.3 $g/m^2.s$。

Measurements： Weight loss and gas exchange (GE).

Stomata Control Couples Leaf Transpiration to Leaf Photosynthesis

Problem:

- Plants have to take up CO_2 from the atmosphere, but simultaneously need to limit water loss.
- Cuticle protects from desiccation
- However, plants cannot prevent outward diffusion of water without simultaneously excluding CO_2 from the leaf and the concentration gradient for CO_2 uptake is much smaller than the concentration gradient that drives water loss.

Solution: Temporal regulation of stomata apertures

• Closed at night: no photosynthesis → no demand for CO_2 → stomata aperture kept small → preventing unnecessary loss of water.

• Open during day: sunny morning; water abundant, light favors photosynthesis → large demand for CO_2 → stomata wide open → decreased stomata resistance to CO_2 diffusion → water loss by transpiration also substantial, but water supply is plentiful, i.e. plant trades water for the product of photosynthesis needed for growth.

Regulation of stomata: -

1. Microfibril mechanism: guard cells attached at tips and microfibrils in cell walls that elongate causing cells to arch open - open stomate or shorten close when water is loss.

2. Ion mechanism: uptake of K+ ions by guard cells. Proton pumps involve. Water enters by osmosis and guard cells become turgid but when guard cells lose K+ ions water leaves by osmosis and guard cells become flaccid.

3. Blue-light receptor in the plasma membrane of guard cells triggers ATP-powered proton pumps causing K+ uptake and stomates open.