WATER LOSS IN PLANTS

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How do plants lose water? How is transpiration different from guttation? Can plants regulate these processes? How do these processes affect plant function?

While most terrestrial plants absorb large quantities of water from the soil, only a very small amount of this water is utilised for their growth and development. The rest is lost from the aerial organs of the plant to the environment. This loss can occur through two processes — transpiration and guttation. Leaves often play an important role in both.

Transpiration

Transpiration refers to a process in which a plant loses water (~ 80-90% of what is absorbed by its roots) as water vapour from special pores, called **stomata** (singular: stoma), that are found on the aerial parts of a plant (see **Box 1**). While the number, size, and distribution of stomata can vary widely, they are usually most abundant on the leaves of a plant.

The amount and rate at which water loss occurs is finely regulated by the number of stomata that are open to gaseous exchange at a given time of the day. This means that the rate of transpiration is highest during the day, in the presence of sunlight. It also means that most of this water loss occurs through leaves. The anatomy of the leaf often puts the plant in a condition that is compared to being 'between the devil and the deep blue sea'. On the one hand, the abundant stomata on the leaf cause the unavoidable loss of water through transpiration (see **Box 2**). On the other hand, these structures along with the intercellular spaces and the air cavities in the internal structure of the leaf facilitate the exchange of gases (oxygen and carbon dioxide) needed for photosynthesis and respiration. Thus, the closing of stomata may limit water loss through transpiration, but may also adversely affect the rate of photosynthesis and respiration by inhibiting gaseous exchange.

Box 1. What are stomata?

Found on the outer surface of the stem, leaves, and even the flowers of a plant, each stoma consists of:

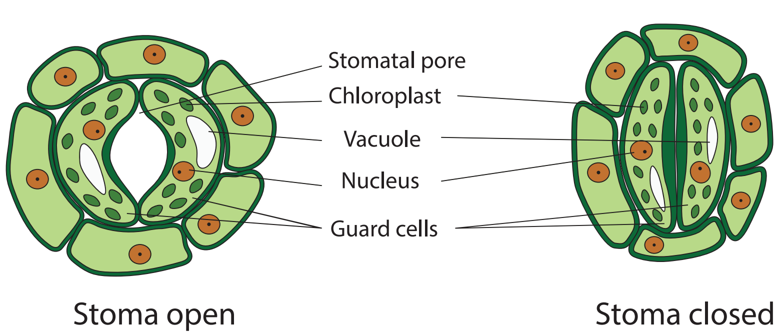
(a) An aperture through which gases (like water vapour, carbon dioxide, and oxygen) are exchanged between the plant and its immediate environment.

(b) Two specialised epidermal cells, called **guard cells**, that line the aperture, and regulate its opening and closing. When these cells are turgid with water, they are stretched away from the pore, opening the stoma to gas exchange. When these cells are flaccid, the stoma closes.

(c) A cavity called the **substomatal cavity** or **respiratory chamber**. This cavity allows rapid diffusion of oxygen, carbon dioxide, and water vapour between the inner layers of the plant and its outer environment.

While some wavelengths of light can induce the opening of stomata; water stress, high temperatures, and high carbon dioxide concentrations can induce their closing. For example, sunlight triggers the stomata of most plants to open completely during the day, which helps facilitate the efficient intake of the carbon dioxide needed for photosynthesis. In the absence of sunlight, the stomata close, which reduces water loss through transpiration. This is also why it is widely believed that stomata remain completely closed at night. If this were true, plants would no longer be able to respire. However, we know that, unlike photosynthesis, respiration can continue to occur in the absence of sunlight. How? Plants respire at night (at a much slower rate) through stomata that are largely, but not completely, closed. In woody plants and trees, this gaseous exchange also occurs through many special raised pores, called **lenticels**, that are found on their barks.

Interestingly, the stomata (called **scotoactive stomata**) of some succulents remain completely open at night and largely closed in the day. In these plants, the carbon dioxide for photosynthesis is absorbed during the night (which is then converted to organic acids, stored in vacuoles, and used for photosynthesis in the day). This helps reduce the amount of water these succulents lose through transpiration in hot and arid climate.



Guard cells regulate the opening and closing of stoma.

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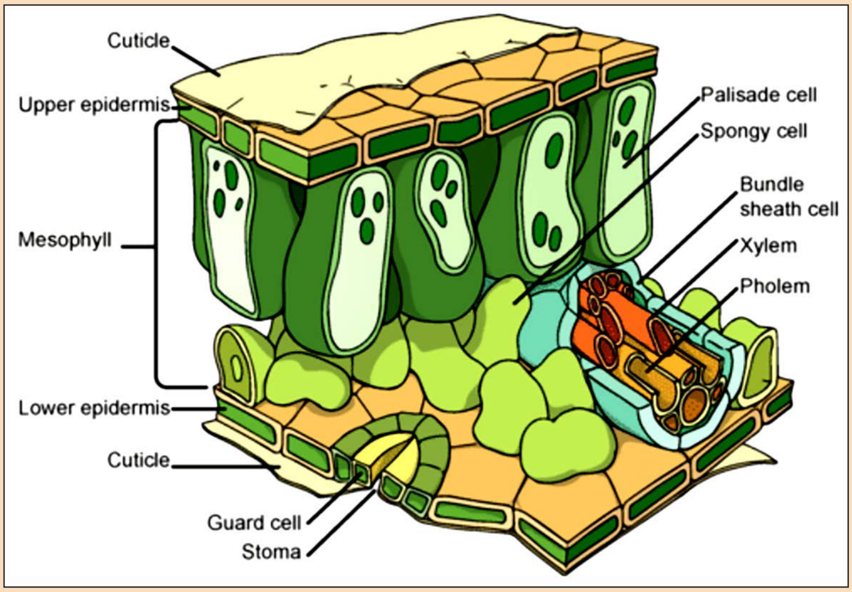
Box 2. How do leaves transpire?

Defined as a lateral, flat, thin and generally green appendage of the stem, a leaf consists of the following layers:

- The outermost layer on its upper and lower surface is called **cuticle**. This is made up of a waxy and nearly water-impermeable substance called **cutin**.
- Below the cuticle is the epidermis. This usually consists of one layer of cells (called **epidermal cells**), but can have more layers in plants that grow under very hot or very cold conditions. Its main function is to protect the plant against infection. It is also in this layer that stomata are located. Stomata are more numerous on the lower epidermis of a dicot leaf; and are found in almost equal frequency on both layers of a monocot leaf.
- The green coloured tissue that lies between the upper and lower epidermis is called **mesophyll**. This layer is composed of two kinds of tissues, called **palisade** and **spongy parenchyma**. The palisade tissue is a compact layer of cells, without any intercellular spaces. Its main function is photosynthesis. The spongy tissue is made up of irregularly-shaped cells that are

How does transpiration affect plant function? It creates a negative water pressure gradient, called **transpiration pull**, in the leaves of a plant. This gradient pulls xylem sap from the roots to the leaves (where it is used for photosynthesis), and water from the soil to move into the roots. In other words, it is because of transpiration that the water absorbed by roots reaches the extremities of even the tallest of trees. This process also helps lower the surface temperature of leaves to what is near optimal for metabolic functions like photosynthesis to occur efficiently.



The internal structure of a leaf consists of many layers of cells.

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loosely arranged into a layer with many intercellular spaces and air cavities (that are connected to the substomatal cavities in the epidermis). The main function of this layer is to store gases, sugars, and amino acids.

- The vein of the leaf consists of a tightly packed sheath of photosynthetic cells which enclose xylem vessels and phloem tubes in a structure that is called a **vascular bundle**. Xylem vessels bring xylem sap (water with dissolved minerals) from the soil to the leaf, while the phloem tubes carry sugars, amino acids, and certain hormones from the leaf to other parts of the plant.

Transpiration from leaves occurs in two steps:

1. The diffusion of water from the cells in the mesophyll into the intercellular spaces, air cavities, and substomatal cavities: we know that the water absorbed by the roots reaches the leaves of a plant through a fine network of xylem vessels. Once the cells in the mesophyll become turgid, some of this water diffuses into the intercellular spaces in the form of water vapour.
2. The diffusion of water vapour from the intercellular spaces, air cavities, and substomatal chambers in the mesophyll layer to the external environment: As the intercellular spaces and air cavities in the mesophyll layer become saturated with water vapour, the vapour pressure within the leaf becomes greater than the vapour pressure of its immediate environment. The speed with which this happens depends on how hot and dry the environment is (the hotter and drier it is, the sooner the vapour pressure in the leaf exceeds that of its environment). The difference in vapour pressure causes the diffusion of water vapour into the atmosphere through the opening of the stomata. This process continues till an equilibrium in vapour pressure is reached within and outside the leaf. The speed with which this equilibrium is reached depends on how humid the immediate outer environment of the plant is (the more humid the environment, the sooner an equilibrium is reached).

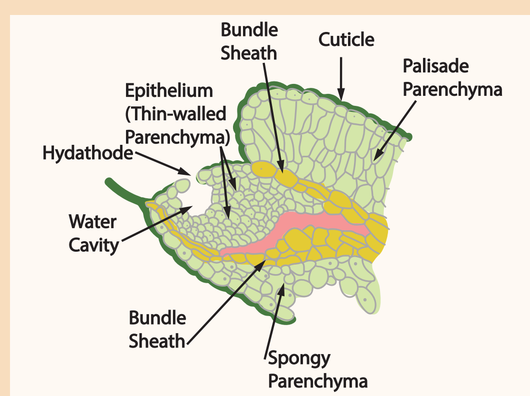
Guttation

Guttation refers to a process in which a plant discharges excess water as droplets of xylem sap from special pores, called **hydathodes** or **water stomata** (see **Box 3**).

Guttation occurs under conditions of high-water uptake and limited transpiration, like in warm soils with high humidity. Thus, unlike transpiration, this process usually happens in the night or early mornings (see **Box 4**). The roots exert a positive water pressure gradient that drives the ascent of xylem sap to the leaves. This sap is released by the xylem vessels in the vascular bundle into the proximal cavity. When this cavity

Box 3. What are hydathodes?

A hydathode is a stoma-like opening (with a proximal substomatal chamber like cavity) in the leaf epidermis, which is uncovered by the cuticle. It is different from a stoma in being larger in size, and remaining open (or unregulated) at all times. Hydathodes are found at leaf tips and margins of plants like tomato, strawberry, rose, water hyacinth, water lettuce, and many grasses.



Hydathodes are pores, uncovered by the cuticle, found at leaf tips and margins of many plants.

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Box 4. How to tell the difference between dew and guttation?

Since guttation occurs in the night and early morning, it can often be mistaken for dew. Here are two important differences:

- While dew drops are smaller in size and distributed across exposed leaf (and plant) surfaces, the fluid from guttation is released in larger drops only from the tip and margins of leaves.
- While dew drops consist of water (atmospheric moisture condensing on cold surfaces), guttation releases xylem sap (moisture secreted from within the plant).

Xylem sap exuded by guttation from the leaf of a balsam plant.

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is completely filled, the sap is exuded from leaves (on drying, this exudation can sometimes leave a whitish crust on leaves). Thus, guttation offers direct evidence of root pressure.

How does guttation affect plant function? It is through this process that roots retain the lower water potential that allows them to draw water with dissolved minerals from the soil. Unlike transpiration, however, this process has no effect on leaf surface temperature.

Key takeaways

- Plants lose most of the water they absorb through their roots by transpiration and guttation.
- Transpiration is the regulated loss of water in the form of water vapour from the stomata found on the aerial parts of the plant. The rate of transpiration is highest in the day, and occurs largely through leaves.
- Guttation is the unregulated loss of water in the form of xylem sap from hydathodes found on the tips and margins of leaves. The rate of guttation is highest in the night and early morning.

Notes:

1. More details about measuring transpiration rate using a low-cost potometer can be found in another article ('My experiences with a Potometer') by the same author in the June 2021 issue of iwonder... (URL: http://publications.azimpremjifoundation.org/2848/), and the recording of an online discussion ('Experiences with a Potometer') with him (URL: https://www.youtube.com/watch?v=FzH43W89E2g).
2. Source of the image used in the background of the article title: Guttation on a rose leaf. Credits: Buntysmum, Pixabay. URL: https://pixabay.com/photos/leaf-foliage-rose-plant-dew-drops-5257161/. License: CC0.

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