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INTRODUCTION

Water being the most vital constituent of all plant tissues, plants absorb large amounts of water from the soil but only 2-5% is used by them for metabolic processes while the rest is translocated to the leaves and lost to the environment in the form of water vapour. Most of the excess water is lost from the aerial parts of the plants by the process of transpiration.

Transpiration is a process during which water in the form of water vapour is lost from the internal issues of plants, through the aerial parts of the plant.

Maximum water loss takes place through the leaves since leaves offer a larger surface area than stems and flowers for evaporation to occur.
Plants take up large amounts of water from soil which passes into the internal parenchymatous tissues. The water from these cells is constantly evaporating and collecting in the intercellular spaces (provided these are not already saturated with water vapour). This water diffuses out into the atmosphere by one of the following ways:

- The 3 main types of transpiration are:
  - Stomatal: occurs through stomata
  - Cuticular occurs through cuticle
  - Lenticular: occurs through lenticels
**What are stomata?**

- Stomata are minute openings in the upper and lower epidermal layer of leaves. During the day, stomata are wide open mainly for the intake of CO2 for photosynthesis. The number of stomata vary from 1000 -10,000/cm².

1. **Stomatal Transpiration:** The epidermis of the leaf has numerous minute pores called stomata (singular stoma). These pores are surrounded by a pair of specialized guard cells (kidney shaped in dicots and dumb-bell shaped in monocots ) which remain open during the day such that water vapour from the cells diffuses out along with respiratory gases.

   The guard cells are specialized epidermal cells with chloroplasts. The guard cells have a structural adaptation: They have thick inner walls and thin outer walls.

   ![Reniform guard cells in dicots](image1) ![Dumb-bell shaped in monocots](image2)

**Mechanism of Stomatal transpiration**

The opening and closing of the stoma is regulated by the turgidity of the guard cells. The stoma opens when the guard cells are turgid and close when they are flaccid(lose turgidity).

- In stomatal transpiration, water absorbed by the roots reaches the xylem tissues of the leaves through the veins.
- Water then reaches the spongy mesophyll cells of the leaf which have plenty of inter-cellular spaces.
- Excess water diffuses out into the inter-cellular spaces forming a thin film of water.
• Water from the thin film evaporates and saturates the inter-cellular space and finally diffuses into the sub-stomatal space (space inner to the stomata).
• Thus, excess water in the form of water vapour escapes through the stomata.

2. Cuticular Transpiration: Some amount of transpiration occurs through the cuticle covering the leaf surface. It is called as cuticular transpiration. Cuticle is a waxy, protective layer secreted by the upper & lower epidermis of the leaf. The thickness of the cuticle varies from plant to plant. Xerophytes have thicker cuticle (an adaptation to prevent loss of water vapour by transpiration).

3. Lenticular Transpiration: Stems of woody plants have openings on their surface called lenticels. Transpiration takes place through these openings. Since the lenticels are always open, the water vapour easily escapes through the loose mass of cells of each lenticel.
Rate of lenticular transpiration is higher than cuticular but lower than stomatal. It has been estimated that under ordinary conditions of light, temperature and humidity, almost 80-90% of transpiration takes place through the stomata.

**Conditions influencing Transpiration**

The rate of transpiration is affected mainly by atmospheric conditions such as sunlight, humidity, temperature and wind velocity.

1. Sunlight:
   a. The degree of stomatal opening varies with the intensity of light. Thus, on a bright sunny day, the stomata are fully open and the rate of transpiration increased. On a cloudy day, the stomata are partially open and transpiration is reduced.
At night, in the total absence of light, the stomata closes and transpiration is greatly reduced, only lenticular or Cuticular transpiration occurs.

b. Leaves absorb radiant (light) energy in order to carry on photosynthesis. Thus, during the day, the temperature of the leaf itself rises and rapid evaporation takes place. Thus, transpiration is enhanced in the presence of sunlight.

2. Temperature of the Air: When the outside temperature is high, the rate of transpiration increases. This is because at higher temperatures water evaporates more freely than at low temperatures. Also, the capacity of the air to hold water vapour increases at high temperature.

3. Humidity of the Air: When the atmosphere is dry, its capacity to receive moisture increases. Thus, when the air is dry, the rate of transpiration increases. If the air is moist or saturated with water vapour (during monsoons) then it cannot receive any more water vapour. Hence, transpiration is minimized.

It may be noted that under humid conditions, transpiration will be checked even though the stomata remains open during the day time.

2. Wind or Air Movement: Transpiration is more rapid or active, when the wind velocity is high, and greatly reduced in still air. This is because in moving air, the water vapour is quickly removed or swept away from the area surrounding the transpiring leaf and transpiration can proceed rapidly.

In still air, the area around the transpiring leaf becomes saturated with water vapour. This limits the amount of water vapour being absorbed from the leaf.

3. Availability of soil water: Transpiration can be maintained only if the roots absorb water from the soil and compensate the loss of water from the aerial parts.
Adaptations to control Excessive Transpiration

While transpiration is of tremendous significance to the plant, excessive loss of water from the plant body can prove harmful for the survival of the plant. Hence, the plants, especially xerophytes, adopt various means, both morphological and anatomical to reduce excessive transpiration. Morphological refers to study of gross internal / external structural features of plants/animals and anatomical refers to internal structures of plant or animal cells/tissues learnt by dissection.

Adaptations to control Excessive Transpiration

1. Morphological Adaptations:

Since maximum water loss takes place through the leaf surface, the leaf area is considerably reduced. This is achieved in various ways.

- Leaves modified into spines as in cacti
- Leaves modified into needles as in pine
- Leaves reduced to spines
- Leaves reduced to scales
a. Leaves may be modified into spines or needles.
b. Leaves may be folded or rolled up.
c. Leaves may be shed, as in deciduous trees.

The reduction of leaf surface also reduces the surface area for the photosynthesis to occur. Therefore, the stem is modified to perform photosynthesis.

2. Anatomical Adaptations

a. The number of stomata are reduced or remain sunken in pits.
b. A thick waxy cuticle develops on the epidermis as in evergreen trees.
c. Shrubs & trees develop a water-proof covering of cork /bark.
d. A multiple epidermis may develop in some leaves.
e. The leaf surface may be covered by a dense coating of cutinized hairs, scales etc.

Sunken stomata in Nerium
**Significance of Transpiration**

1. Removal of excess water from the plant.
2. Absorption of water and nutrients from the soil.
3. Ascent of sap.
4. Distribution of water and salts throughout the plant body.
5. Cools the plant.
6. Prevents the plant from drying up.
7. Cools the environment.

**Anti transpirants:**

These are substances or chemicals used to cut the rate of transpiration artificially. These include certain chemicals like colourless plastic resin, silicon oils and low-viscosity waxes.

These anti-transpirants when sprayed on leaves, fruits, vegetables and flowers bouquets form a thin film on the transpiring surface. This film is permeable to respiratory gases but not to water. A few examples of anti-transpirants are:

Phenyl Mercuric Acetate, Abscisic acid etc.

**Guttation : Exudation of Water**

In certain plants like the water lettuce, grapevine, tomato, banana etc. tiny droplets of water (containing dissolved organic and inorganic salts) appear along the leaf margin in the early hours of the morning. This water escapes from special tissues that develop along the leaf margin and open on the leaf surface. These water pores are called hydathodes and the process by which the sap escapes from them is known as exudation or Guttation.

Guttation takes place due to increased hydrostatic pressure that builds up within the cells. The wall pressure that develops in fully turgid parenchymatous cells force the water out.
Conditions favouring Guttation

1. Large amounts of water in the plant.
2. Suitable temperature (at very low temperatures, practically no Guttation takes place).
3. All conditions, that inhibit transpiration, favor Guttation.

Water droplets seen arising from hydathodes located at the margin of veins

Bleeding:

The exudation of cell sap from any cut or injured part of a plant, due to increased root pressure is known as bleeding.
## Experiments

**Aim:** To measure the rate of transpiration in a potted plant.

**Apparatus:** A well-watered potted plant, a compression (or pan) balance, polythene sheet

**Procedure:**

1. The polythene sheet is wrapped around the pot and tied firmly round the stem of the plant. This is done to prevent direct evaporation of water from the soil in the pot.
2. The plant is weighed on the pan balance as shown in the diagram alongside and the weight is noted.
3. The plant is reweighed after a given period of time.

Observation:
A decrease in weight is noted.

Inference:
The difference in weight of the plant shows the amount of water lost in given time. This is the measure of the rate of transpiration.

Assumption:
Increases in weight due to photosynthesis or decrease in weight due to respiration are very small compared to transpiration and can hence, be neglected.
Experiment 2

Aim: To demonstrate difference in rate of transpiration between two surfaces of leaf.

Requirement: A herbaceous broad leaved plant, filter paper, 5% cobalt chloride solution, hot plate/oven, wire gauze, cellotape, dessicator, slides, rubber bands.

Procedure

• Prepare 100 mL of 5% cobalt chloride solution and immerse them in cobalt chloride solution taken in a petridish for 3-5 minutes and dry the filter paper strips
• Keep one dry (strip) cobalt chloride paper on the upper surface of leaf and stick it with cellotape. Similarly stick another strip of CoCl2 on the lower surface. The CoCl2 strips can be held in position with the help of two slides and rubber bands.
• Place the potted plant in sunlight.

Observation

Observe the colour of cobalt chloride paper attached to both surfaces of leaf at regular intervals and note down your observations.

Conclusion

It will be observed that the filter paper attached to the lower surface turns pink much faster than the strip on the upper surface. This is because the number of stomata is generally more in the lower epidermis than in the upper surface. As a result, the amount of water vapour lost by transpiration from the lower surface is more than the upper surface.

POTOMETERS

GANONG’s potometer…

It is a device to measure the rate transpiration rather the rate of water that is absorbed by a leafy shoot.

• The device consists of:

• 1) a wide tube fitted with a freshly cut leafy shoot(cut under water to prevent air bubbles) & fitted airtight
• 2) a reservoir with a stop-cock
• 3) a graduated long capillary tube
• 4) a beaker filled with colored water
Experiment 3

Aim: To measure the rate of transpiration by observing the rate of water uptake in a leafy shoot using Ganong’s potometer.

Apparatus: Ganong’s potometer, a cut leafy shoot, oil, paraffin wax.

Procedure:

1. The potometer is filled with water.
2. A leafy shoot cut under water (to prevent air entering the conducting vessels of the stem) is fitted into the upper wide end of apparatus through a cork or rubber bung. Paraffin wax is used to make the connection air-tight.
3. The distil end of the potometer is immersed in a beaker containing coloured water. Since the water is coloured, the movement of the water through the narrow tube is seen easily.
4. When the coloured water rises in the horizontal arm of the apparatus remove the tube from the beaker for a while and allow air to enter it.
5. Reintroduce the tube in the beaker of water.

Observation:

An air bubble is seen which travels through the horizontal arm of the potometer.

Inference:

As water is lost by the leaves due to transpiration, more is drawn from the stem, which in turn draws out water from the potometer tube.
Images of types of potometers

Farmer’s potometer

Darwin’s potometer

Ganong’s photometer
Limitations of Ganong’s Potometer

1. The potometer does not measure water lost by transpiration but only the water drawn by the plant as a result of transpiration. This is because all the water, which is drawn by the plant, is not transpired.
   
   a. Some of the water is used by the cells for vital processes such as manufacture of food.
   b. Water in the vacuoles, gives turgidity to the cells and also serves as a solvent for minerals and enzymes.

2. The potometer uses only very small volumes of water. Therefore, changes in temperature produce almost negligible contractions and expansions which do not significantly affect the results of the experiment.

3. Difficult to introduce the air bubble.

4. It is actually the amount of water absorbed & not transpired.

5. The twig may not survive long.

6. Changes in the environment affect the position of the air bubble