Chapter 34

Water Relations of Plants

- **Water** is essential for all physiological activities of plants.
- Water plays a key role in photosynthesis and acts as a source of oxygen.
- Water also plays a direct role in many useful reactions operating in cells.
- Water is a **major constituent of protoplasm** (about 90%).
- Protoplasm has a capacity of retaining its life even when there is **bare minimum of water**.
- If the bare minimum of water **decreases** protoplasm cannot restore its life even after the addition of water.
- **Properties of H_2O :** Water has high specific heat, latent heat of evaporisation, adhesive force, cohesive force and high surface tension.
- Two hydrogen atoms are attached to the atom of O_2 at an angle of **105^0**.
- Water is an **universal solvent**.
- Water is **useful for maintaining the turgidity of cells** which is **essential for cell enlargement**, **growth and the form of herbs**.
- Water is a **reactant** in many biochemical reactions.
- **Dispersal of fruits**, **seeds**, **spores** and **mobility of gametes** depends upon by water.
- Water is used to **regulate the heat in plants through transpiration**, **guttation**, **evaporation**.

DIFFUSION, IMBIBITION, OSMOSIS

- Physical processes associated with water relations of plants are : **diffusion**, **imbibition**, and **osmosis**.
- The movement of ions, atoms or molecules from a region of higher concentration to a region of lower concentration is called **diffusion**.
- Diffusion **cannot occur between two solids**.
- Solutions are formed by diffusion of **solute in a solvent**.
- When alcohol and water are mixed **water diffuses into alcohol** and **alcohol diffuses into water**.
- When O_2 and CO_2 are mixed **O_2 diffuses into CO_2** and **CO_2 diffuses into O_2**.
- **A plant cells has three physiological compartment -** cell wall, protoplast and central vacuole.
- Two membranes separate these three compartements, tonoplast around central vacuole and plasmalemma around protoplast but below the cell wall. Both are selectively permeable.
- Central vacuole contains an osmotically active fluid called cell sap.
- **Diffusion processes involved in plants** are -
  - Passive absorption of ions
  - Entry of ions into apoplast
  - Liberation of water vapour through stomata
  - Exchange of gases through stomata
  - Entry of water from the cell wall into the cell.
- **Apoplast** is the system of cell walls extending through a plant body and along which water containing mineral salts, etc. can move passively. It is an important pathway for movement of these substances outside the xylem.
- **Symplast** is the living system of interconnected protoplasts extending through a plant body.
- The process of increase of the volume of a solid due to absorption of water by hydrophilic colloids is called **imbibition**.
- Increase of a solid is due to **absorption of water** by hydrophilic colloids (imbibants) such as proteins, cellulose, starch etc.
- Imbibition **involves three important**

characteristics : **volume change**, **heat production** and **pressure development**.

- As the water molecules are arranged on the surface in the process of imbibition, they **lose some of their kinetic energy** which then appear as the heat in the system.
- The substance which shows imbibition is called **imbibant** and the pressure created by imbibant is called **imbibitional pressure**.
- Wooden pieces of doors and windows become tight during **rainy season** due to the process of **imbibition**.
- Rubber **does not show** imbibition.
- Imbibition processes in plants are exhibited by the following – **(i) raisins, (ii) dry seeds, (iii) cell walls, (iv) velamen roots, (v) dry lichens** etc.
- **Significance of imbibition** –
  - It is the **dominant and first step of water absorption.**
  - Imbibition is the **first step in germination of seeds**, *i.e.*, first imbibition occurs by seed coat and then by embryo and other parts.
- The term osmosis was coined by **Abby Nollet** (1978).
- **Osmosis** is the diffusion of water from its pure state into a solution when the two are separated by semipermeable membrane or it is the diffusion of water or solvent **from a dilute solution to a strong solution** through a semipermeable membrane.
- A solution which can cause an osmotic entry of water into it is said to be **osmotically active solution**.
- Membrane which **allows diffusion of both solvent and solute molecules and ions through** it, is called **permeable membrane**, *eg.*- cellulose wall of cells.
- Membranes which **do not allow diffusion of both solvent and solute particles** through them are called **impermeable membranes**, *eg.*- suberised cell walls in plants.
- Membranes which **allow some solutes to pass through them along with the solvent molecules** using different mechanisms, are called **differentially permeable membrane**, *eg.*- Plasma membrane, tonoplast and membrane surrounding cell organelles.
- Semipermeable membranes **allow diffusion of solvent molecules** but **do not allow the passage of solute molecules**.
- **Egg membrane** is a semipermeable membrane.
- Semipermeable membranes prepared in the laboratory are **collodian**, **cellophane**, **parchment paper**, etc.
- Semipermeable membrane is permeable to ions of salt but not to the **sugar molecules**.
- Common experiment to demonstrate osmosis is **thistle funnel experiment**.
- Experiment useful for demonstrating osmosis by using a living tissue is **potato osmoscope**.
- **Osmosis in plants helps in** –
  - Absorption of water
  - Maintaining turgidity and expansion of cell
  - Movement of water
  - Opening and closing of stomata.
- **Reverse osmosis** is expulsion of pure water from a solution through a semipermeable membrane under the influence of external pressure higher than O.P. of solution.
- Reverse osmosis is **used in removing salts from saline water as well as extrapurification of water.**
- **Signification of osmosis** are –
  - Osmosis is responsible for absorption of water by roots.
  - Osmosis is responsible for turgidity of plant organs.
  - Osmosis is responsible for cell to cell movement of water.
  - It is responsible for opening & closing of stomata.
  - It is responsible for resistance of plant to drought, frost, etc.
- **Factors controlling osmosis** are –
  - Presence of a perfectly semipermeable membrane is a must for the operation of osmosis.
  - Concentration of dissolved solute on the two sides of semipermeable membrane.
- Pressure required to prevent the entry of water into a solution is called **osmotic pressure**.
- The term osmotic pressure was proposed by **Pfeffer**.
- Osmotic pressure is a **positive value**.
- Pure solvent has **no osmotic pressure**.
- When solute is added to pure solvent it **develops osmotic pressure**.

- Osmotic pressure (O.P.) can be **calculated by OP – CRT**, *where* C is molar concentration of solution, R is gas constant and T is absolute concentration.
- The value of osmotic pressure is related to **number of particles** and **not molecules**.
- In **non-electrolytes** the number of particles and number of molecules is **same**.
- In **electrolytes** (eg. NaCl) number of particles (or ions) is **more** than the number of molecules.
- Osmotic pressure value of solution of ionising substance will be **greater** than osmotic pressure of solution of non-ionising substance though their concentrations are same.
- Pressure exerted by diffusing ions or molecules is called **diffusion pressure**.
- **Diffusion pressure** is the pressure exerted by a substance due to tendency of its particles to diffuse. It is also called **suction pressure** (S.P.), the pressure with which water enters into a cell.
- **Diffusion pressure deficit** (D.P.D) is the reduction in the diffusion pressure of water over its pure state.
- Diffusion pressure of a **pure solvent is maximum** and it decreases with the addition of solute.
- Water moves from a system with **low D.P.D.** to a system with **high D.P.D.**
- When water diffuses into a cell through the process of osmosis the cell becomes swollen, thus swollen cell is called **turgid cell**.
- A system have two or more types of diffusing particles, eg., oxygen and carbon dioxide.
- Each diffusing substance exerts its own diffusion pressure called **partial diffusion**.
- Particles of different substances diffuse according to their own partial pressure.
- Tendency of different substances to diffuse according to their own partial pressures or concentrations is known as **independent diffusion**.
- Outward pressure exerted by plasma membrane on the cell wall is called **turgor pressure**.
- Inward pressure exerted by cell wall on the plasma membrane is called **wall pressure**.
- The values of turgor pressure and wall pressure are equal.
- In a flaccid cell **suction pressure is equal to osmotic pressure**.
- Suction pressure in a turgid cell and turgor pressure in a flaccid cell is **zero**.
- In a turgid cell **osmotic pressure is equal to turgor pressure**.
- When water moves along the energy gradient free energy is liberated. The amount of energy liberated from a substance when its potential energy is converted into kinetic energy is called **free energy**.
- Free energy present in 1 mole of a substance (Avogadro no. of substance 6.023×10^{23}) is called **chemical potential**.
- Chemical potential of water is called **water potential**.
- The term **water potential** is **used in the place of D.P.D. and SP.** The difference between free energy of water in a system and free energy of pure water at atmospheric pressure is also called **water potential**.
- The term water potential was proposed by **Slatyer and Taylor**.
- **Symbol** of water potential is ψ.
- Water potential of pure water is **zero**.
- When a solute is added to pure water, **water potential of solution decreases** and is expressed in **–ve values**.
- Water potential is measured in **bars**. **1 bar = 0.998 atm** (0.987 atm) or **10^6 dynes/cm^2.**
- The difference between water potentials of two solutions is expressed as **$D\psi W$**.
- If y *W* value of cell *A* is - 2 bars and y *W* value of cell *B* is - 10 bars water diffuses into *B* cell. Therefore water moves from a system **with a high water potential to a system with low water potential**.
- Potential required for the entry of water into a solution is called **osmotic potential**.
- Osmotic potential has a **–ve value** and its symbol is **yp (ys)**.
- The **symbol for pressure potential** is ψ ***P***.
- Pressure potential is **used in the place of turgor pressure**.
- The **relation between water potential, osmotic potential and pressure potential** can be represented as : $\psi W = \psi\pi + \psi P$.
- Entry of water into a cell through a plasma membrane is called **endosmosis**.

- Exit of water from a cell through a plasma membrane is called **exosmosis**.
- Solution that has the same osmotic concentration as that of another solution is called **isotonic**.
- Solution having an osmotic concentration lower than that of another solution is called **hypotonic solution**.
- Solution which has an osmotic concentration higher than that of another solution is called **hypertonic solution**.
- If a cell is placed in hypotonic solution **endosmosis takes place.**
- If a cell is placed in hypertonic solution **exosmosis takes place.**
- If a cell is placed in isotonic solution **no changes occur** which means that number of molecules entering into cell is equal to number coming out.
- Shrinkage of plasma membrane or protoplast from the cell wall due to exosmosis is called **plasmolysis**.
- The cell showing plasmolysis is called **plasmolysed cell**.
- In a plasmolysed cell **turgor pressure is zero** and space between cell wall and plasma membrane is **occupied by hypertonic solution**.
- Cell wall is **permeable** to solution.
- Stage at which plasma membrane or protoplast showing starting of shrinkage is called **incipient plasmolysis**.
- When a plasmolysed cell is placed in a hypotonic solution endosmosis takes place and this phenomenon is called **deplasmolysis**.
- Lower epidermal cells of *Tradescantia* leaves are generally used for the demonstration of plasmolysis because their cells contain **anthocyanin pigments**.
- Saprohytic bacteria or fungi cannot survive on **salted dishes due to plasmolysis**.
- Weeds are killed by adding salt. The principle involved is **plasmolysis**.

ABSORPTION OF WATER AND ASCENT OF SAP

- Land plant absorb water mainly from the **soil**.
- For this the roots must be metabotically active, respiring and continuously growing.
- Roots are usually restricted to that area of soil which lies well above the water table.
- Soil has several **types of water - capillary, gravitational, hygroscopic, combined and water vapours.**
- The chief source of water to the soil is **rain**.
- Other sources of water to the soil are **water table, melting of snow or ice** and **irrigation of fields**.
- **Water table** is the depth at which the earth crust is saturated with water.
- The total amount of water present in the soil is called **holard**.
- Available water to the plant is called **chesard** and water which is not available to plant is called **echard**.
- The **capillary water** is readily available to the plants and it is the main source of practically all the water absorbed by plants.
- **Field capacity** is the maximum amount of water a soil can hold after gravitational flow has stopped.
- Water beyond field capacity causes **water-logging**.
- Water logging **reduces soil oxygen and decreases water absorption.**
- Under water logging conditions the soil air is expelled out and plants fail to survive due to **deficiency of air in the soil**.
- If the amount of water in the soil is less than field capacity, the **plants show symptoms of wilting**.
- Water is absorbed by plants in **small quantity** in the saturated atmosphere.
- Most of the water absorption occurs **through roots** from the soil.
- Plants **absorb all gases and nutrients which are dissolved in water.**
- Region of root useful for absorption of water is **root hair region** or **piliferous zone**.
- Structures useful for absorption of water in piliferous zone are **root hairs**.
- Root hairs serve to **increase the area of contact between the root surface and soil.**
- **Kramer** recognized two distinct mechanisms which independently operate in the absorption of water plants.
- **Two mechanisms of water absorption** are –
  - **Active absorption –** Water is absorbed **by the roots** *i.e.* roots takes part actively in absorption and the pressure responsible for absorption develops in roots itself.

– **Passive absorption** – Water is absorbed **through** the roots *i.e.* the roots are passively involved in the absorption. The pressure responsible for pull of water develops in the shoot.

- Absorption of water due to activity of root itself is called **active absorption**.
- Cell sap of root hair usually possesses **higher OP (2 - 8 atm)** compared to OP of soil water (< 1 atm).
- Water always moves according to the **potential gradient**.
- Soil water with **high potential gradient** moves into **root, stem, leaf** and **finally reaches atmosphere** having **low potential gradient,** in the form of water vapour.
- Active absorption takes place according to the principle of **osmosis** and it **requires energy**. (**According to Renner**, active absorption of water occurs in the absence of **transpiration**.)
- **Osmotic theory of active absorption** was proposed by **Atkins** and **Priestly**.
- **Osmotic theory of active water absorption** states that entry of solute as well as water at the surface of cell membrane takes place due to **imbibition by cell wall of root hairs**.

Principle involved in osmotic theory of active water absorption

High O.P. and low T.P. in root hairs
↓ causes
Increase in D.P.D. (in root hairs)
↓ results in
Endosmosis
↓
Absorption of water by root hair
↓ results in
Increase T.P. and thus D.P.D. is decreased in root hair with respect to adjacent cell
↓
Same process, *i.e.*, Increase in T.P. and decrease in D.P.D. occurs in the cells of intermediate channels like cortex, endodermis etc.
↓ thus
Water finally reaches to xylem

- Absorption of water against concentration gradient utilising respiratory energy is **non-osmotic theory of active water absorption**.
- The factors such as low temperature, poor O_2 supply etc. **reduces the rate of respiration and water absorption**.
- **Auxin** increases the rate of respiration as well as water absorption.
- Absorption of water due to pressure developed in shoot is called **passive absorption**.
- Passive absorption of water is due to **transpiration pull**.
- Passive absorption of water was proposed by **Kramer** and **Lachenmeir**.
- The **theory of passive absorption works on the following principle**.

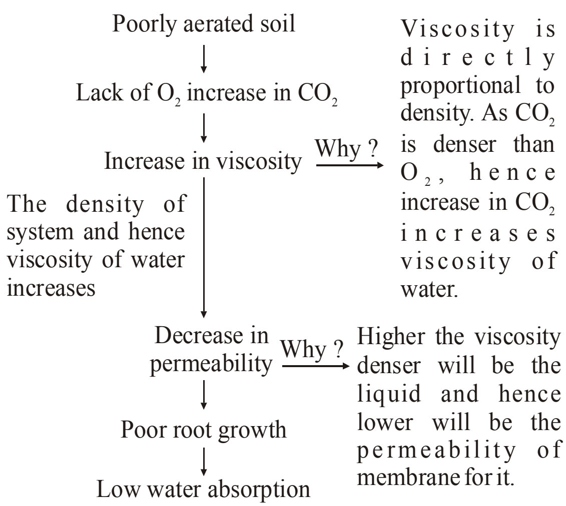
Loss of water in mesophyll cells due to transpiration
↓ causes
Decrease in T.P.and hence increase in D.P.D
↓ causes
Water absorption by mesophyll from adjacent xylem cells
↓
This creates transpiration pull
↓
This pull is transmitted downwards upto roots
↓ which is
Removed after absorption of water from soil

- Movement of water from root hairs to the xylem vessels through cortical cells is called **lateral** or **radial conduction of water**.
- This movement of water occurs according to the **osmotic potential gradient**.
- Plant absorbs water between **field capacity** and **permanent wilting percentage**.
- If loss of water from aerial parts of a plant (transpiration) exceeds the rate of absorption, plant wilts.
- The partial loss of turgidity which does not cause visible wilting is known as **incipient wilting**.
- If plants fails to regain their original stage due to general loss of turgor, **stage represents permanent wilting.**
- In herbaceous plant during summer season, plant wilt during hot days and regain their turgidity and freshness during night, the type of wilting is called as **temporary wilting.**
- Wilting is observed usually in those plants in which tissues are made up of thin walled. Parenchymatous cells are **responsible for maintaining the turgidity in plants.**

- **Permanent wilting percentage (PWP)** is the percentage of water on the dry weight basis of the soil that is present in the soil when the plants growing in it fresh, touch the condition of permanent wilting.
- This value varies between 1–15% and depends upon the texture of soil, e.g., clay has higher PWP than sand.
- No water is absorbed **below permanent wilting percentage** or wilting coefficient.
- No water is absorbed in **frozen soil** as frozen soil is **impermeable** for water.
- Rate of water absorption decreases below 20°C because of **increased viscosity of water**, **decreased permeability of membrane**, **poor root growth** and **low metabolic rate**.
- Water is generally absorbed when concentration of root hair cell sap is **more than outer soil water**.
- Upward movement of water (sap) through xylem against the force of gravity is called **ascent of sap**.
- Ringing experiments were proposed by **Malpighi** and **Stephen Hales** to demonstrate that ascent of sap takes place through xylem vessels.
- **Types of theories to explain ascent of sap** are – **vital theories**, **root-pressure theory** and **physical theories**.
- Theories which consider the **living cells responsible for ascent of sap are vital theories**, eg. **relay pump theory, pulsation theory** etc.
- Scientists who proposed vital theories are - **Godlewski**, **Mac Dougel** and **Jagadish Chandra Bose**.
- According to **relay pump theory** (clambering theory) proposed by **Godlewski (1883),** ascent of sap takes place due to rhythmic changes of O.P of xylem parenchyma cells.
- **Pulsation theory** was proposed by **J.C. Bose**, (1923).
- The plant used by J.C. Bose is *Desmodium gyrans*.
- According to pulsation theory ascent of sap takes place due to the **pulsating activity of living cells of innermost layers of cortex**.
- Ascent of sap occurred even after **killing the living tissues** with picric acid and cyanides. This was reported by **Strasburger (1891)** and thus discarded vital theories.
- The term **root pressure** was coined by **Stephen Hales**.
- A positive hydrostatic pressure developed in roots due to accumulation of absorbed water is called **root pressure**. This theory was proposed by **Priestley** (1916).
- Root pressure can be measured by **manometer**.
- Maximum root pressure in plants will be around **2-3 bars** (0.2 - 0.3 MP). 1 MP = 10 bars.
- **Root pressure theory explains mechanism of ascent of sap in herbs.**
- Root pressure theory is not acceptable because **root pressure is absent in gymnosperms and actively transpiring plants**, though ascent of sap occurs in them.
- Ascent of sap also takes place after the **removal of root system** (reported by Strasburger).
- Root pressure exhibits **negative tension**.
- Water drops formed at the margins of leaves of grasses after humid warm nights are the **best evidence of root pressure**.
- The exudation of water in the form of liquid from the aerial parts of a plant is called **guttation**.
- In *Saxifraga* guttation is more during flowering season.
- **Cavitation** is the formation of water vapour pocket, which puts a "break" in chain and stops flow.
- Theories which consider the physical forces are responsible for ascent of sap are called **physical theories**.
- **Capillary theory** (1874) was put forward by **Bohm** (1863).
- Unger (1869) and Sachs (1874) proposed **imbibition theory**.
- **Dixon and Jolly** (1894) proposed **cohesion-tension theory**.
- **Cohesion-tension theory is widely accepted** physical theory for ascent of sap.
- **Main principles involved in ascent of sap** are –
  - Adhesive forces of water
  - Cohesive forces of water
  - Transpiration pull.
- **Backbone of cohesion-tension theory** is high surface tension of water.
- Surface energy of water is available to surface films of water. As a result water molecules are adhered to the **innerwalls of xylem vessels**.
- Water molecules are attached to one another due to their cohesive forces (cohesion). As a result **water column is formed in xylem vessels**.

- Water column extends upto the **vein endings** of leaves.
- Main force useful for ascent of sap is **transpiration pull**.
- Wall surfaces of mesophyll cells lose water thereby water potential decreases in **mesophyll cells**.
- **Water potential gradient** is established between mesophyll cells and xylem vessels of root.
- **Transpiration pull** is a force developed in mesophyll cells due to transpiration.
- Tension developed in mesophyll cells is transmitted to the root system through **xylem vessels**. Due to this tension developed in the mesophyll cell water volume is pulled to the upper part of the plant.
- If concentration of soil water is high due to dissolved salts (saline soil), there are chances of exosmosis. Such soils are called **physiologically dry soils**.
- Absorption of water proceeds more rapidly in well aerated soil as compared to those which are not.
- In poorly aerated soil root growth is poor and thus **water absorption is low**.

In poorly aerated soil, O_2 concentration reduces and CO_2 increases. If O_2 concentration in soil is low, rate of respiration of root cells is reduced and thus influence (reduces) metabolic activity. Reduced metabolic activity causes poor root growth and hence low absorption of water.



- In poorly aerated soil, water is absorbed slowly also **because of increased viscosity of water and poor permeability of membrane.**
- **When transpiration is low**, the root has to take part actively in absorption. Thus slowly transpiring plants show active absorption.
- **When transpiration is high,** the tension developed in mesophyll cells pull water upwards. There, roots do not play any significant role rather work as mere intermediate channel in water absorption. Thus rapidly transpiring plants show passive absorption.
- The aerial roots of epiphytic roots have **specialized tissue (velamen)** for absorbing rain water and condensed water vapours.
- **Soil plant atmosphere continnum** (SPAC) is the pathway for water moving from soil through the plant to the atmosphere.
- The transport of water along this pathway occurs in separate components, defined differently between three scientific disciplines of the environment.

TRANSPIRATION

- The loss of absorbed water in the form of vapours from the living tissue of aerial parts of the plant is termed as **transpiration**.
- A very small fraction of water absorbed by plant **(generally less than 5%) is utilized in plant development and metabolic processes** and the remaining is lost in the process of transpiration,
- It is also estimated that loss of water from a forest is about 36,400 litres per acre per day.
- A **corn plant** may **transpire upto 54 gallons of water** in one growing season (which equals to about 100 times of its own weight).
- From a **deciduous forest**, during one complete year, the water loss can be equal to 30% of rainfall of the area.
- In a **crop**, 90 to 500 kg of water is lost for the production of 1 kg of dry matter.
- **Transpiration ratio** or **water requirement** or **efficiency of transpiration** is the amount of water transpired by a plant for the synthesis of a unit dry matter.
- Transpiration ratio gives an idea of the **requirement of water/irrigation by crops**, shrubs and trees.

- Transpiration is useful for **passive absorption of water.**
- Transpiration is **responsible for mass flow or bulk flow of mineral along with water.**
- The pressure developed by transpiration is responsible for **ascent of sap**.
- It is useful for temperature regulation in plants because heat is removed by transpiration.
- Water deficit formed due to transpiration **leads to wilting and injury in plants.**
- Some chemicals when sprayed on leaves reduce the rate of transpiration. Such substances are called **antitranspirants**.
- Antitranspirants are of **two types - metabolic inhibitors and surface films**.
- **Metabolic inhibitors** reduce transpiration by reducing the stomatal opening for a period of two or more weeks without influencing other metabolic processs. The most promising of these inhibitor is phenyl mercuric acetate (PMA, 10^{-4} M). Another is abscissic acid (ABA).
- **Film forming chemical** check transpiration by forming a thin film on the transpiring surface. They are sufficiently permeable to carbon dioxide and oxygen to allow photosynthesis and respiration but prevent movement of water vapours through them.
- The important chemicals of this group are silicon emulsions, colourless plastic resins and low viscosity waxes.
- When crop plants are suffering from water deficit, antitranspirants are given as **foliar spray**.
- Common experiment used to demonstrate transpiration is **bell jar experiment**.
- Chemical used in transpiration experiments is **cobalt chloride**.
- The diagramatic representation of the size of stoma at different times of the day is **stomatal clock (prepared by Von Mohl)**.
- **Potometer** is an instrument for measuring the rate of transpiration by shoots by measuring the rate of their water absorption.
- **Porometer** is an instrument for measuring the degree of stomatal opening.
- **Psychrometer** is an instrument for measuring both the relative humidity and transpiration.
- **Tensiometer** is an instrument used for measuring soil-water tension.

Types of transpiration

- Transpiration is of **four types** : **cuticular**, **stomatal lenticular** and **bark transpiration**.
- **Cuticular transpiration** is the loss of water in vapour form from the general surface (leaves and young stems) through the layer of cuticle.
- Cuticular transpiration continues throughout the **day and night**. About **10%** of water is lost by this type of transpiration.
- **Stomatal transpiration** is the loss of water in the vapour form from stomata present on the surface of leaves and to a lesser extent from the surface of flowers and young stems (cauline transpiration).
- Stomatal transpiration occurs only when **stomata are open**. About **90%** of the total transpiration occurs through stomata.
- Transpiration which occurs through stomata of leaves is called **foliar transpiration**.
- **Lenticular transpiration** occurs through the lenticles which are small regions on bark and bears small loosely arranged cells called complementary cells. Negligible amount of water is lost through lenticular transpiration.
- Lenticular transpiration is the **main method of water loss from deciduous trees after leaf fall.**
- Lenticular transpiration **continues throughout day and night**.
- A very small quantity (0.17%) of water is lost from the corky bark of the stem. It is known as **bark transpiration**.
- **Mayor (1956)** has reported that some of the herbaceous plants, under favourable conditions, transpire the entire volume of water which a plant has and it is replaced within a single day.

Stomata

- Stem and leaf epidermis are provided with numerous pores called **stomata**. The number of stomata per sq. cm of leaf epidermis is variable.
- **Stomata** are **meant for gaseous exchange** during photosynthesis and respiration but **also the main source of transpiration**.
- Stomata consists of two guard cells, which are

generally bean shaped or kidney shaped, but in grasses they are dumbell shaped.

- The guard cell usually measured 45 × 15 micron in size and they cover just 1 - 2% of total leaf area.
- Stomatal width increases when they are close.

Type of plant	Type of stomata	Location of stomata
Apple and mulberry type	Hypostomatous	On the lower surface of leaf, eg, apple, peach
Potato type	Amphistomatous	On both surface of leaf but numerous on the lower surface, e.g. potato, bean.
Oat type	Isostomatous	Equally distributed on both the surfaces of leaf, eg. wheat, rice, potato, bean.
Water-lily type	Epistomatous	Only on the upper surface of leaf. These are found in plants with floating leaves.
Potamogeton type	Astomatous	Either absent or non-functional. This is characteristic feature of submerged hydrophytes.

- They enclose a tiny opening called **stomatal pore or stoma.**

	Type of stomata	Nature of stomata
1.	**Barley or cereal type** (dumb-bell shaped), eg. maize, wheat.	Open for a few hours during the day.
2.	In **Alfafa or leucerne type,** eg. pea, bean, grape	Remain open throughout the day, close at night.
3.	In **Potato type**, eg. potato, *Cucurbita*, bananas	Open throughout day and night but close for a few hours in case of water deficiency.
4.	In *Equisetum* **type**, eg emergent hydrophytes	Remain open and seldom close.

- The term stomatal apparatus is then applied to the opening as well as guard cells and guard cells may be surrounded by varying number of specialised epidermal cells called subsidiary or accessory cells.
- Stomatal opening **depends upon availability of K^+ ions from adjacent epidermal cells.**
- A number of other minerals are also essential for stomatal movemets, *e.g.*, P, N, Mg, Ca, etc.
- When guard cells are **fully turgid**, **stoma opens**. When guard cells are in **flaccid state**, **stomata closes**.
- Based on stomatal distribution, plants are divided into categories - **apple and mulberry type, potato type, oat type, water lily type, potamogeton type.**
- Depending upon the periods of opening and closing stomata are of four types as given below.
- **Main theories about the mechanism of stomatal movement are** –
  - **Guard cell photosynthesis theory** - Given by **Schwendener (1881)** and also hinted by **Von Mohl (1856)**.
  - **Starch hydrolysis theory** - First given by **Llyod**. Formulated by **J.D. Sayre (1923)** and modified by **Steward (1964)**.
  - **Malate or K^+ ion pump hypothesis** - Proposed by **Levitt (1974)** and elaborated by **Raschke (1975)** and **Bowling (1976)**.
- In night guard cells become flaccid in absence of sugar which is only formed by photosynthesis and **stomata become closed**.
- **Guard cell photosynthesis theory may be represented as** –

Chloroplast in guard cells
↓ Photosynthesis in day time
Formation of sugar in guard cells
↓
Osmotic concentration in guard cell increases
↓
Induces water absorption from adjacent cells
↓
Guard cells turgid
↓
Stomata open

- **Objections to guard cell photosynthesis theory** are –
  - Photosynthetic activity of the guard cell chloroplasts is not confirmed.
  - Sugar does not occur in detectable quantity in the guard cells.
  - In some plants stomata open during night.
- **According to Llyod** (1908), **the conversion of starch into sugar** in the day time and *vice versa* at night causes opening & closing of stomata. **Sayre** (**1926**), **Scarth** (**1932**) **suggested** that this conversion is **controlled only by pH of the guard cells** whereas **Steward** (**1964**), regards that this is partly enzymatic and partly controlled by pH.
- **Starch-hydrolysis theory may be represented as-**

In day time

CO_2 of intercellular spaces
↓ photosynthesis
Starch
↓ H^+ concentration lowers and enzyme phosphorylase activates
Glucose-1-phosphate
↓ phosphoglucomutase
Glucose-6-phosphate
↓ phosphate
Glucose + phosphate
↓
OP & OPD of guard cell increase
↓
Water absorption by guard cells from adjacent cells
↓
Guard cell become turgid and swell
↓
Stomata open

In dark

Glucose
↓ pH decrease due to accumulation of CO_2 in substomatal cavity
Glucose - 1 - phosphate
↓
Starch
↓
OP & OPD of cell sap decreased
↓
Guard cell become flaccid
↓
Stomata close

- **Objection of starch-hydrolysis theory** are –
  - Glucose does not occur in detectable quantity in the guard cells of open stomata.
  - Starch ⇌ sugar interconversion is too slow to account for rapid stomatal opening and closing.
- **According to Levitt** (1974), opening and closing of stomata is controlled by active K^+ transport and pH of guard cells.
- **Theory of K^+ transport and hormonal regulation may be represented as** –

During daytime

↓
Rise in pH
↓
Hydrolysis of starch
↓
PEP
↓ PEPcase, CO_2
OAA
↓
Malic acid in guard cells
↓
H^+ + malate ions
↓ K^+ ion exchange from subsidiary cells
K^+ + malate ion
↓
Osmotic pressure of guard cells increase
↓
Endosmosis
↓
Stomata open

During night time

↓
CO_2 conc. increases in substomatal cavity
↓
ABA participation
↓
K^+ ion exchange stopped
↓
K^+ ion back into subsidiary cells
↓
pH decreased
↓
Synthesis of starch
↓
Osmotic pressure decreases
↓
Exosmosis
↓
Stomata close

- **Scotoactive stomata** are stomata which **open in dark and close during daytime.** These **occur in succulents.**
- Both **red and blue lights** stimulates stomatal opening though blue light is slightly more effective.
- In dry weather, stomata tend to close while in humid environment they remain open for longer period.
- **Rise in temperature** induces stomatal opening and *vice-versa.*
- At 38° - 40°, stomata open even in dark.

Factors affecting transpiration

- Transpiration is **directly proportional** to the **light intensity, temperature, wind velocity, leaf surface area, root-shoot ratio, number of stomata**.
- Transpiration is **inversely proportional** to **CO_2 concentration** and **atmospheric humidity**.
- Low **carbon dioxide** concentration induces stomatal opening and *vice-versa.*
- Increase in carbon dioxide causes **stomatal closure** hence reduce transpiration.

External factors

- *Light* – Light increases transpiration through opening of stomata and increased protoplasmic permeability.
- *Temperature* – The temperature of the leaf is slightly higher than the environment. Increase in temperature brings about an increase in vapour pressure gradient thus increases transpiration.
  For eg., at 30°C a leaf may transpire three times as fast as it does at 20°C.
- *Humidity* – Increase in humidity decreases transpiration & *vice-versa*.
- *Atmospheric pressure* – The rate of transpiration is inversely proportional to atmospheric pressure.
- *Availability of soil water* – Transpiration is directly influenced by availability of water. Reduced availability of soil water causes wilting or loss of turgidity resulting in drooping & rolling.
- *Wind velocity* – Wind has an significant effect on transpiration. Air movement increases the rate of transpiration by bringing dry air and removing moist air around the transpiring material. High velocity wind, however, closes stomata.

Internal factors

- *Structure of leaves* – Thick cuticle, waxy coating on leaves, sunken stomata, covering of dead hairs on leaves decreases transpiration, therefore these **adaptation are found in xerophytes**. Reduced leaf area reduces the rate of transpiration as in succulents. (cacti or euphorbias). Plants possessing broad leaves show high rate of transpiration (due to increase surface area) and *vice-versa.*
- *Root-shoot ratio* – The roots absorbs water and the leaves transpire. If the rate of absorption becomes slower than transpiration, the latter is also decreased correspondingly. According to Parker, 1949 the transpiration increases with the increase of root-shoot ratio.
- *Stomatal frequency* – The rate of transpiration is directly proportional to the stomatal frequency (no. of stomata per unit of leaf area). Rate of transpiration will be high in leaves having more stomata per unit area.

Significance of transpiration

- It controls the rate of absorption of water from soil.
- It helps in absorption of mineral salts.
- It is responsible for ascent of sap.
- It regulates the plant temperature by contributing to cooling of leaves and also the surroundings.
- It protects the leaves from heat injury, particularly under conditions of high temperature and intense sunlight.
- Transpiration causes loss of huge amount of water absorbed by plants. Also water deficit formed due to transpiration leads to wilting and injury in plants. It often produces water deficit in plant which check photosynthesis, reduces growth and if too severe may cause death from dessication.
- Inspite of various disadvantages the plant cannot avoid transpiration due to their peculiar structure of leaves which is basically meant for gaseous exchange during respiration and photosynthesis. Therefore **transpiration is also regarded as "necessary evil" by Curtis (1926) or "unavoidable evil" by Steward (1959)**.

GUTTATION

- Loss of water as droplets from the tips and margins of leaves is called **guttation**.
- The term guttation was coined by **Bergerstein**.
- Guttation takes place through **hydathodes** and the motivative force is **root pressure**.
- **Hydathodes** are stomata like pores generally present at the tip or margins of leaves of those plants that grow in moist shady places. (e.g., *Tropaeolum*).
- Pores are present over a mass of loosely arranged cells with large intercellular spaces called epithem.
- For this the roots must be metabolically active, respiring and continuously growing.
  The term **bleeding** simply means a **slow exudation** of **water sap from a cut or injured part of plant**.
- The exudation of latex in the para rubber tree is the best example of this type.

End of the Chapter