Uttar Pradesh Rajarshi Tandon
Open University

UGBY-102

Bachelor of Science

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Block

1

Plant Physiology I

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Course Introduction

The term physiology (Gr Physis=nature and logos = study) means the study of functions and vital process of living organism. As we know that plants are also living organism, therefore the study of vital processes of plant is known as plant physiology. The physiological processes of plant includes biophysical and biochemical reactions in side the plant. The plant physiology is divided into physical aspects, plant metabolism, growth and development.

The physical aspects includes study of soil, water relation including absorption, translocation of water and transpiration. The plant metabolism includes photosynthesis and respiration. The photosynthesis is an anabolic reaction in which synthesis of food occurs where as respiration is a catabolic process in which break down of food substrate takes place. The growth and development includes physiology of growth, growth hormones, photoperiodism and vernalization. The plant physiology is an interdisciplinary approach and has role in other branches of botany like morphology, anatomy, taxonomy, embryology, ecology, cell biology, cytology, genetics, molecular biology etc. when you are studying this SLM you will go through a variety of topics of plant physiology. This is a 2 credit course containing 2 blocks in which block I and II deals with plant physiology 1 and 2 respectively.

Plant physiology

Block I- Plant physiology I

Block II- Plant physiology II

Block I- has 4 units in which you are going to study some basic concepts i.e. physiology of absorption of water, the upward translocation of absorbed water and water loss or transpiration in plant.

Block II- has 4 units in which you will study the mineral nutrients and their absorption by plant, physiology of photosynthesis occurring in plant, hormones and their role in vegetative and reproductive growth of plants and physiology of respiration.

Block-I

Plant Physiology I

This block has four units 1, 2, 3 and 4. Unit 1 deals with concept of diffusion, imbibition, osmosis and water potential. The knowledge of these concepts is must for understanding the various physiological phenomenon occurring in plant. The unit 2 deals with physiology of absorption of water in plants which will inform you the role of water in plant and how plants absorb water. After unit 2, there is unit 3 which deals with ascent of sap means upward translocation of water. First of all water is absorbed from the soil by the root of the plant, then it is translocated to the tip of the plant. After going through this unit you will be able to understand that how does the water get absorbed by the plants. After studying the unit 4 deals with water loss or transpiration. The whole water absorbed by plant is not used by them in their own metabolic activities. After studying this unit you will be acquainted that only a small amount of absorbed water is used by plant and a large amount of water is lost in the environment by the phenomenon of transpiration.

Objectives :

After studying this block you should be able to :

- Know the basic concepts of plant physiology.
- Phenomenon of absorption of water by plant.
- The upward translocation of water from root to the tip of the plant.

The phenomenon of transpiraton occurring in plants.

UNIT-1

The Concept of Diffusion, Osmosis and Water Potential

Structure

1.1. Introduction

Various physiological phenomenon like absorption of water, upward translocation of water, cell to cell movement of water and loss of water occurs in plant. These physiological phenomenon can be explained after knowing the concept of diffusion, osmosis, imbibition and water potential. This unit deals with all above concepts.

Objectives

After studying this unit you should be able to :

- Know the permeability, immpermeability, semipermeable membrane and selectively permeable membrane.
- The imbibition, Imbibition pressure and various factors affecting imbibition.
- Osmosis, experiments to demonstrate osmosis, importance of osmosis, osmotic pressure, turgor pressure and wall pressure.
- Diffusion pressure deficit, plasmolysis, water potential and its various components.

1.2 Permeability

If a body allows the passage of Substances through it , it is said permeable and the property is called permeability. eg. plant cell wall. It allows to pass both- solvent and solute and is permeable (See fig 1.1)

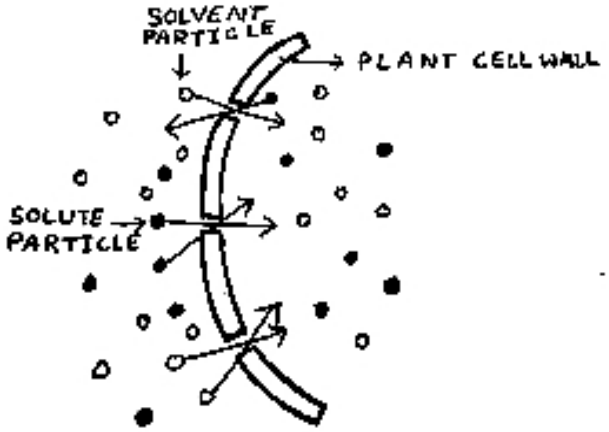

Fig 1.1 Permeability

Source : Concept taken from plant physiology by Dr. H.N. Srivastava

Impermeable:- The body through which neither solute nor solvent can pass eg. cuticle layer. (See Fig 1.2).

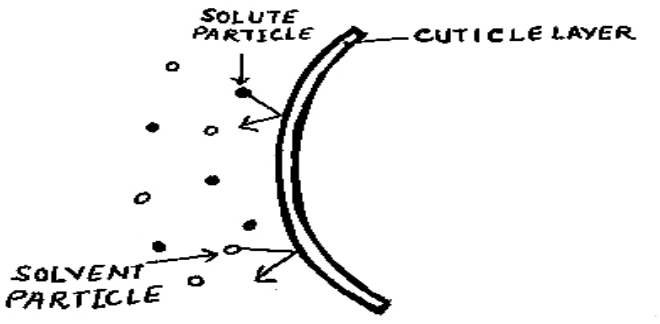

Fig 1.2 Impermeable

Fig 1.2 Source : Concept taken from plant physiology by Dr. H.N. Srivastava

Semipermeable membrane:- Which allows to pass only solvent molecules but not the solute particles eg. cellophane, colloidion membrane (see fig 1.3)

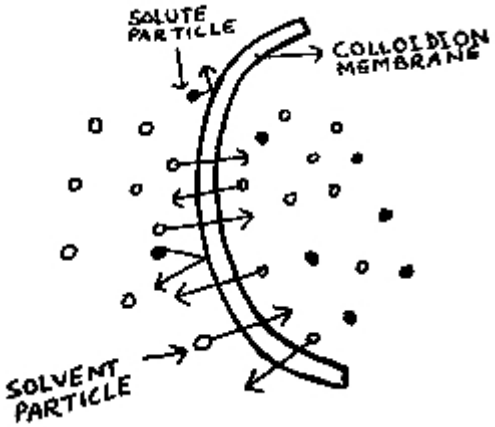

Fig 1.3 Semipermeable

Source : Concept taken from plant physiology by Dr. H.N. Srivastava

Selectively permeable or differentially permeable:- Which allows to pass solute molecule only up to a certain extent eg. biological membrane (See. Fig 1.4)

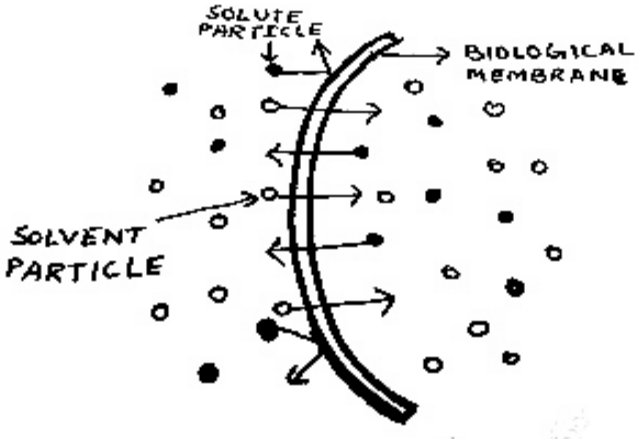

Fig 1.4 Selectively permeable

Source : Concept taken from plant physiology by Dr. H.N. Srivastava

Imbibition :- The phenomenon of adsorption of water or any other liquid by the solid particle without forming a solution is known as Imbibition. In this process the liquid molecules move from the region of the high partial pressure to the lower partial pressure. Thus, we can say that imbibition is a special kind of diffusion where water moves along the diffusion gradient

and water potential gradient exists between the two components of the system.

In humid rainy season, wooden doors and windows absorb water and increase in their volume so that they are hard to open or close. This is becaue of Imbibition.

Imbibition Pressure or Matric Potential :- The pressure developed in an imbibant if submerged in pure imbibing liquid is called imbibition pressure or matric potential.

Factors affecting Imbibition :-

Temperature :- The rate of imbibition increases with the increase in temperature. It is because of increase in kinetic activity of the imbibing molecules.

Concentration of Solute in the medium :- The rate of imbibition decreases with increasing the concentration of solute in the medium.

P^H:- The H^+ concentration and P^H of the medium largely affects the process of imbibition.

Specificity :- An attractive force exists between imbibant molecule and imbibed liquid. If that force is absent imbibition does not occur even if other necessary conditions are fulfilled.

1.3 Diffusion

It is the movement of molecules or ions of a solute or a solvent (Solid, liquid or gas form) from the region of its higher concentration to the region of lower concentration. eg. if a bottle of perfume or ethyl ether is opened a corner of room the odour of perfume can be smelled from an other corner after some time. The diffusion is important in plant because it helps in take of CO_2 and out put of O_2, in transpiration and in the transport of water & minerals (See. Fig 1.5)

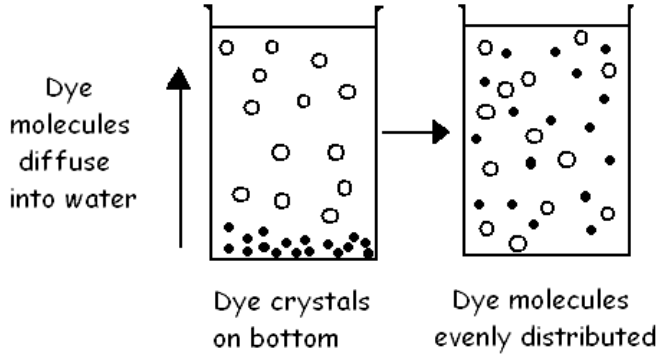

Fig 1.5 Diffusion
Source : www.google.com

Osmosis :- when two solutions are separated by means of a semi permeable membrane the molecules of water or solvent move from region of higher potential (weak solution) to the region of lower potential (Concentrated solution). This movement of water or solvent is called osmosis.

The phenomenon of osmosis can be demonstrated with the help of potato osmoscope and thistle funnel method.

Potato Osmoscope :- Take a large potato tuber and peel off its outer skin and cut its one end to make the base flat now make a hallow cavity in potato tuber nearly upto the bottom and fill the half of the cavity with sugar solution. Mark the level of solution in the cavity by inserting pin in the wall of the tuber. Put the potato in beaker containing a small amount of water and allow the experiment to stand for some time. (see. Fig 1.6)

After that rise in the level of solution in the potato cavity will be observed which is because of osmosis. The wall of potato tuber is of plasma membrane which acts as differentially permeable membrane therefore, water of the beaker flows into the potato cavity and level of solution rises. (see. Fig 1.6)

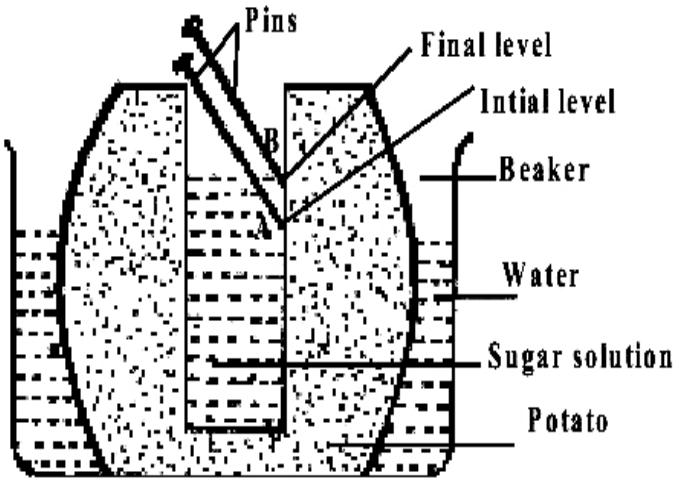

Fig 1.6 Potato Osmoscope
Source : www.google.com

Thistle funnel Method :- Take a thistle funnel and cover its broad open end with cellophane or goat's bladder (both act as semipermealbe membrane) and fill the funnel with salt solution. Mark the level of solution in vertical tube of the funnel. Now submerge the thistle funnel in a beaker having pure distilled water. The concentration of salt solution is greater than pure water present in beaker therefore, water molecules move into the funnel through semipermeable membrane and level of liquid in the vertical tube rises as a result of osmosis. (see fig 1.7)

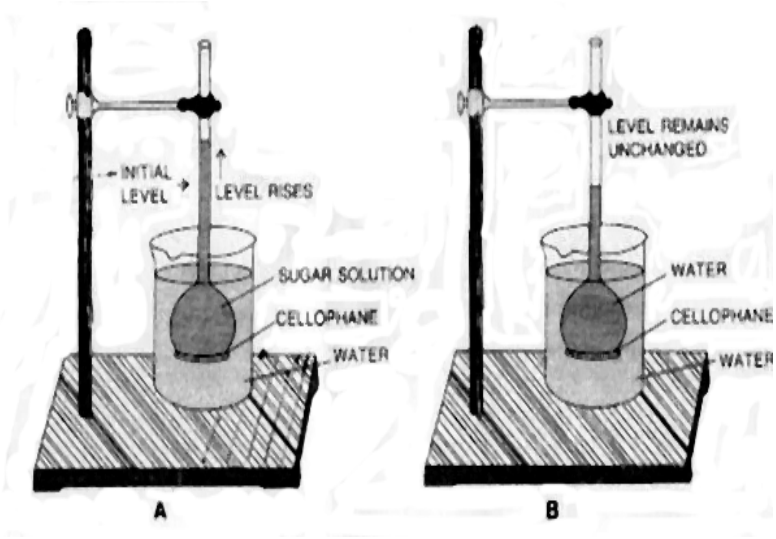

Fig 1.7 Thistle funnel
Source : www.google.com

Types of osmosis: It is of two types-

Ex-osmosis:- In ex-osmosis the movement of water molecule will be from cell sap to outside eg. when fresh grapes are dipped in a water glass having strong salt solution, the grapes will show shrinkage after sometime due to ex-osmosis (see. Fig 1.8)

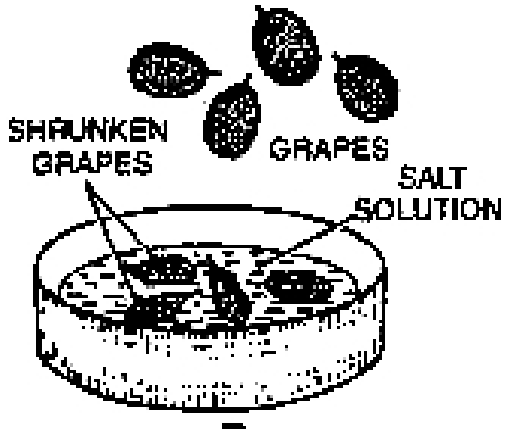

Fig 1.8 Exosmosis
Source : www.google.com

Endosmosis:-

The water molecules enters into the cell sap by simple osmosis eg. when dry raisins are dipped in water or dilute solution, the raisins swell up after some time due to endosmosis (see fig 1.9)

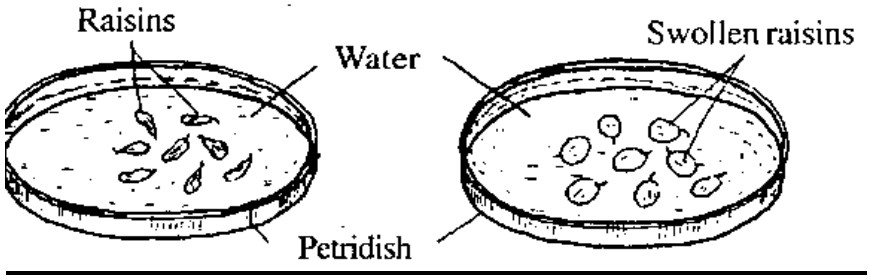

Fig 1.9 Endosmosis
Source : www.google.com

Importance of Osmosis in plant :-

- It is important in the absorption of water by plants.
- Cell to cell movement of water in the plant body is because of osmosis.
- Rigidity of plant organs is maintained due to osmosis.
- Turgidity and expansion of leaf is due to osmotic pressure.
- Turgidity of growing point of root is because of osmosis which helps in penetration in soil.
- Opening and closing of stomata in plant is due to osmosis.

1.4 Osmotic Pressure (OP)

Osmotic pressure is the applied pressure required to stop the phenomenon of osmosis when a solution is separated from pure water by semi permeable membrane (See fig 1.10)

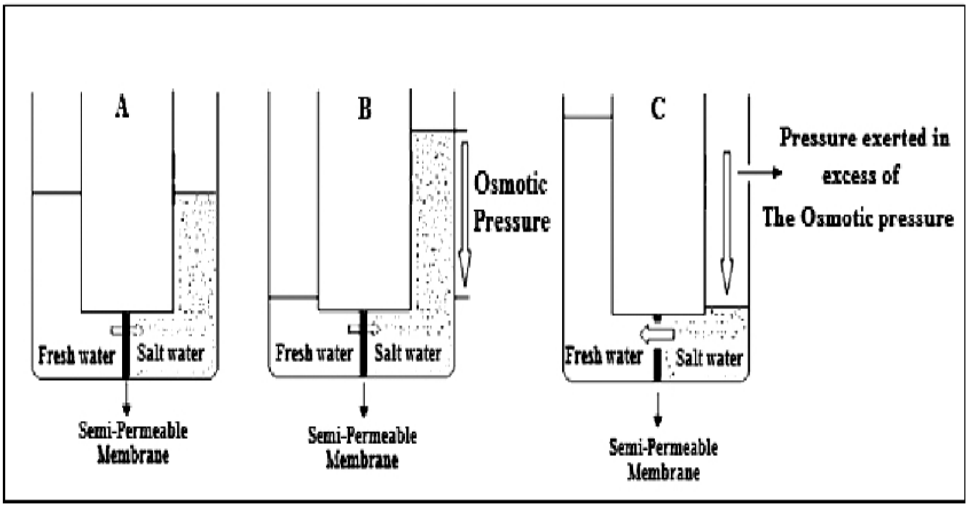

Fig 1.10 Osmotic pressure
Source : www.google.com

Turgor Pressure (TP) : The pressure which develops in a cell due to osmotic diffusion of water, is called Turgor Pressure. During endosmosis the turgor pressure increases gradually in a solution and when it has reached its maximum limit, it is equal to the osmotic pressure. The actual growth of a cell occurs when turgor pressure exceeds wall pressure.

Wall Pressure (WP): Cell wall is rigid and elastic therefore, it exerts an equal and opposite pressure against the expanding protoplasm. This is called wall pressure. At a given time-

TP = WP (see fig 1.11)

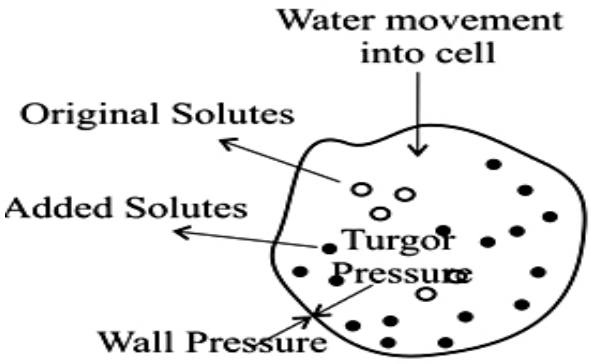

Fig 1.11 TP=WP Plant cell in pure water
Source : www.google.com

Diffusion Pressure Deficit (DPD) or Suction pressure (SP):- A pure solvent is supposed to have maximum diffusion pressure. When certain solute particles are added to the pure solvent, the diffusion pressure of the resulting solution gets lowered. The amount by which the diffusion pressure of a solution is lowered than that of its solvent at the same temperature and atmospheric pressure is called diffusion pressure deficit (DPD)

The relation ship of OP,TP, WP and DPD will be

DPD= OP-WP

WP= TP

DPD=OP-TP

In case of fully turgid cell

OP=TP

DPD= OP-TP

= O

In case of flaccid cell-

TP=0

DPD=OP-TP

DPD=OP

In case of a plasmolysed cell

OP=10 TP= -2

DPD= 10-(-2)

=10+2=12

DPD= more

On the basis of concentration, solutions are of three types:-

1.5 Types of Solution

- **Hypertonic Solution:-**Concentrated solution which can gain water by osmosis
- **Hypotonic Solution:-** Less concentrated solution and can loose water by osmosis.
- **Isotonic Solution:-** Which neither gains water nor looses water by osmosis when separated by semi-permeable membrane.

Plasmolysis:- If a plant cell is placed in a highly concentrated sugar or salt solution, water from the cell sap flows out due to exosmosis through the plasma-membrane outside the cell. Due to this the protoplasm shrinks, separates from the cell wall and assumes spherical shape. This phenomenon is called plasmolysis and cell is called plasmolysed cell.

The first sign of shrinkage of cell contents form the cell wall is called incipient plasmolysis.

If a plasmolysed cell is placed in pure water endosmosis takes place and the protoplasm as well as cell as a whole regain its original shape and size. This phenomenon is called deplasmolysis.

In a plasmolysed cell the space between the protoplasm and cell wall is occupied by external solution and water which was leached out of the protoplasm (See fig 1.12)

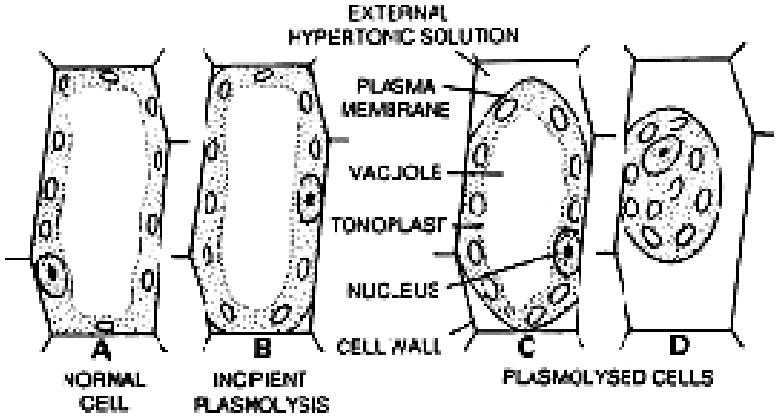

Fig 1.12 Stages of Plasmolysis
Source : www.google.com

1.6 Water Potential

The movement of water can not be accurately explained in terms of difference in concentration but it is explained in term of free energy of the water between the two regions.

"Thus the difference between the free energy of water molecules in pure water and the energy of water in any other water system (eg. water is a solution.) is called water Potential."

The pure water at atmospheric pressure has a water potential zero and presence of solute reduces the free energy and decrease the water potential (negative value). If a difference in water potential exists between the two regions spontaneous movement of water will take place from high water potential (pure water) to the region of low water potential. The movement of water continues until the water potential of the two regions becomes equal. Water potential is designated by symbol Ψ (Psi) and is measured in bars (unit)

Components of water Potential: Cell has a cell wall, vacuole and a layer of cytoplasm between the vacuole & cell wall. When the cell is subjected to movement of water, many internal factors such as matric potential (Ψm), Solute potential (Ψs) and pressure potential (ΨP) determine the water potential of cell sap.

$$\Psi = \Psi m + \Psi s + \Psi p$$

(water Potential)

Matric potential (Ψm) is due to adsorption of water molecules on the surface. It has a negative value and in case of plant and tissue, it has no significance in osmosis then

$$\Psi = \Psi s + \Psi p$$

Solute potential (Ψs) is the amount of solute by which water potential is reduced. It's value is always negative.

Pressure potential (ΨP) is always positive and it operates in a cell as wall pressure and turgor pressure. (see fig.1.13)

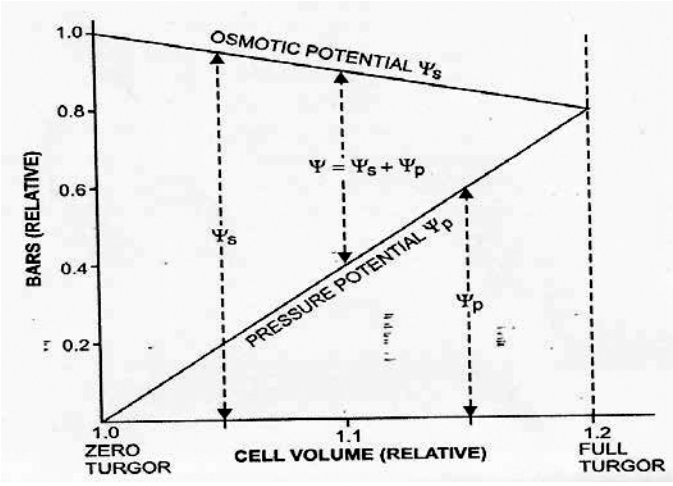

Fig 1.13 Graph showing relationship among osmotic potential (Ψs) ,water potential(Ψ) and pressure potential (Ψp) at zero turgor and full turgor.

Source : www.google.com

1.7 Summary

- The body which allows the passage of substances through it is said permeable.
- The body through which neither solute nor solvent can pass, is called immpermeable.
- The body which allows to pass only solvent molecule is said semipermeable.
- The body which allow to pass solute molecule upto a certain extent is said selectively permeable.
- The absorption of water or any liquid by solid particle is known as imbibition and pressure developed due to imbibition is known as imbibition pressure.
- The temperature, concentration of solute in the medium, pH and specificity affects the imbibition.
- Diffusion is the movement of molecules (solid, liquid or gas) from region of higher concentration to the region of lower concentration.
- Osmosis is the movement of water or solvent from the region of higher potential to the region of lower potential through a semipermeable membrane.
- In exosmosis water moves from cell sap to outside and in end-osmosis water moves from outside to cell sap.
- The osmotic pressure stops the phenomenon of osmosis.
- Turgor pressure develops due to endosmosis and in response to turgor pressure wall pressure develops in a cell.
- The reduction in the diffusion pressure of water in solution over its pure state due to presence of solute in it, is known as diffusion pressure deficit.
- Hypertonic solution can gain water where as hypotonic solution can loose water and isotonic solution can neither gain nor loose water.
- The cell placed in hypertonic solution shows plasmolysis. Their protoplasm shrinks, separates and becomes spherical.
- The difference in free energy of water molecule in pure water and energy of water in solution is known as water potential. Its various components are matric potential, solute potential and pressure potential.

1.8 Terminal Questions

Q.1 What do you mean by water potential? Describe the relationship among matric potential, solute potential, pressure potential and water potential.

Answer:----------

Q.2 Define osmotic pressure (OP), Turgor pressure (TP), wall pressure (WP) and diffusion pressure deficit (DPD). What is their relationship in a plant cell?

Answer:----------

Q.3 With the help of labelled diagram describe the phenomenon of osmosis by potato osmoscope method.

Answer:----------

Q.4 With the help of labelled diagram describe the phenomenon of osmosis by thistle funnel method.

Answer:----------

Q.5 Write short notes on :

(a) Osmosis

(b) Imbibition

(c) Plasmolysis

(d) Turgor pressure

Q.6 Differentiate between :

(a) Osmosis and diffusion

(b) Osmotic pressure and turgor pressure

(c) Semipermeable and differentially permeable membrane.

(d) Permeable and Impermeable.

(e) Exosmosis and endosmosis.

MCQ.

1. Wooden doors swell in rainy season due to :

   (a) Imbibition (b) Osmosis

   (c) Diffusion (d) Plasmolysis

2. Raisins when soaked in a hypotonic solution :

   (a) Shrink (b) Remains the same

   (c) Swell (d) None of these

3. The reverse of plasmolysis is :

   (a) deplasmolysis (b) Imbibition

   (c) Osmosis (d) None of these

4. The movement of water molecule from cell sap to outside is known as :

   (a) Exosmosis (b) Endosmosis

   (c) Imbibition (d) None of these

5. The movement of water molecule from outside to the cell sap is known as :

   (a) Exosmosis (b) Diffusion

   (c) Imbibition (d) Endosmosis

Answers

(1) a (2) c (3) a (4) a (5) d

UNIT- 2

Absorption of Water

Structure

2.1 Introduction

Water is the main content of a plant cell. It is absolutely essential for the protoplasm. The hydration of protoplasm is essential for its proper organization and for correct functioning of the organelles it contains. Thus water is an excellent solvent and a medium for various dissolved substances like gases, minerals, organic substances etc. in the xylem and phloem. Water present in the vacuoles and cytoplasm helps in maintaining the turgidity of cell and the plant as a whole. The various physiological activities in the plant like respiration, photosynthesis, growth and absorption of dissolved substances occur in the plant under turgid conditions. Water also maintains the uniform temperature in the plant tissue. Thin layers of water surrounding the cells are present in the microspace between the solid substance of the cell walls and forms a

continuous network throughout the plant through which movement of dissolved substances take place. The absorption of water also makes up the loss of water taking place in transpiration which helps in maintaining the turgid condition of the cell and the plant as whole.

Objectives

After studying this unit you should be able to :

- Know the soil water relation and water absorbing parts in the plant.
- The mechanism of water absorption, various theories of water absorption and difference between active and passive absorption.
- The concept of apoplast, symplast and cell to cell movement of water.
- The factors which affect absorption of water.

Study guide :

In the last unit you have studied about the concept of permeability, diffusion, osmosis etc. These concepts are required to understand the process of absorption in plant. Therefore, revision of Unit-I is must to understand this unit.

2.2 Role of water in plant :

The main constituent of plant cell is water which performs the following major functions.

(1) Water is an excellent solvent and easily dissolves glucose and amino-acids. All reactions in a cell occur in aqueous medium. Thus water acts as a reagent in various chemical reactions in plant cells.

(2) It maintains the turgidity of plant body.

(3) Uniform temperature in plant tissues is maintained by water.

(4) Water helps in various process of plant like respiration, photosynthesis, growth and absorption of dissolved substances.

Soil water relation

The soil plays an important role in storage of water. The land plants absorb water mainly form the soil. The main sources of water to the soil is rain. The water of the soil can be categorised as-

(1) Gravitational water :- The rain water which gradually penetrates through the dry layers of soil under the influence of gravity is known as gravitational water. This water is not available to the plants.

(2) Capillary water :- The remaining water that is held tightly by hydrogen bonds to the soil particles against gravitational force is

known as capillary water. This water is available to the roots of plant.

(3) Hygroscopic water :- The water held by colloidal soil particles due to cohesive force (force of attraction between same molecules) is called hygroscopic water. Plants can absorb a very small quantity of this water.

Field capacity : The amount of water actually retained by the soil is known as field capacity or water holding capacity of soil. The value of field capacity differs from soil to soil. The capacity of clay soil is 40-50%, silt 20% and sand 5-10%.

Water absorbing parts of the plant

The root system of the plant is mainly responsible for absorption of water. Some of the plants have deep seated root system while others have shallow roots spread out just below the surface of soil. The deep roots are in contact with large and permanent supply of underground water at different levels but surface roots are in contact with water after rainfall.

Absorption of water in plants take place by root system. A root has 4 zones-

(1) Root cap zone

(2) Cell division zone

(3) Cell elongation zone

(4) Root hair zone

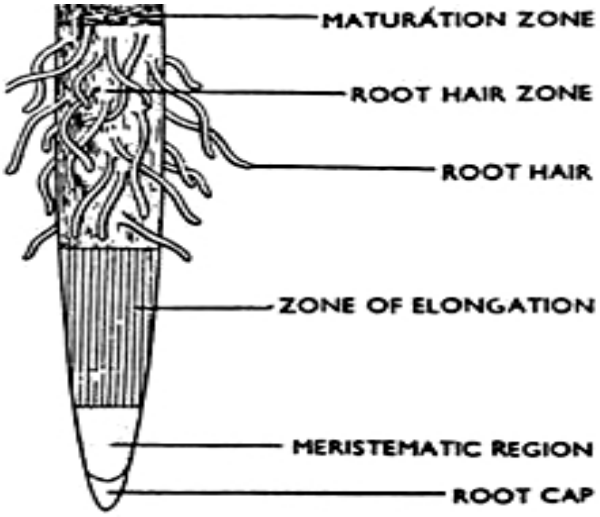

Fig 2.1 Root tip showing different zones of root.
Source : www.google.com

Maximum water is absorbed in the root hair zone. A root hair is the unicellular tubular prolongation of the outer epiblema. The cell wall of root hair is made up of two layer, the outer layer of pectin substance and an inner layer of cellulose. Inside the cell wall there is cell membrane, Cytoplasm and a central vacuole which has cell sap.

2.3 Mechanism of water absorption :-

It is well known that non transpiring plants exhibited the phenomenon of exudation or guttation but the rapidly transpiring plants did not. This indicates difference in the mechanism of absorption of water by these plants. Absorption of water is also known as water uptake. The water molecules are imbibed by the outer pectic layer of the cell wall and then these molecules enter into the cell sap.

Renner (1912, 1915) recognized two mechanism for uptake of water. One for slowly or non transpiring plant that is (1) Active Absorption and other for transpiring plants that is (2) Passive Absorption.

(1) Active Absorption :- In active absorption roots are actively involved means the force responsible for the intake of water develops in the living cells of the roots. The evidence of active absorption of water comes form the phenomenon of exudation or guttation exhibited by non transpiring plant.

The active absorption is of two types.

(i) Osmotic theory of active absorption

(ii) Non-osmotic theory of active absorption.

(i) Osmotic theory of active absorption :- According to this theory water molecules move along the concentration gradient or water potential gradient. The water enters through the cell wall and comes in contact of differentially permeable plasma membrane. The osmotic potential of soil water remains approximately below 2 atmospheres. Where as of cell sap is usally 2-8 atmosphere. There exist a difference in osmotic potential of two sides due to which water molecules move from out side to inside. The soil solution has less osmotic potential and high water potential where as cell sap has high osmotic potential and low water potential. Thus water molecules move due to water potential gradient or along the concentration gradient.

(ii) Non osmotic theory of active absorption :- According to this theory water is absorbed against the concentration gradient. It has been observed that absorption of water also take place if the concentration of cell sap is lower than the soil water. Normally in such conditions exosmosis should take place but still water is absorbed against the concentration gradient. Such type of absorption requires expenditure of energy that comes from the respiration of root cells.

There are evidences in support of relationship between respiration and water uptake-

(1) Repiratory inhibitors such as KCN, Sodium azide, Indolaetic acid inhibits respiration and also reduce absorption of water.

(2) Factors like low temperature lack of O_2 inhibits respiration. It also inhibits absorption of H_2O.

(3) Auxin which increase rate of respiration also promotes water absorption.

The energy released in respiration is not directly involved in water absorption. It probably increases the permeability of cells, absorption and accumulation of salts in the xylem which influences absorption of water.

Passive Water Absorption :- The factors responsible for water absorption develop in the upper part of the plant that is Leaf. Transpiration regulates the passive absorption of water. Due to transpiration the diffusion pressure deficit of the water in the cells of mesophyll increases. As a result water diffuse out of the xylem elements of the leaf into mesophyll cell and a tension develops in the water column present in the xylem elements. The tension developed in the upper part of the xylem element in transmitted downwards and results withdrawal of water from adjoining cells of the root in the root hair zone. The pericycle cells get water from endodermis, cortex and root hair cells. In this way the tension created in the xylem due to rapid transpiration results absorption of water in the root hair zone. Thus water is absorbed passively inwards without involving osmotic force of individual cells.

The observation that the rate of transpiration is approximately equal to the rate of absorption supports the passive absorption of water.

Difference between Active and Passive Absorption of Water

Active Absorption	Passive Absorption
1. Active absorption of water is due to activity of roots specially in the root hairs.	1. Passive absorption is due to the activity in the upper part of the plant like stem and leaves.
2. The Water is absorbed by osmotic and non-osmotic mechanism.	2. The water is absorbed due to the active transpiration process in the upper part of the plant.
3. In osmotic mechanism the root hair has more diffusion pressure deficit (DPD) as compared to soil solution. Therefore, water is taken in along the concentration gradient when soil solution has more DPD as compared to root	3. The passive absorption occurs because of tension created in the xylem sap by transpiration pull. Due to tension, water is sucked from neighbouring cells in the root and

hair. Even then water is taken in against the concentration gradient by non-osmotic mechanism in which energy is required. 4. The pathway of water is Symplast. 5. Evidence for active absorption are- (i) Root pressure (ii) Bleeding (iii) Guttation	simultaneously water enters into the root from soil solution. 4. The pathway of water is apoplast. 5. Evidence for passive absorption can be seen by cutting the roots under water. The absorption of water still occurs if all the roots are removed.

2.4 The Concept of Apoplast and Symplast

This concept was given by Munch in 1930 to explain the flow of water and minerals in plants. According to Munch the dead part of plants like interconnecting cell wall, intercellular spaces, cell walls of endodermis excluding the casparian strips, cell wall of pericycle, xylem tracheids and vessels form a single system, called apoplast. The water moves, through this system due to capillary action or free diffusion along the gradient. On the other hand, the living system including the cytoplasm of all living cells connected through plasmodesmata in their cell walls is termed as symplast. The water moves through this system due to osmosis.

Cell to Cell Movement of Water :- Water is first absorbed from the soil by the root hair and other epidermal cells. Then it moves centripetally across the cortex, endodermis, pericycle and finally to the xylem.

There are three pathways for the movement of water across the cortex :

(i) Through apoplast pathway

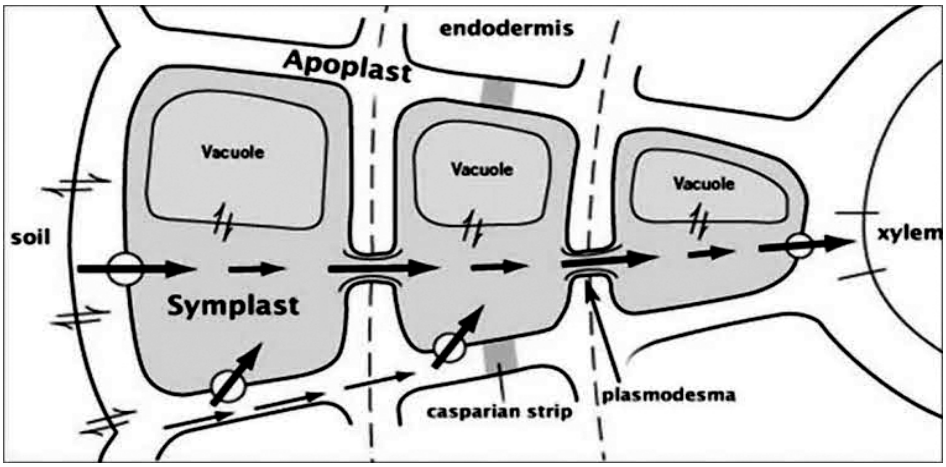

Fig 2.2 Diagram showing apoplast and symplast pathway of water movement in root.

Source : www.google.com

(ii) Through symplast pathway

(iii) Through the living cytoplasmic membranes, cytoplasm and vacuoles of the cortex cells. In this pathway movement of water occurs due to water potential gradient from cell to cell in the cortex and finally reaches endodermis. Then water moves through passage cells of endodermis and enters into the xylem through pericycle. As water enters into the lumen of xylem tracheids and vessels, it moves upwards due to driving forces.

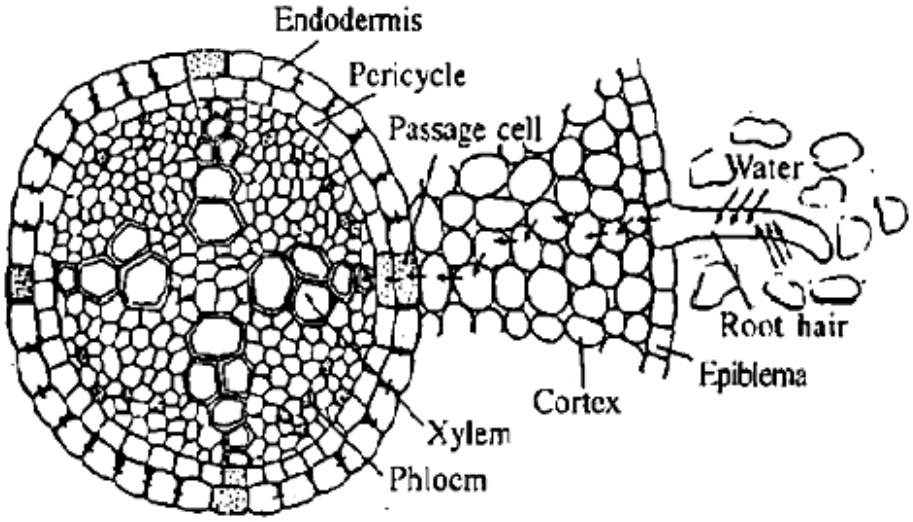

Fig 2.3 T.S of a young dicot root showing lateral transfer of water from root hair to xylem elements across the living cells of cortex.

Source : www.google.com

2.5 Factors Affecting Water Absorption

(i) Temperature of the soil affects absorption. Low temperature reduces absorption of water. Maximum absorption occurs between 20^{0C} to 30^{0C} soil temperature.

(ii) Deficiency of O_2 in soil reduces absorption and accumulation of CO_2 in the soil also inhibits absorption.

(iii) If the soil water is in the form of concentrated solution, it inhibits absorption of water.

(iv) If water in the soil is beyond the field capacity, the absorption is affected.

2.6 Summary

In this unit you have learnt that :

- Water is an excellent solvent and easily dissolves glucose and aminoacids.
- It maintains the turgidity and uniform temperature of plant body. Water is also required for various processes like respiration, photosynthesis, growth and absorption of dissolved substances.
- The rain water which gradually penetrates in soil under the influence of gravity is known as gravitational water.
- The water held tightly by hydrogen bond to the soil particle against gravitational force is known as capillary water.
- Plants absorb capillary water.
- Water held by colloidal soil particles due to cohesive force is called hygroscopic water.
- The amount of water actually retained by the soil is known as field capacity.
- The main water absorbing part of the plant is root which has four zones. Maximum water is absorbed in the zone of root hair.
- There are two mechanism of water absorption i.e. Active absorption and passive absorption.
- In Active absorption the force responsible for the intake of water develops in the living cells of the root.
- There are two theories in active absorption. One the osmotic theory of active absorption in which the water molecules move along the concentration gradient or water potential gradient. The other non-osmotic theory of water absorption in which water is absorbed against the concentration gradient. This absorption requires expenditure of energy.
- In passive water absorption, the factor responsible for absorption of water develop in the upper part of the plant that is leaf.
- The dead part of the plant like inter connecting cell wall, intercellular spaces, endodermis and pericycle, cell wall, tracheids, vessels forms apoplast. The water moves through this system is known as apoplast pathway.
- The living part of the plant is known as symplast. The water moves through this system is known as symplast pathway.
- The factors like low temperature, deficiency of O_2 in soil, high concentration of soil water and water in the soil beyond the field capacity reduces the water absorption.

2.7 Terminal Questions

Q.1 Describe the mechanism of absorption of water in land plants.

Answer:----------

Q.2 Describe the osmotic and non osmotic theory of active absorption.

Answer:----------

Q.3 Differentiate between active absorption and passive absorption.

Answer:----------

Q.4 Describe concept of apoplast and symplast. How water moves cell to cell?

Answer:----------

Q.5 Describe soil water relation and the factors which affects water absorption.

Answer:----------

Short Questions

Q.6 Write short notes on :

(1) Field capacity

(2) Gravitational water

(3) Capillary water

(4) Hygroscopic water

(5) Osmotic theory of Active absorption

(6) Non-osmotic theory of Active absorption

(7) Passive absorption theory

(8) Water absorbing part of the plant

Q.7 Multiple choice questions :

(1) Which water is available to the plant :-

(a) Gravitational water (b) Capillary water

(c) Hygroscopic water (d) None of the above

(2) The water absorbing part of the plant is :-

(a) Stem (b) Root

(c) both (d) None of the above

(3) In which zone of the root maximum water is absorbed :-

(a) Zone of root hair (b) Root cap zone

(c) Cell division zone (d) Cell elongation zone

(4) In which absorption roots are actively involved :-

(a) Active absorption (b) Passive absorption

(c) Both (d) None of the above

(5) In which absorption the factors responsible for water absorption develops in the upper part of the plant :

(a) Active absorption (b) Passive absorption

(c) Both (d) None of the above

2.8 Answers

(1) b (2) b (3) a (4) a (5) b

UNIT- 3

Ascent of Sap

Structure

3.1 Introduction

The ascent of sap in the xylem tissue of plants in the upwards movement of water and minerals from root to the crown. Xylem is a complex tissue consisting of living and non-living cells. The conducting cells in the xylem are typically non-living and include, in various groups of plants, vessels members and tracheids.

The water after being absorbed by the root is distributed to all parts of the plant. In order to reach the topmost part of the plant, the water has to move upwards through the stem. This upwards movement of water is known as ascent of sap.

Starting from the roots to aerial parts of the plant the upward transport of water is called ascent of sap. In the plants the process occurs through xylem tissue. The water absorbed by hairs passes through the cortex passage cells and pericycle enter the tracheary elements of xylem. This takes place either actively through DPD gradient or passively through transpiration pull. Water is lifted upto leaves as a continuous column in

the tracheary elements of xylem by virture one or more forces like root pressure, cohesion and adhesion of water and transpiration pull acting concurrently. This continuous and unbroken transportation of water along with dissolved inorganic mineral salts is called the ascent of sap.

Objectives

After studying this unit you should be able to :

- Know the path of ascent of sap.
- Various theories of ascent of sap like root pressure theory, vital theory and physical theory.
- The most accepted theory of ascent of sap that is transpiration pull and cohesion theory.
- Factors affecting ascent of sap.

3.2 Path of ascent of sap

Water is first absorbed by root hair cells which you have studied in unit 2. After this water moves through root tissues such as certex, endodermis, pericycle and finally enters the xylem tissue. Then water moves upward in the xylem continuously until it reaches the mesophyll tissues of the leaves. The bulk of water enters the mesophyll cells and finally evaporates and transpires through the stomata, only small amount of water is used in the metabolism and growth.

Theories of Ascent of sap :

There are various theories to explain the ascent of sap.

3.2.1 Root pressure theory.

3.2.2 Vital theory.

3.2.3 Physical theory.

3.2.1 Root pressure theory :

Root pressure is the pressure which develops in the tracheary elements of xylem as a metabolic activity of root.

According to this theory root pressure is responsible for upward movement of water. Though root pressure is a dynamic force but this force is not sufficient to drive water to a distance of 400ft tall trees because :-

(1) The magnitude of root pressure is found to be under 2 atmosphere and about 20 atmosphere pressure is needed to raise water to the top of tall trees.

(2) In many plants root pressure is not observed.

(3) Ascent of sap was observed in the plants is which roots were removed.

(4) Root pressure has been found to be lowest during summer when the rate of transpiration is very rapid where as highest in spring when the rate of transpiration is quite low.

(5) Water continues to rise up even in the absence of root pressure.

On the basis of above objections the root pressure theory of ascent of sap can be discarded.

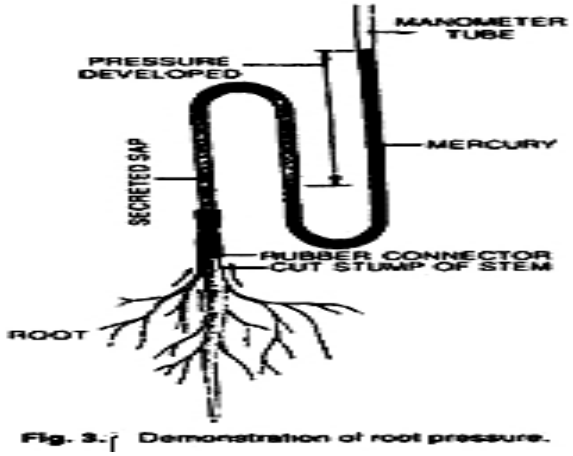

Fig : 3.1 Demonstraton of root pressure

3.2.2 Vital theory of Ascent of sap :

This theory was proposed by goldewski, Bose and Molish.

According to this theory the living cells are responsible for ascent of sap.

Goldewski (1884) proposed relay pump theory to explain ascent of sap and according to him the rhythmic change in the osmotic pressure of the living cell of xylem parenchyma and medullary rays brought about a pumping action due to which water moves in an upward direction.

Sir J.C. Bose observed a pulsating movement in the inner most cells of cortex with the help of electrical probe and concluded that the cells associated with xylem show pumping action and pump its sap into the xylem cells.

Molish successfully repeated the experiments of Bose and concluded that pulsating activity of cell can be greatly increased with drugs that cause increased cardiac activity in the animals.

But this theory was also discarded as when some poisonous substances like picric acid carbolic acid were translocated through xylem

fails to stop the ascent of sap. Thus the fundamental basis of vital theories fails.

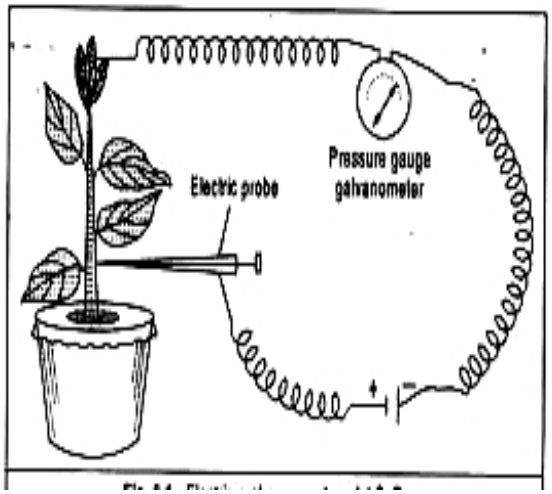

Fig 3.2 Electrical probe of J.C Bose.

3.2.3 Physical Theories :

According to this theory the dead cells of xylem are responsible for ascent of sap. There are following theories.

1. Imbibiton theory
2. Capillary theory
3. Atmospheric Pressure theory
4. Transpiration pull and cohesion theory

(1) Imbibition theory :- The theory was proposed by Unger (1868) and supported by Sachs (1878). According to this theory the ascent of sap in plant is because of imbibitional activity of the cell wall of the xylem. The magnitude of imbibitional force is 100-1000 atmosphere. This magnitude is sufficient to raise water upto the top of tall trees. Later on the ringing experiments proved that water moves through the lumen of cell and not through the wall, therefore this theory was discarded.

(2) Capillary Theory :- This theory was given by Boehm (1809) According to this theory the capillary force play an important role in the upward movement of water through the lumen of xylem. But this theory is rejected because the magnitude of capillary force is very low which can not rise water in tall trees. Vessels conduct more water than tracheids because vessels are broader than tracheids. The vessels of spring wood (with broader lumen) conduct more water as compared to vessels of

autumn wood (with smaller lumen). This is against the law of capillarity therefore this theory was discarded.

(3) Atmospheric pressure theory : According to this theory atmospheric pressure is responsible for ascent of sap. The transpiration of water occurs from the leaves of the plant which reduces pressure in the xylem cells and this gap is filled by the water just below. It is due to atmospheric pressure. This theory has certain objections :-

(i) To operate atmospheric pressure, pressure of free surface at the lower end i.e. root is required.

(ii) The atmospheric pressure can raise the water only upto 34 feet.

Therefore this theory did not get much support.

3.2.4 Transpiration pull and cohesion theory (Most accepted theory of Ascent of sap) :

This theory was originally proposed by Dixon and Joly in 1894 and then supported by many workers. This theory is based on :-

(1) Cohesive force of water molecule.

(2) Adhesive force of water molecule.

(3) Transpiration pull.

Water molecules have strong cohesive force (mutual attraction) due to which they can not be easily separated. They also have adhesive force (attraction of water molecules with the wall of xylem).

The xylem vessels are tubular structure extending from root to top of the plant. The xylem cells are placed one above the other with their end walls perforated forming a continuous tube.

The water filled inside the xylem vessels forms a continuous water column due to cohesive and adhesive force and this water column can not be broken or pulled away.

Various forces like weight of the column itself and resistance put to it during translocation can try to break the water column but the magnitude of cohesive force is much higher (upto 350 atmosphere) and the column is not broken.

Another important factor which can break the continuity of water column is entry of air bubbles in the xylem. The air bubbles entered into

the xylem does not block the entire conducting system. Thus the water column in the xylem is just like a rope extending from substomatal cavity in the leaf to the root. If this rope is pulled from the top, the entire rope will move upwards. In plants this pull is generated by transpiration. This is called transpiration pull.

The mesophyll cells of leaf loose their water due to transpiration as a result water potential of mesophyll cells decreases. Thus the water moves from cell to cell along the water potential gradient and reaches up the xylem elements. This exerts a pull and water filled in the xylem cells come in a state of tension. This pull or tension results upwards movement of water.

This theory is most accepted one among the plant physiologist today.

Evidences in support of cohesion theory :-

- Scholander provided evidences in favour of continuous freely mobile sap column and absence of metabolic pump.
- All the forces combined together have been found to be 50 atmosphere in the tallest tree which creates obstacle, but the cohesive force of water is upto 350 atmosphere which prevents the breaking of water column.
- If water is under tension, the strain in the vessels should cause their diameters to decrease. A decrease in diameter of tree stems have been observed when the transpiration is high.

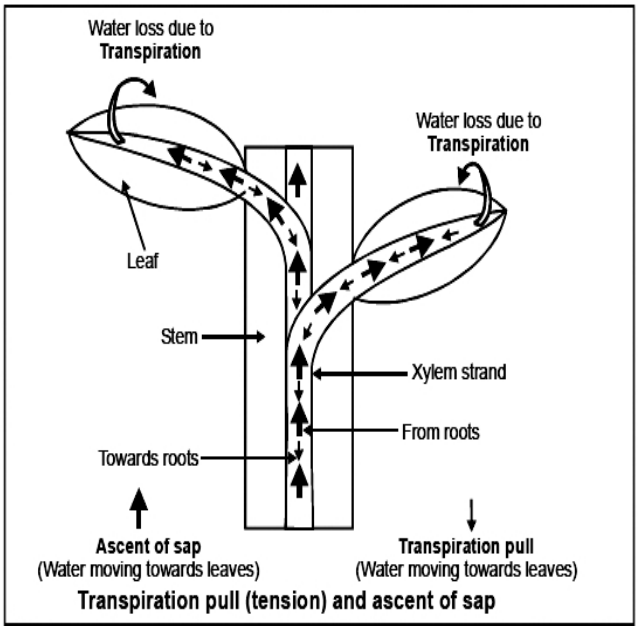

Fig 3.3 Transpiration pull(tension) and ascent of sap.

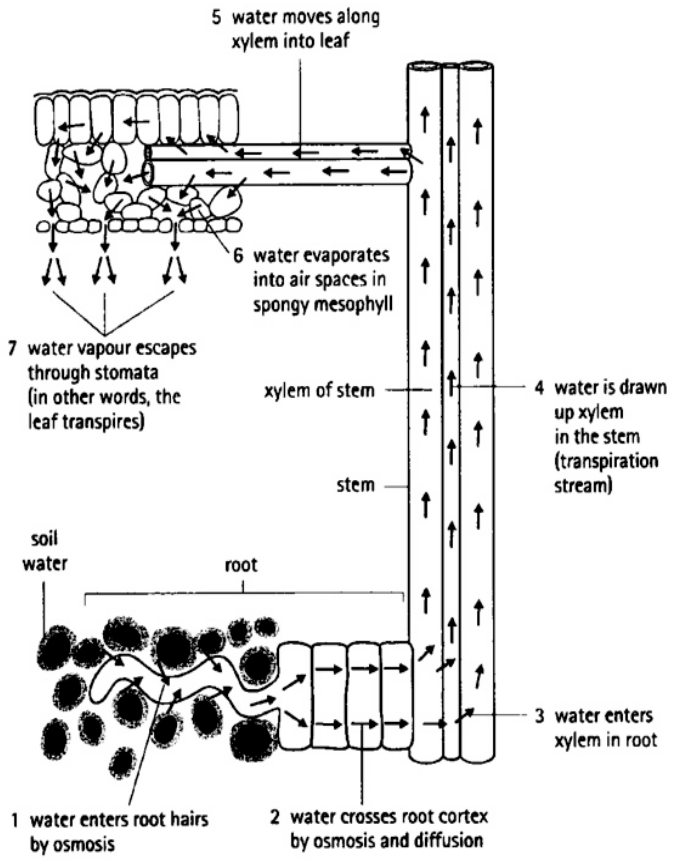

Fig 3.4 Transpiration pull and cohesion theory.

3.3 Factors Affecting Ascent of Sap :

Since the transport of water in plant is regulated by root pressure and transpiration therefore all those factors which affects root pressure and transpiration also affects transport of water. High temperature, low atmospheric humidity, high atmospheric pressure and wind velocity increases transpiration and thus also increases upwards transport of water. Deficiency of water in soil also cause decrease in the ascent of sap indirectly by influencing the absorption of water. Opening and closing of stomata also regulates movement of water in plants. The wilting of a plant is coupled with the closure of stomata which results in the decrease of ascent of sap.

3.4 Summary

- The upward transport of water in the plant through the xylem is known as ascent of sap.

- There are various theories to explain the phenomenon of ascent of sap in plants.
- According to root pressure theory the pressure of root is responsible for the ascent of sap.
- According to vital theory the living cells of the plant are responsible for ascent of sap.
- According to physical theories the dead cells of xylem are responsible for ascent of sap.
- The physical theories include imbibition theory, capillary theory, atmospheric pressure theory and transpiration pull and cohesion theory.
- The most accepted theory of ascent of sap is transpiration pull and cohesion theory.
- According o this theory a continuous water column is formed in the xylem vessel due to cohesive and adhesive force of water molecule and water is pulled upward due to transpiration.
- The factors which regulate root pressure and transpiration in plant also affects phenomenon of ascent of sap.

3.5 Terminal questions

Long questions

Q.1 Write an essay on ascent of sap in plant.

Answer:----------

Q.2 Explain Dixon's theory of ascent of sap.

Answer:----------

Q.3 Write the most accepted theory of ascent of sap.

Answer:----------

Short questions

Q.4 Write short notes on :

(i) Transpiration pull and cohesion theory.

(ii) Root pressure theory.

(iii) Vital theory.

(iv) Capillary theory.

(v) Atmospheric pressure theory.

Q.5 **Multiple choice questions (MCQ)**

(i) Upward translocation of water is called -

(a) Ascent of sap (b) Ascent of water

(c) Transpiration (d) Guttation

(ii) Most accepted theory of ascent of sap is –

(a) Transpiration pull and cohesion theory

(b) Root pressure theory

(c) Imbibition theory

(d) Vital theory

(iii) Cohesion theory was given by –

(a) Deovnis and turpe (b) Dixon and Joly

(c) J.C. Bose (d) Golaewski

(iv) Vital theory was given by –

(a) Goldewski, Bose and Molish

(b) Dixon and Joly

(c) Briggs and Shantz

(d) None of these

(v) Imbibiton theory was proposed by –

(a) Sachs (b) Unger

(c) Boehm (d) None of these

3.6 Answers

(i) a (ii) a (iii) b (iv) a (v) b

UNIT – 4

Water Loss (Transpiration)

Structure

4.1 Introduction

Plants absorb water from the soil to maintain their turgidity and performing various physiological activities but all the water absorbed by plant is not utilized. Only a small fraction of the absorbed water is utilized by the plant is evaporated in the form of vapour from the aerial part of plant.

Mayer (1956) had reported the magnitude of transpiration. According to him some of the herbaceous plants under favourable conditions transpire the entire volume of water which plant has and it is replaced with in a single day. A corn plant may transpire up to 54 gallons of water in one growing season. A beech tree lose an amount of water equal to nearly five times the fresh weight of its leaves. A deciduous forest loss water equal to the 30% of rainfall of the area during one complete year. Thus the amount of water absorbed and lost by various species of plants differs considerably.

The occurrence of transpiration in plant is a natural phenomenon because of their anatomy. The plants have stomata for exchange of gases like CO_2 and O_2. These stomatal cavity has water filled mesophyl cells which open to outside atmosphere through stomata. Therefore water is lost in the atmosphere.

Objective

After studying this unit you should be able to :-

- Know the phenomenon of transpiration in plants and types of transpiration.
- The mechanism of opening and closing of stomata.
- Various theories of opening and closing of stomata.
- The various factors which affects the rate of transpiration in plant.
- Significance of transpiration in the plant.
- Antitranspirants, hydathodes, Guttation and Difference in transpiration and Guttation.

Study Guide

For the study of this unit the basic concepts given is Unit-I of this book is required. Therefore you should revise Unit-I before studying this unit.

4.2 Transpiration

Water is necessary for plants but only a small amount of water taken up by roots is used for growth and metabolism. The remaining 97-99.5% is lost by transpiration and guttation. In transpiration water is lost in the form of vapours whereas in guttation water is lost in the form of liquid.

"The loss of water in the form of vapour from the aerial part of the plant is known as transpiration."

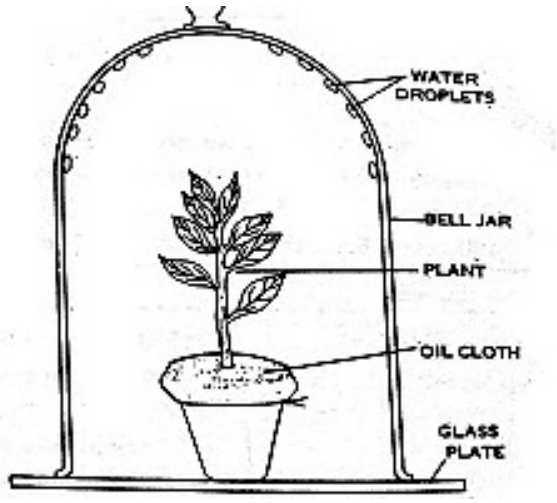

Fig 4.1 Process of Transpiration.

Types of Transpiration

It is of three types :-

1. **Stomatal Transpiration-** water vapour diffuses out through minute pore (Stomata) present in aerial part of plant is known as stomatal transpiration, About 85-90% of water is loosed by stomatal transpiration.

2. **Lenticular transpiration-** The water loss occurring through lenticels are called lenticular transpiration. It is about 1% of total transpiration loss. It occurs in fruits and woody stems.

3. **Cuticular Transpiration-** Loss of water through cuticle of the plant is known as cuticular transpiration it is only upto 20% of the total transpiration.

The water lost in stomatal transpiration is more than cuticular transpiration this can be experimentally proved by four leaves method as given below :-

Four Leaf Method Experiment :- Take four dorsiventral leaves of almost same size and age. Hang them in a series by tieing their petiole with a thread as shown in the Fig 4.2 Named them as leaf A, B, C and D. Now spread the vaseline on both the surface of leaf A, only on the lower surface of leaf B, on the upper surface of leaf C and do not spread vaseline on leaf D.

After few hours it will be observed that leaf D wilts first followed by C and B. The leaf A remain turgid. The leaf C becomes less turgid as compared to A and B. This is because in dorsiventral leaves the stomata are distributed mainly on the upper surface of leaves. In leaf A due to vaseline loss of water is checked on both the surface therefore leaf A remain turgid. In leaf B only cuticular transpiration occurs from the upper surface which is insignificant therefore leaf B remains more turgid as compared to leaf C in which cuticular transpiration was stopped and stomatal transpiration was allowed. This shows that stomatal transpiration is much more as compared to cuticular transpiration. (Fig 4.2)

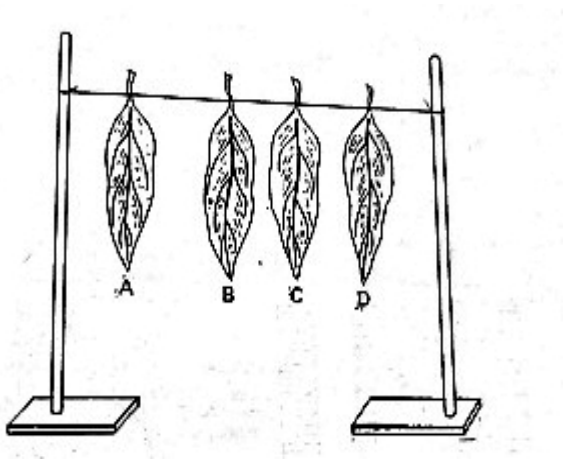

Fig 4.2 Four leaf experiment.

The rate of transpiration can be measured experimentally as given below-

Experiment Ganong's Potometer to measure the rate of transpiration-

The apparatus consists of a fine graduated capillary tube with a wide vertical end on one side and bent end on the other side. A reservoir is fixed to it near the wide end to store water. The apparatus is fitted as shown in the Fig 4.3 The whole apparatus is filled with water. A twig is cut under water and is immediately fixed to the wide end of the potometer through a hole in the cork. The bent end of the potometer has an opening which is dipped in coloured water kept in a small tube. The experiment is set up in the sunlight. To start with the bent end of the potometer is taken out from the coloured water. After few minutes it is seen that air enters into the tube through the opening. After this the bent tube is again dipped in water. The water transpired by the plant will be compensated by the water of the capillary tube. Absorption of water by the twig will cause movement of the water from the other end. This will be indicated by the movement of the closed air bubble. The distance covered by the air bubble in a minute gives the rate of transpiration. (Fig 4.3)

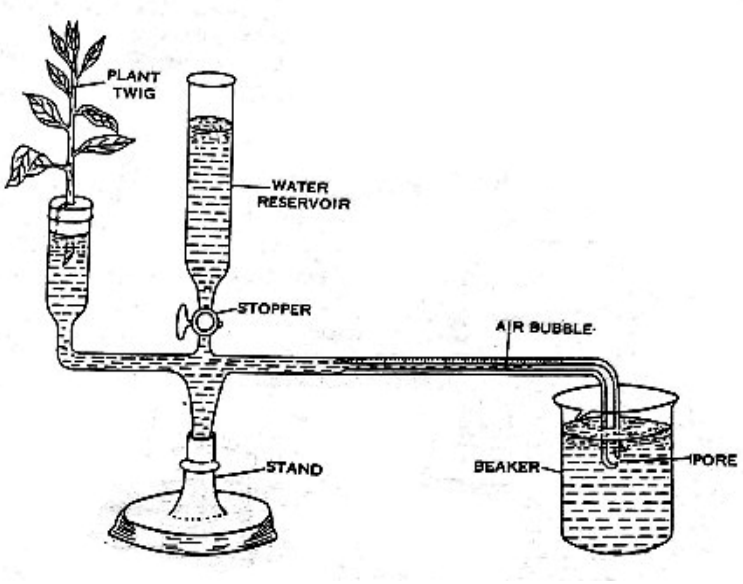

Fig 4.3 Ganong's Potometer

4.3 Mechanism of stomatal opening and closing

Opening and closing of stomata is brought about by change in volume and shape of guard cells. The guard cells absorb water from the surrounding cell and becomes turgid. The outer thin wall of guard cell bulge out due to pressure exerted on it resulting in pulling of inner thick wall which becomes concave and stomata opens when guard cell loose their turgidity the inner thick wall revert to their original position resulting in closing of stomata (Fig. 4.4)

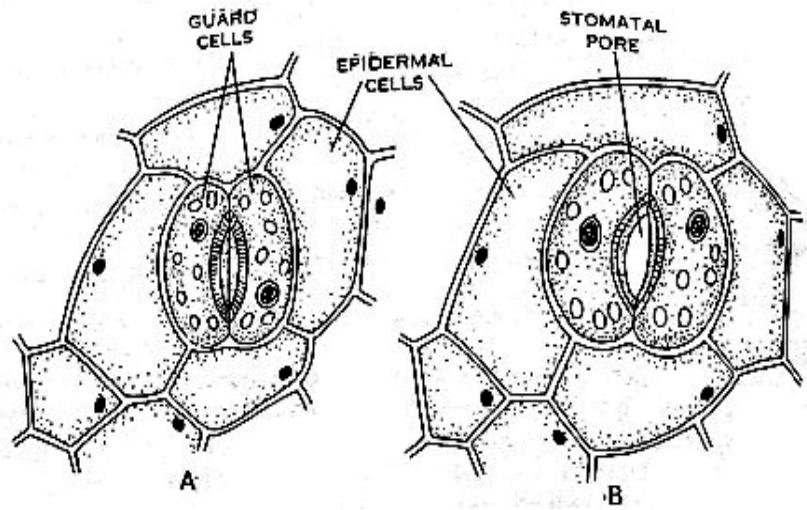

Fig 4.4 Stomata Closed. Stomata Open.

There are various theories regarding the opening and closing of stomata.

1. Photosynthetic production in the guard cell

According to this theory the chloroplast present in the guard cell manufactured osmotically active substances by photosynthesis which increases the osmotic pressure of guard cell as a result endosmosis take place in the guard cell. The turgidity of guard cell increases resulting in streaching of inner thick wall of guard cell. The inner wall becomes concave and stomata open.

There are certain objection-

1. Increased concentration of Co_2 in bright light lead to increased opening but it causes partial closure of stomata.
2. The chloroplast of guard cell are either incapable of photosynthesis or can have only feeble photosynthesis.

2. Starchsugar Hypothesis : According to this theory the turgidity of guard cell is controlled by a change in osmotic potential caused by inter convesion of starch and sugar.

In Light : According to this theory the Co_2 liberated in respiration is used by plants in photosynthesis during day time. So the Co_2 can not accumulates in the intercellular space of leaf. This lowers H^+ concentration of guard cell i.e. pH high which favoures conversion of starch into sugar.

In dark : In the dark Co_2 released in respiration accumulates in the intercellular spaces resulting in increased H^+ concentration and decreased pH which favoures conversion of sugar into starch.

There are certain objection-

1. It can not explain how change in Co_2 inside the leaf raise the pH.
2. Sugar has never been observed to appear in the guard cell when starch disappears. The starch is converted to organic acid (Malic Acid)
3. In monocots guard cell do not form starch at all.

3. Active K^+ Transport Mechanism : According to this theory stomatal opening and closing is due to active transport of K^+ into the guard cell and out of them.

In Light : In light starch disappears from the guard cell. It is converted to organic acid (Malic acid).

The organic acid dissociate into Maltate ion and H^+ into the guard cell. The H^+ are transported to the subsidiary cell and K^+ are taken into the guard cell. This ion exchange process is an active process and energy required for exchange comes from respirtion as mitochondria is reported in guard cell.

K^+ are balanced by organic anions. Some Cl ions are also taken into the guard cell to neutralized the small percentage of K^+.

Increased K^+ and maltate ion causes sufficient osmotic pressure in the guard cell to absorb water from surrounding cell. This increased turgor of the guard cells resulting to open stomata.

In Dark : The concentration of Co_2 increases and stops the transport of K^+ into guard cell decreased pH and Abscissic acid inhibits the K^+ uptake by changing the permeability of guard cell and K^+ are transported out from the guard cell into the surrounding epidermal cell. The osmotic potential of guard cell decreases as a result exosmosis take place in the guard cell and guard cell become flaccid. The inner thick wall of guard cell revert back to their original position and stomata closes.

4.4 Factors Affecting the Rate of Transpiration

The following factors affect the rate of transpiration :-

1. **Light :** Light directly affects the rate of transpiration by opening the stomata. Rate of transpiration increases in direct sunlight as well as in diffused day light. In the absence of light stomata are closed and stomatal transpiration is completely checked.

2. **Temperature :** Increase in atmospheric temperature increases the rate of transpiration. Increased temperature increases evaporation of water from cell surface, opens stomata and decreases relative humidity of atmosphere. All these conditions favour transpiration.

3. **Wind velocity :** The transpiring surface of leaf becomes saturated because of continuous addition of water vapour to the atmospheric air. It reduces the rate of transpiration. The wind velocity removes the air of that area and results in an increase in the rate of transpiration.

   High wind velocity decreases the rate of transpiration because it causes hindrance in diffusion.

4. **Atmospheric Pressure :** At lower atmospheric pressure at high altitudes, the rate of transpiration is increased but the increase is offset by the prevailing low temperature at these heights.

5. **Available soil water :** In deficient soil water rate of transpiration is decreased due to partial or complete closure of stomata.

6. **Structural Features of Plants :** Stomatal transpiration depends upon the size, position and distribution of stomata on the leaves. Presence of thick cuticle, wax reduces cuticular transpiration. Reduced size of leaves and falling of leaves also reduces rate of transpiration.

4.5 Significance of Transpiration

Or

Transpiration a necessary evil

Significance of transpiration in plant is the most controversial subject. Some consider it as a beneficial process while other regard as a harmful and useless process.

The so called advantages of transpiration are-

1. **Supposed Role in Ascent of Sap :** Transpiration bring about rapid translocation of water in the plant to compensate loss of water during transpiration but this advantage is insignificant and useless for the plant as if there were no transpiration there would be no need of rapid translocation of water and plant cell maintain their turgidty even in the absence of transpiration.

2. **Supposed role in Absorption and translocation of mineral salt :**

It was believed that minerals are absorbed along with water but now this concept is changed and minerals are absorbed activly thus transpiration has no significant role in absorption of minerals.

Transpiration helps in translocation of mineral salt through the xylem duct when it enters into them. Increased ash in the plants was observed under high transpiration conditions. If this is so then more ash would be in the top of the plant and less in the root. But experimental evidences does not support this view. Lack of transpiration does not create any mineral deficiency in the plant.

Therefore transpiration is not necessary for the absorption and translocation of mineral salt.

3. **Supposed role in regulation of temperature :**

Transpiration is supposed to prevent heating of the leaf and regulate temperature of the leaf. But the plants in which transpiration is checked by treating surface of the leaf by vaseline do not show any rise in temperature. The xerophytic plants are adopted for reducing transpiration yet they do not show any harmful effect of heat.

Transpiration may account for the loss of some heat but regulation of temperature is infact a physical process of radiation of extra heat into the outer atmosphere.

Conclusion : It is well known that transpiration is harmful. If transpiration rate is high the soil water is in deficient supply. The plant faces severe drought, dried up and get killed. Therefore plants are variously modified to keep the rate of transpiration to the minimum.

The occurrence of transpiration is a natural consequence of the basic facts of the plant anatomy.

The loosely arranged water filled mesophyll cells with large intercellular spaces are connected to the outer atmosphere through the stomatal opening are essentially meant for exchange of gases.

In such type of leaf anatomy the phenomenon of transpiration is unavoidable. Therefore we can say transpiration as the necessary evil.

4.6 Antitranspirants

Antitranspirants are the substances applied to the plant for reducing transpiration without causing significant effect on other plant processes.

Several substances such as colourless plastics, silicone oil, low viscosity waxes were used as an antitranspirants but failed to give promising results.

Phenyl mercuric acetate (fungicide) when sprayed in plant results partial closure of stomata for two weeks but it is toxic to fruits and vegetables.

Aspirin and ABA induce the closure of stomata but they are not economic due to high cost value.

Co_2 is yet another antitransparent but high concentration of Co2 around the plant causes complete closure of stomata which affects the process of photosynthesis. Thus till date no suitable antitranspirant is available to solve the problem.

Hydathodes: Hydathodes are stomata like pore present at the tip or margin of the leaves growing in moist shaddy place. Pores open in a cavity which has loosely arranged cells called epithen lie above the ending of the vein.

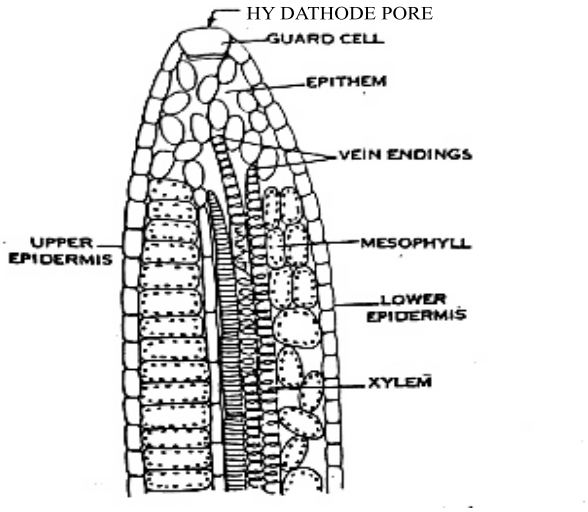

Fig 4.5 Leaf Showing Hydathodes.

Guttation : When absorption of water greatly exceeds transpiration excess of water escapes through hydadothes. Somtimes water may also scapes from the stem through the scars of leaves and lenticels. This type of excudation of water is called "guttation". It generally occurs in night but also occurs in day time if plants are growing in moist warm soil or under humid conditions. Guttation is due to root pressure which develops in the xylem ducts of root system below.

The fluid which ooze out in guttation, normally contains a variety of dissolved organic and inorganic substances when the guttated liquid evaporate the salts are concentrated on the leaf surface and may cause injury to the leaf through which pathogenic fungi and bacteria can enters into the plant.

The phenomenon of guttation in plant can be demonstrated by the experiment given below.

Experiment : Take a well watered potted plant of garden Nasturtium. Place the pot on a glass plate. Cover the open surface of soil with an oil cloth to avoid evaporation. Cover the plant with a bell-jar. Close the mouth of bell-jar with a cork, provided with a hole. Connect the hole by means of a glass tube to aspirator as shown in Fig. 4.6 .Make the apparatus air tight by smearing grease, keep for sometime then observe. The drops of water will appear on the margins of leaves due to guttation. (Fig. 4.6)

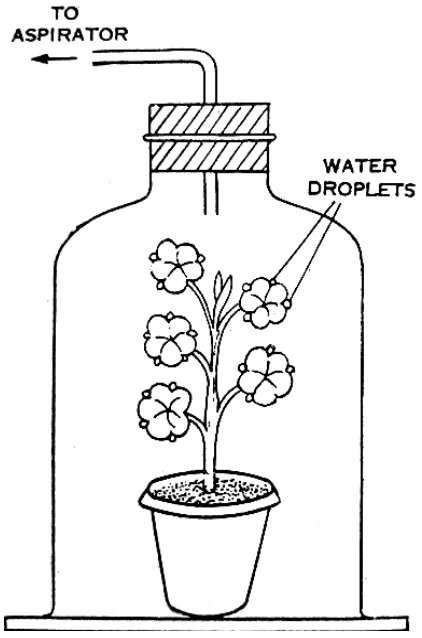

Fig 4.6 Phenomenon of Guttation.

Difference between transpiration and Guttaion.

	Transpiration	Guttation
1.	It occurs in day	It occurs in night
2.	Pure water is lost in the form of vapours	Water is lost as liquid in guttation and has many dissolved substances.
3.	It occurs through cuticle, stomata or lenticle	It, occurs through hydathods
4.	It is a controlled phenomenon.	It is uncontrolled phenomenon.

4.7 Summary

- The loss of water in the form of vapour from the aerial part of the plant is known as transpiration.
- Transpiration is of three types: stomatal transpiration occurs through stomata of plant. Cuticular transpiration occurs through cuticle of plant. Lenticular transpiration occurs through lentical of plant. Maximum water loss in plant occurs through stomata of the plant.
- The four leaf experiment shows that stomatal transpiration is much more as compared to cuticular transpiration.
- Ganong's Potometer is used to measure the rate of transpiration.
- The opening and closing of stomata depends upon the turgidity of the guard cell. When guard cell is turgid stomata opens and when guard cell is flaccid stomata closed.
- There are various theories to explain the turgidity of guard cell. According to photosynthetic production theory the turgidity of guard cell is due to synthesis of osmotically active substance by photosynthesis.
- According to starch Sugar hypothesis, stomata opens in light due to conversion of starch into sugar and closes in dark when sugar is converted into starch.

- According to K^+ transport mechanism in the light the K^+ are taken into guard cell which increase osmotic potential of guard cell which results in endosmosis and stomata open. In the night the K^+ are transported out side the guard cell which decreases osmotic potential of guard cell. The guard cell becomes flaccid and stomata get closed.

- The factors like light, temperature, wind velocity, available soil water, structural features of plants affects the rate of transpiration. Rate of transpiration increases in direct sunlight, at increased temperature, in wind velocity. But High wind velocity decreases rate of transpiration. At low atmospheric pressure transpiration increases.

- In deficient soil water rate of transpiration is decreased.

- Size, position and distribution of stomata on leaves also affects the rate of transpiration.

- The transpiration is harmful to the plant yet this phenomenon can not be avoided due to anatomy of plant which has water filled loosely arranged mesophyll cells with large intercellular spaces connected to the outer atmosphere through the stomata basically for exchange of gases (Co_2 and O_2).

- Antitranspirants are substances applied to the plant for reducing transpiration without disturbing other physiological process of the plant. Many substances are suggested as antitranspirants but till date no suitable antitranspirant is available.

- Hydathodes are stomata like pores present at the tip or margin of the leaf.

- The guttation occurs through hydathodes in which water is lost in the form of liquid.

4.8 Terminal Questions

Q.1 Discuss the mechanism of transpiration in plants.

Answer:----------

Q.2 Explain the mechanism of stomatal movement.

Answer:----------

Q.3 Comment upon 'Transpiration is a necessary evil'.

Answer:----------

Q.4 Describe in brief significance by transpiration.

Answer:----------

Q.5 Define transpiration and factors affecting rate of transpiration.

Answer:----------

Q.6 Write short notes on-

(1) Transpiration and its types

(2) Guttation

(3) Antitranspirants

(4) Active K^+ transport mechanism of stomatal opening and closing.

(5) Starch Sugar Hypothesis of stomatal opening and closing.

(6) Photosynthetic production in the guard cell.

Q.7 Very short answer type question.

(a) Name the process in which water from plants is lost in liquid form.

(b) Name the monovalent cation involved in the opening and closing of stomata.

(c) The turgidity of guard cells results in the _____ of stomata.

(d) Name the instrument used for measuring rate of transpiration.

(e) Name the process in which water is lost from the plant as vapour.

Q.8 Multiple choice questions (MCQ)

(1) Loss of water in the form of vapour by plant is called :

(a) Guttation (b) Transpiration

(c) Excretion (d) All the above

(2) Transpiration in plants occur through:

(a) stomata (b) Cuticle

(c) Lenticel (d) All the above

(3) Loss of water in the form of liquid by plant is called :

(a) Guttation (b) Transpiration

(c) Excretion (d) Non of the above

(4) Guttation in plants occur through:

(a) Stomata (b) Hydathodes

(c) Cuticle (d) None of the above

(5) Stomatal opening and closing is assisted by :

(a) K^+ and H^+ (b) Light and darkness

(c) Guard cells (d) all the above

4.9 Answers

Very short answer type :

(a) Guttation

(b) K^+

(c) Opening

(d) Ganong's potemeter

(e) Transpiration

MCQ :

1. (b) 2. (d) 3. (a) 4. (b) 5. (d)

Uttar Pradesh Rajarshi Tandon
Open University

UGBY-102

Bachelor of Science

Block

2

Plant Physiology II

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UGBY-102/56

Course Introduction

The term physiology (Gr Physis=nature and logos = study) means the study of functions and vital process of living organism. As we know that plants are also living organism, therefore the study of vital processes of plant is known as plant physiology. The physiological processes of plant includes biophysical and biochemical reactions in side the plant. The plant physiology is divided into physical aspects, plant metabolism, growth and development and biochemistry.

The physical aspects includes study of soil, water relation including absorption, translocation of water and transpiration. The plant metabolism includes photosynthesis and respiration. The photosynthesis is an anabolic reaction in which synthesis of food occurs where as respiration is a catabolic process in which break down of food substrate takes place. The growth and development includes physiology of growth, growth hormones, photoperiodism and vernalization. The plant physiology is an interdisciplinary approach and has role in other branches of botany like morphology, anatomy, taxonomy, embryology, ecology, cell biology, cytology, genetics, molecular biology etc. when you are studying this SLM you will go through a variety of topics of plant physiology. This is a 2 credit course containing 2 blocks in which block I and II deals with plant physiology 1 and 2 respectively.

Plant physiology

Block I- Plant physiology I

Block II- Plant physiology II

Block I- has 4 units in which you are going to study some basic concepts i.e. physiology of absorption of water, the upward translocation of absorbed water and water loss or transpiration in plant.

Block II- has 4 units in which you will study the mineral nutrients and their absorption by plant, physiology of photosynthesis occurring in plant, hormones and their role in vegetative and reproductive growth of plants and physiology of respiration.

Block-II

Plant Physiology II

This block has four units 5, 6, 7 and 8. Unit 5 deals with mineral nutrients required by plants and their absorption. Unit 6 throws light on the photosynthesis, the most important metabolic process of green plants. The study of this unit would let you know that how plants synthesize food from the raw materials with the evolution of O_2. These are plants which supply food to the other organism on one hand and purify the atmosphere on the other hand. Unit 7 deals with hormones like auxins, gibberellins, cytokinins, absissic acid, ethylene and flowering hormone florigen. The study of unit 7 would tell you the role of hormones in vegetative and reproductive growth of plants. In the unit 8^{th} you will study the another metabolic process of plant that is respiration. This physiological phenomenon will tell you that how energy is released by the break down of carbohydrates. This energy is used by plants to perform their various activities.

Objectives :

After studying this block you should be able to :

- Know about various nutrients, their role in plant and phenomenon of mineral salt absorption.
- The process of photosynthesis occurring in green plants.
- Various hormones and their role in vegetative as well as reproductive growth of plant.
- To know the respiration, the most important energy yielding process.

UNIT-5

Mineral Nutrition

Structure

1.1. Introduction

Green plants are autotrophs means they are independent of outside sources of organic food. The green plants have chloroplast because of which they can synthesize organic food for themself by the process of photosynthesis. These plants provide food to the whole living world but they require nutrients for their healthy growth.

Plants obtain this nutrient from the soil. Our attempts in this unit will be to throw light on mineral elements, their requirements for the plants and various theories of mineral salt absorption.

Objective

After studying this unit you should be able to-

- Know the list of essential macro and micronutrients required by plant for their proper growth.
- Role of nutrients in plants and diseases caused due to deficiency of nutrients.
- Explain how these elements are absorbed by root cell from the soil.
- Various theories of absorption of salt explain the mechanism of absorption of minerals from the soil.

Study Guide :

For the study of this unit you should revise unit-I of this book.

5.2 Essential elements

Green plants require inorganic matter from outside to synthesize their own organic matter. The inorganic elements required by plants are present in the soil as minerals and known as mineral nutrients such a nutrition in known as mineral nutrition. The mineral nutrients are classified as macronutrients and micronutrients. These are essential elements.

Macronutrients and Micronutrients

The term macronutrients is used for those elements which are required in large amount eg. Carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, potassium magnesium and calcium. The term micronutrients or trace elements is used for those elements which are required in smaller amount eg. iron, boron, manganese, zinc, copper, molybdenum, chlorine, cobolt, sodium, silicon and iodine.

Role of Nutrients in plant :- The specific role of Macronutrients and micronutrients in plant is as follows :-

1. **Carbon, Hydrogen and Oxygen :** Carbon is essential for the synthesis of carbohydrates and fats. Hydrogen and oxygen are present in water which is essential for the various vital activities of the plants. Deficiency of carbon, Hydrogen and oxygen results in extremely poor growth of plant.

2. **Nitrogen :** It is absorbed by plants from the soil in the form of nitrate, nitrites and ammonium salts. Nitrogen in found in Amino acids, Proteins, Purines, Pyrimidines, DNA, RNAs and coenzymes. The deficiency of Nitrogen causes-

1. Suppressed shoot growth.
2. Sparse foliage.
3. Thin and weak stem with red and brown spots.
4. Early defoliation.

3. Sulphur : Sulphur is absorbed by plants as sulphate ion from the soil. It is found in sulphur bearing aminoacids (cystine, cysteine, methionine) and vitamins (biotin, thiamine and coenzme A).

The deficiency of sulphur causes-

1. Stunted plants.
2. Sparse foliage
3. Chlorosis followed by anthocyanin formation.
4. Hard woody stem.

4. Phosphorus : Plants absorb phosphorus from the soil as phosphate ions. It is structural component of the nucleic acids, phospholipids, sugar phosphate, ATP, NADP and many phosphorylated compounds.

The deficiency of phosphorus causes-

1. Premature leaf fall and leaves turn dark blue green.
2. Brown necrotic patches on leaves.
3. Growth of root and shoot is restricted and sparse branching.
4. Delayed flowering.

5. Calcium : Plant requires calcium for structure of cell wall, cell membrane and turgidity. It also influences nitrate reductase, ion transport, cell elongation and as activators of amylases, ATP ase etc. Deficiency of calcium in plants causes-

1. Death of root, stem and leaf tips.
2. Chlorosis along the margin of younger leaves and malformation of younger leaves.

6. Potassium : It is the only monovalent cation essential for plant growth. It affects permeability, osmotic regulation and hydration. stomatal movements, synthesis of chlorophyll, translocation of sugars and Enzymes concerned with plant synthesis.

The deficiency of potassium in plant causes-

1. Scorching of old leaves.
2. Decolourization, Chlorosis of leaf tips and margins.

7. Magnesium : It is the component of chlorophyll and activator of many photosynthetic and respiratory enzymes magnesium combines the subunits of ribosomes, synthesize and hydrolyse the ATP.

The deficiency of magnesium in plant causes-

1. Chlorosis, necrosis and formation of anthocyanin pigment.

8. Iron : Iron is absorbed by plant in the form of ferrous. It occurs in the structural component of porphyrin molecules : cytochromes, hemes, hematin ferrichromes, leg hemoglobin and non heme molecules.

Deficiency of iron in plant causes-

1. Chlorosis in leaf with green veins.
2. Young leaves become white or yellow.

9. Boron : Boron is absorbed by plant as borate or tetraborate anion. It is essential for translocation of sugars, active absorption of salt, enzymes of phosphorylation, metabolism of RNA and phenols, flowering and fruiting.

The deficiency of boron in plant causes-

1. Reduction in the growth of stem and root tips.
2. Death of meristematic regions and stop in flowering.
3. Shift in metabolism from glycolysis to pentose phosphate pathway.
4. Physiological diseases.

10. Copper : This element is required in very small quantity. It acts as a catalyst in oxidation-reduction reaction. It is required by plant in photophosphorylation mediated by plastocyanin.

The deficiency of copper in plant causes physiological diseases e.g. die-back disease of citrus and reclamation disease of cereals.

11. Zinc : It acts as activator of certain enzymes e.g. carbonic anhydrase, alcohol dehydrogenase. It is essential for the synthesis of Auxin and protein metabolism.

Deficiency of zinc in plant causes-

1. Reduced stem growth and chlorosis.
2. Diseases like little leaf disease, mottle leaf disease.
3. Malformation in fruiting tree and suppressed seed formation.

12. Molybdenum : It is required in very small quantity by the plants. it's main role is in nitrogen metabolism. It also acts as an activator for the nitrate reductase enzyme.

The deficiency of molybdenum in plant causes-

1. Chlorosis of the lower leaves.
2. Inhibition of flowering.
3. Diseases like whip tail disease of cauliflower.

13. Chlorine : It is essential for plant in the transfer of electron to photosystem II.

The deficiency of chlorine in plant causes poor growth of the plants.

Hydroponics

It is a technique in which plants are grown in pure salt solution in the absence of soil to know the requirement of essential elements for the growth of plant. In this simple salt solution, pure sand or gravel is used in place of soil. The vegetable or ornamental plants like tomatoes, carrots or roses are grown in large shallow vats having nutrient solution. The vats are covered with wire netting for the support of the plants. The aeration to the solution culture is given by inlet tube as shown in Fig 5.1. Such cultures are known as hydroponics, tank farming or soilless growth

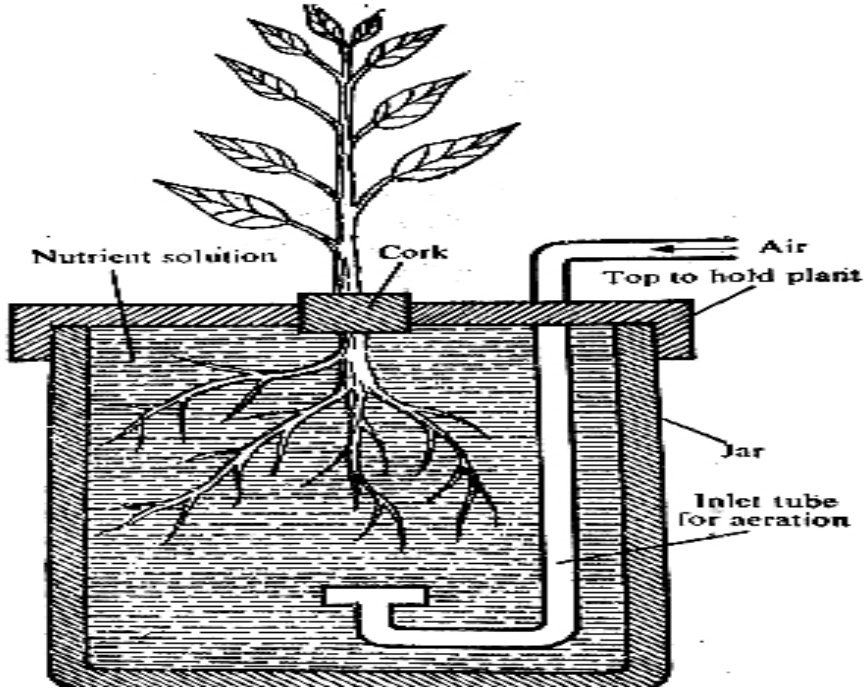


Fig 5.1 Modern solution culture.

5.3 Mineral Salt-Absorption or Absorption of solute

The minerals present in soil solution are absorbed by the roots of the plant from the cells of epiblema. Various theories have been given to explain the mechanism of mineral absorption.

On the basis of involvement of metabolic energy the mechanism of mineral salt absorption can be divided into two groups.

Passive Absorption (Metabolic energy is not involved in the absorption of salt)	Active Absorption (Metabolic energy is involved in the absorption of salt)

Passive Absorption: The following theories explain passive absorption of minerals:

1. **Mass flow Hypothesis :** According to this principle ions are taken up by the roots with the mass flow of water taking place due to transpiration.

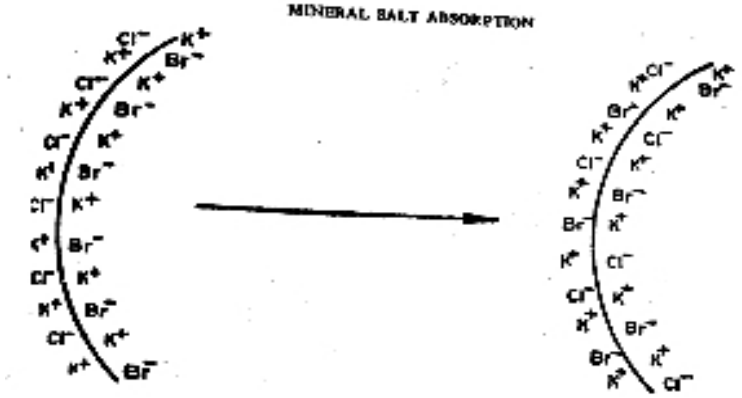
2. **Diffusion :** The movement of ions and molecules from the region of its higher chemical potential to the region of lower chemical potential along the concentration gradient is known as diffusion. When a cell or tissue is placed in a solution having relatively higher chemical potential, the ions move into them by the process of free diffusion.

3. **Ion Exchange theory :** According to this anions or cations are exchanged for anions or cations of equivalent charges between cell and of the external solution in which the tissue is immersed. (There are two theories to explain the ion exchange.)

Fig 5.2 Ion Exchange

Concept taken form plant physiology by Dr. V. Verma

(1) Contact exchange theory	(2) Carbonic Acid Theory



(1) Contact exchange theory:

The ions absorbed by root and clay particles are not held tightly but they oscillate with in a certain space of small volume and when the oscillation volume of one ion overlaps with the oscillation volume of another ion, the exchange of ion taks place.

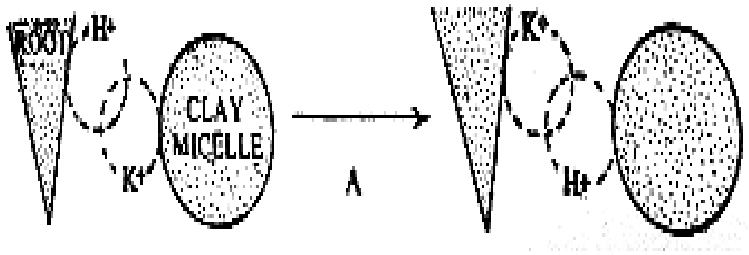


Fig 5.3 Contact Exchange theory
Source: Plant physiology by Dr. V. Verma

(2) Carbonic Acid Theory:

According to this theory the Co_2 released by respiration of root combines with water and forms carbonic acid which dissociates into hydrogen ion and carbonate ion.

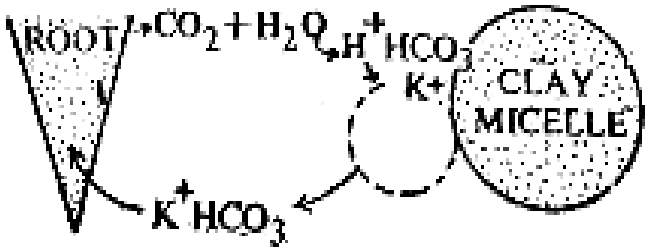


Fig 5.4 Carbonic Acid Theory
Source: Plant physiology by Dr. V. Verma

(2) Donnan Equilibrium : According to this non diffusible anions (R-) accumulates on the inner surface of the outer membrane. The outer membrane is impermeable to fixed anions. These anions are balanced by the entry of cations (K^+) from out side.

The external anions (Cl) enter into the cell because of the diffusion gradient they are taken along with a cation of equal charge to maintain the electrical balance or equilibrium. This is known as Donnan Equilibrium.

Active Absorption

According to this ions are actively absorbed across the membrane against the concentration gradient with the expenditure of energy.

There are various evidences which supports active absorption-

(1) Due to anion absorption rate of respiration increases.

(2) Temporary absence of O_2 stops active absorption.

(3) Cyanide and azide enzymes are poisons. They not only inactivate respiratory chain but also decrease the active absorption.

There are various mechanism to explain the active absortion.

(1) Carrier concept | (2) Cytochrome pump theory | (3) Protein as a carrier

1. Carrier Concept :

According to this ions are transported across the membrane with the help of a carrier. It is believed that there are two different carriers for cation and anions.

These carriers are first activated then they combine with the ions on the outer surface of membrane and form ion carrier complex which move across the membrane and on reaching the inner side of the membrane complex break down and ions are released. The metabolic energy is used up in various steps of the process.

Isotopic exchange, saturation effects and specificity in the absorption of ions supports the carrier concept.

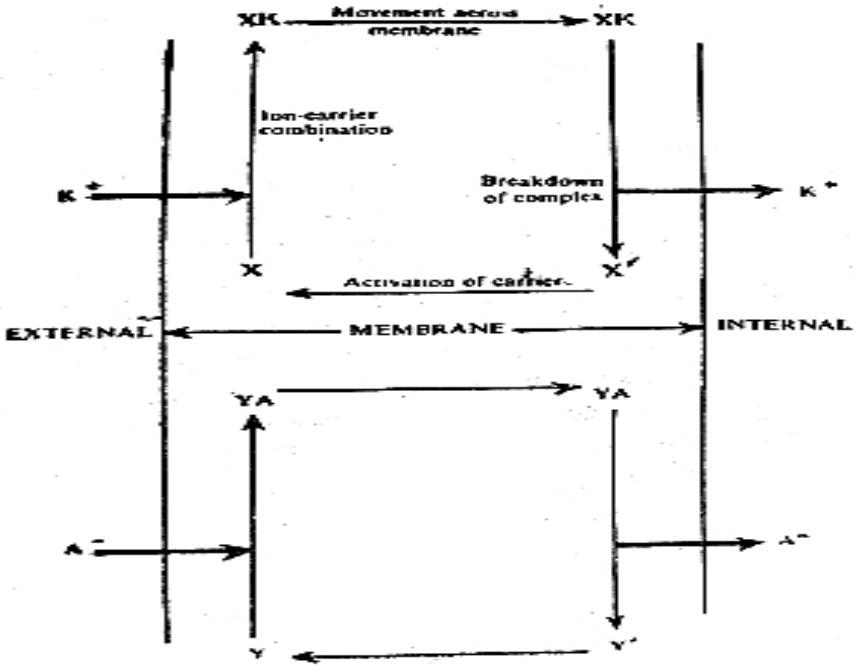


Fig 5.6 Carrier Concept
Source: Plant physiology by Dr. V. Verma

2. Cytochrome pump theory :

According to this theory anions are absorbed actively. The dehydrogenase enzyme on the inner surface of the membrane produces electrons and proton H^+. The electron moves outside through the cytochrome chain and reduces terminal cytochrome on the outer surface of the membrane. The reduced cytochrome get oxydised, releases electrons which combines with H^+ and O_2 to produce H_2O. Oxidised cytochrome accept anion which move towards the inner side over the cytochrome chain. On the inner side cytochrome get reduced and anions are released.

the cations (M^+) are absorbed passively along the membrane.

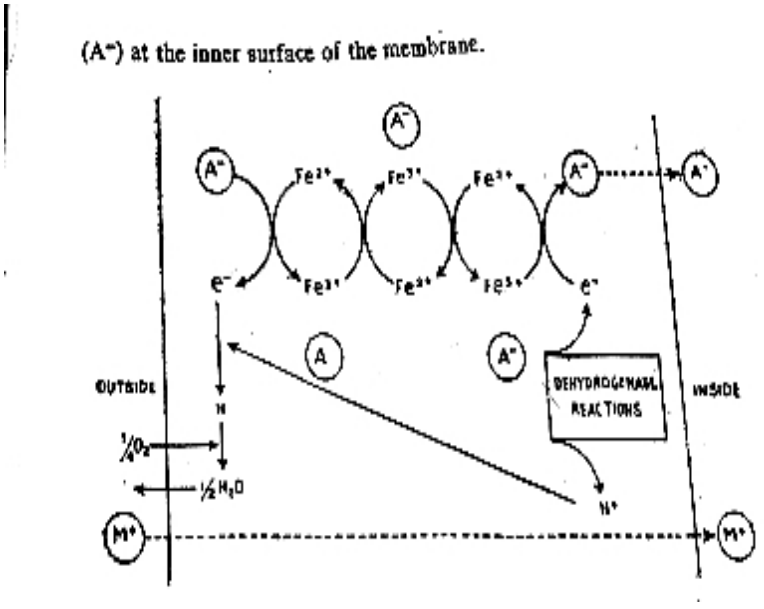


Fig 5.7 Cytochrome pump theory
Source: Plant physiology by Dr. H.N. Srivastava

Criticism

1. It does not explain the involvement of metabolic energy.
2. Cations have also shown characteristics of stimulating soil respiration.
3. Selective uptake of ions cannot be explained by this theory.

3. Protein as a carrier : According to this peptides present in the cell membrane binds both cations and anions on the outer surface on the membrane. These cations and inions move as such and release on the inner side of the membrane.

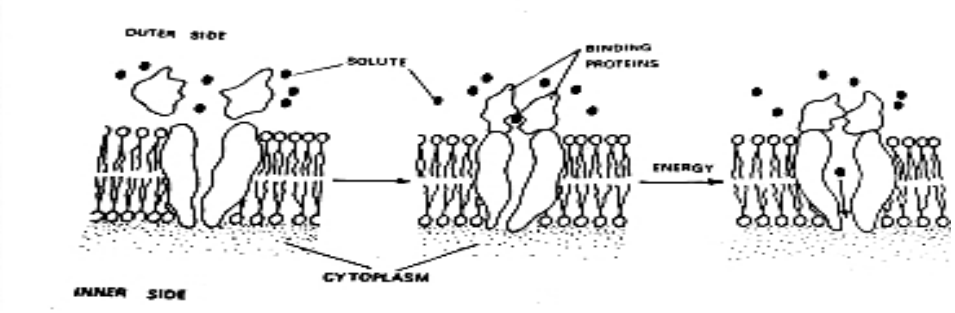


Fig 5.8 Protein as a carrier.

Source: Plant physiology by Dr. H.N. Srivastava

5.4 Summary

In this unit you have learnt that:

- Mineral elements are essential for the growth of plant.
- C, H and O make the back bone of organic molecules. The N, P, K, Ca, S and Mg are known as macronutrients as they are required by plant in large amounts.
- Fe, Cu, Mn, Zn, Cl, B and Mo are known as micronutrients as they are required by plant in lesser amounts.
- Carbon is essential for the synthesis of carbohydrates and fat and H & O_2 are present in water.
- Nitrogen is absorbed as nitrate, nitrite and ammonium salt. It is found in aminoacids.
- Sulphur is absorbed by plant as a sulphate ion and found in sulphur bearing aminoacids.
- Phosphorus is absorbed by plant as phosphate ion. Also it is structural component of nucleic acid, ATP, NADP and many phosphorylated compounds.
- The cell wall of plants require calcium.
- Potassium affects the permeability, osmotic regulation and hydration.
- Magnesium in the component of chlorophyll and iron occurs in the structural components of porphyryn molecule.

- Boron is absorbed by plant as borate or tetraborate anion. The copper element acts as a catalyst in oxidation and reduction reaction.
- Zinc acts as activator of certain enzymes and molebdenum has role in nitrogen metabolism.
- The chlorine transfers electron to photosystem-II in photosynthesis.
- Minerals present in soil are absorbed by root of plants either through passive absorption or by active absorption.
- In passive absorption process the metabolic energy is not involved in the absorption of minerals. It includes : mass flow hypothesis in which minerals are absorbed with the mass flow of water, Ion exchange theory in which cations and anions are exchanged between the root tissue and soil solution. It is explained by contact exchange theory and carbonic acid theory. The Donnan equilibrium also explains the absorption of cation.
- In active absorption process the metabolic energy is involved in the absorption of minerals. It includes carrier concept, cytochrome pump theory and protein as carriers.
- According to carrier concept the cations and anions are transported across the membrane with the help of carriers. There are separate carrier for cations and anions.
- According to cytochrome pump theory anions are absorbed actively across the membrane whereas cations are absorbed passively.
- According to protein as a carrier theory cations and anions are transported with the help of peptides present in the cell membrane.

5.5 Terminal Questions

Long answer type questions :

1. What are micronutrients? Describe the role of any four micronutrients in plant life.

Answer:----------

---

2. What are macronutrients? Describe the role of any four macronutrients in plant life.

Answer:----------

---

3. Discus the roles of molybdenum, manganese and chloride in plants.

Answer:----------

---

4. Write an essay on symptoms produced in plant due to deficienty of minerals.

Answer:----------

---

5. Explain different theories of absorption of salts in the plant.

Answer:----------

Short Questions :

1. Write short note on active absorption of ions.
2. Write short note on passive absorption of ions.
3. Write short note on the carrier concept.
4. Write short note on Donnan Equilibrium.
5. Write short not on hydroponics.
6. Write short note on cytochrome pump hypothesis.

Multiple Choice Questions (MCQ) :

1. Essential element are :

   (a) Micronutrients only (b) Macronutrients only

   (c) Both (d) None of these

2. Plants absorb nitrogen as :

   (a) Nitrate (b) Nitrite

   (c) Ammonium salt (d) All the above

3. Iron is absorbed by plant as :

(a) Ferrous (b) Ferric

(c) Both (d) None of the above

4. The deficiency of magnesium in plant causes :

(a) Chlorosis

(b) Necrosis

(c) Formation of anthocyanin pigment

(d) All the above

5. Plant absorbed phosphorus as :

(a) Elemental phosphorus (b) Phosphate ion

(c) Both a and b (d) None of the above

Very Short answer type questions :

1. Which one of the following is considered as macronutrients : Cl, Ca, Zn, Mo.
2. Which mineral element besides nitrogen is the component of Chlorophylls.
3. Which mineral element is common in heme protein-Cytochromes and non heme protein feredoxin.
4. Which one of the following is considered as micronutrient : Fe, K, C, H, O.
5. Premature leaf fall and leaves turn dark blue green due to deficiency of :-

(a) Sulphur (b) Calcium (c) Phosphorus (d) Iron

5.7 Answer

MCQ-

(1) a (2) d (3) a (4) d (5) b

Very short answer type questions :

(1) Calcium (2) Magnesium (3) Iron (4) Iron (5) Phosphorus

UNIT – 6

Photosynthesis

Structure

6.1 Introduction

Most of us are familier with the concept of a factory, where raw materials enter and finished products exit. Imagine photosynthesis occurring in two connecting factories. The product of first factory is energy carrying molecules ATP (adenosine triphosphate) and NADPH (reduced nicotinamide adenine dinucleotide phosphate) and second factory to make sugar, the final product. All organisms, including humans need energy to fuel the metabolic reactions of growth, development and reproduction. But organisms can not use light energy directly for their metabolic needs. The green plants have chloroplast and can synthesize their own food by the process of photosynthesis. The entire humanity depends on plant for food. Every year about 200 billion tons of carbon is

utilized in the process of photosynthesis. Thus the photosynthesis is the most massive chemical event going on the earth. The plants take up 7×10^{11} tons of Co_2 to produce roughly 5×10^{11} tons of solid plant material. The 90% of the world's photosynthesis in carried out by marine and fresh water algae. Thus the photosynthesis is a very important metabolic process because :-

1. It supplies food to the biological world.
2. It purify the atmosphere because it takes Co_2 from the atmosphere and releases O_2 to the atmosphere.

Objectives

After studying this unit you should be able to :

- Know the structure and function of chloroplast.
- Process of photosynthesis in plant.
- Emerson effect and cyclic and non cyclic photophosphorylation.
- C_3, C_4 and CAM cycle of dark fixation of Co_2.
- Difference in C_3 and C_4 plant.

6.2 Definition of Photosynthesis

Photosynthesis is the synthesis of carbohydrates from Co_2 and H_2o in presence of sunlight on chlorophyll.

$$6Co_2 + 12H_2o \xrightarrow[Chlorophyll]{Light} C_6H_{12}o_6 + 6o_2 + 6H_2o$$

Photosynthesis is a very important metabolic process as-

(1) It supplies food to the biological world.

(2) It perify the atmosphere

6.2.1 Structure of Chloroplast

It is found in all photosynthesizing cells except prokaryotes. They are semiautonomas as they can grow and divide and their DNA contains a portion of genetic information needed for the synthesis of chloroplast for this it is said that chloroplast was once an independent cell which was engulfed into another cell as an endosymbiont.

Shape and size : In higher plant it is usually discoid, ovoid, ellipsoidal or biconvex lens shaped. The average diameter of chloroplast in higher plant is 4-6 μm.

The chloroplast is a heterogenous structure. It has two distinct structure -

(1) Grana (2) Stroma

(1) Grana : Grana is small disc like structure. About 10-100 disc like grana or thylacoid are super imposed just like pile of coin and are called granum. The grana are interconnected by stroma lamellae which are extension of the membrane of grana into the matrix.

With in the membrane of grana layers of particles called quantasomes are present. Quantasomes are discovered by Park and Biggins. Photosynthetic pigments are arranged within each quantasome.

A monolayer of chlorophyll along with carotenoid and phycobilines are present between lipid and protein, layer in such a way that head of chlorophyll is towards the protein layer and tail towards the lipid layer.

(2) Stroma : It is the colourless matrix of protenacious nature. It contain enzymes of photosynthesis, salts, starch grain, osmophilic granules RNA and DNA. Grana are embedded in stroma.

Grana is the site of light reaction of photosynthesis where as stroma is the site of dark reaction of photosynthesis.

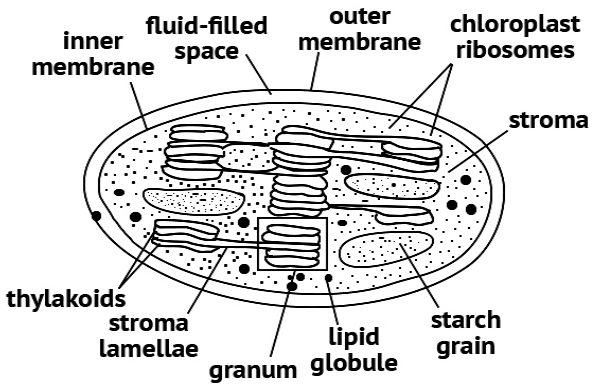


Fig 6.1 Structure of chloroplast

Mechanism of Photosynthesis

The process of photosynthesis is completed in two steps :-

1. Light reaction or photochemical reaction.
2. Dark reaction or light independent biochemical reaction or Dark Fixation of Co_2 or Black man's reaction.

6.3 Evidence for existence of Light and dark reaction

6.3.1 Evidence from intermitted light Experiment, warburg's Experiment :

The rate of photosynthesis was found greater in intermitted light. In continuous light the product of light reaction $NADPH+H^+$ and ATP are not consumed at the same rate at which they are produced. Thus they get accumulated. But in intermitted light the product of light reaction are quickly utilized.

6.3.2 Evidence from Temperature Co-efficient or Q_{10}-

Q_{10} = Rate of reaction at given temperature

Rate of reaction exactly at 10^0C lower temperature

The value of Q_{10} is 2 or more for purely chemical reaction and Q_{10} is unity for a photo-chemical reaction.

Blackman demonstrated that Q_{10} 2 or more for a well illuminated plant and unity under low intensity of light.

6.3.3 Emerson effect and two pigment system :-

Quantum yield or photosynthetic yield

$$= \frac{No\ of\ oxygen\ molecule\ evolved}{Per\ quanta\ of\ light\ absorbed} = \frac{1}{8} = 12\%$$

Emerson and his co workers exposed chlorella plant to only one wavelength of light at a time and measured quantum yield. This was done just to find out that at which wave length of light quantum yield is more.

They observed a decline in photosynthetic yield at a wavelength above 680mμ i.e. in the red region of visible sepctrun (380-760 mμ). This fall in photosynthesis is called Emerson's red drop (first experiment).

Again in another experiment Emerson and his Co-workers supplied shorter wavelength (red light) along with long wave length (far red light). They observed enhancement in photosynthesis. This is called Emerson's enhancement effect.

The quantum yield from the two combined beam of light (red + far red) was found to be greater than the sum effect of both beams used separately.

Emerson's effect clearly shows the existence of two photo chemical process. One is driven by wave length exceeding 680 μm and other by shorter wave length. The two photochemical processes are believed to be associated with two specific group of pigments called pigment system-I and pigment system-II.

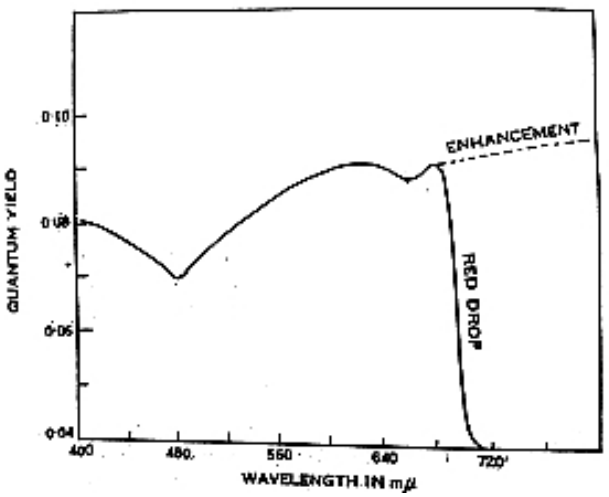


Fig 6.2 Graph showing Red Drop and Enhancement.

6.3.4 Pigment System-I :- It contains pigment like chlorophyll a b, carotenoils, xanthophyll and phycobilins. The reaction center of PSI is P700. The special chlorophyll a molecule which absorbs light near 700 ml.

It is active both in red light and far red light and carried out reduction of NADP+. It is associated with cyclic electron transport.

6.3.5 Pigment system II :- It absorbs shorter wave length its reaction center is P680 and pigments are chlorophyll a, b, and carotenoid. It is involved in non cyclic electron transport and causes photo oxidation of H_2o and evolution of O_2.

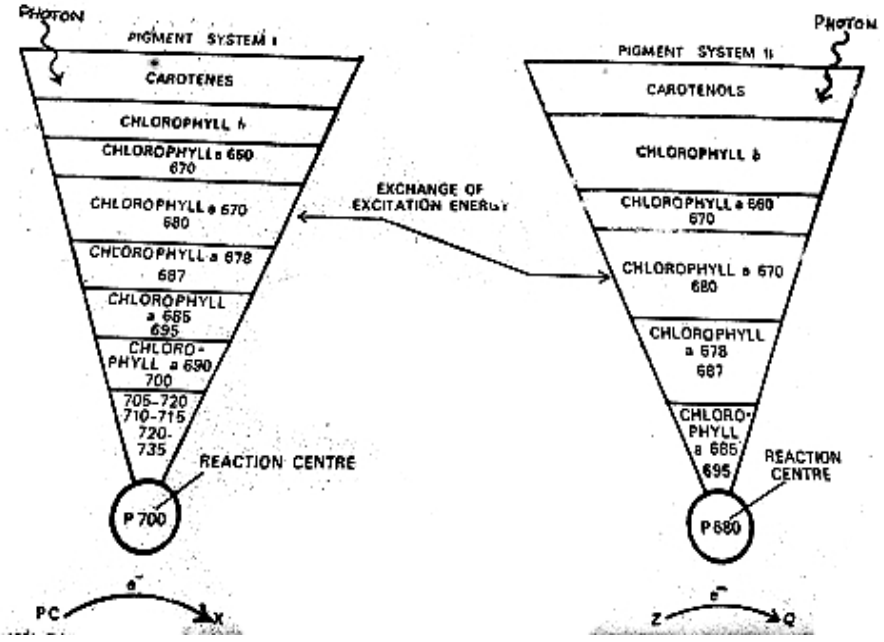


Fig 6.3Pigment System I Pigment System II

6.4 Light reaction -Mechanism

In the light reaction following events occur -

(1) Photo oxidation of water take peace and O_2 is released.

(2) Synthesis of ATP take place called photo phosphorylation.

(3) NADP+ is reduced to NADPH+H^+ Nicotinamide adenine dinucleotide phosphate (coenzme II)

Ruben et al-used radioactive O_2 in water supplied to the plant and found that O_2 released in photosynthesis comes form water-

$$6Co_2 + 12H_2{}^{18}o \rightarrow C_6H_{12}O6 + 6H_2O + 6^{18}O_2$$

The photophosphorylation is of two types:

- Non cyclic photophosphorylation or Z scheme.
- Cyclic photophosphorylation.

6.4.1 Non cyclic photophosphorylation or Z Scheme :

Q= Quinone

cytb cyto chromeb

PQ= Plastoquinone

Cyf= Cytochrome f

PC= Plastocyanin

X (F-S)= An unknown primary electron acceptor which is a iron sulpher protein.

Fd= Ferrodoxin.

In this both the photosystem I and II are operated. Light of longer wave length hits pigment of photosystem-I as a result P700 get excited and releases electrons which are accepted by an unknown primary electron acceptor X (Fe-S) believed to be an iron sulpher protein complex and get reduced. From reduced X (Fe-S) the electrons are accepted by a nonhemeiron protein called ferrodoxin (Fd) and from reduced Fd electrons are transferred to $NADP^+$ and $NADP^+$ get reduced to NADPH+H^+. This causes deficit of electron in photo-system I. This deficit is made up by photo excitation of P680 of photosystem I and electron deficit created in photosystem II is filled by electrons derived by the photo-oxidation of water in presence of Mn^{++} and cl^- ions.

When a lower wave length of light is received by PS II P680 looses an electron which is accepted by quinone. The electron then travels down hill through a series of carriers A, Cyto chromeb PQ, cytf and plastocyanin. The energy released in the transfer of electron from PQ to cytf is utilised to convert ADP into ATP and electron goes to PS I. At this stage water dissociates into H^+ and OH^- ions. The hydroxyl ion (OH) looses electrons and transferred to PS II. The H^+ are taken up by $NADP^+$ which get reduced to $NADPH+H^+$.

Thus in non cyclic photophosphorylation the electron is not cycled back. Therefore it called non cyclic photophosphorylation.

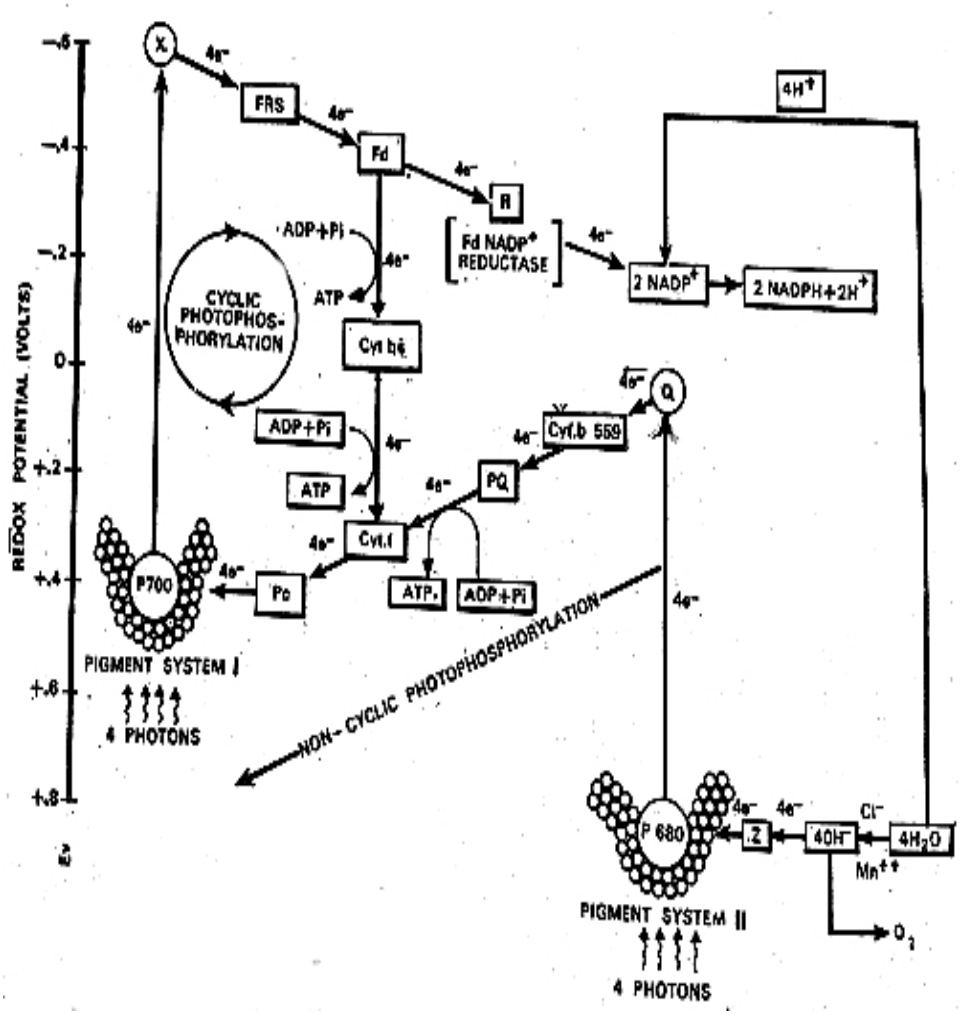


Fig 6.4 Cyclic and Non Cyclic phoyophosphorylation.

6.4.2 Cyclic photophosphorylation :

Cyclic photophosphorylation take place under certain conditions. It operates when Co_2 assimilation is curtailed and NADPH starts

accumulating. The cyclic transport is for more production of ATP when needed by chloroplast.

In this process only photosystem I operates. So no photoxidation of water take place therefore no evolution of O_2 and no formation of $NADPH+H^+$.

The electron flows from P700 to X (Fe-s) Then to Fd which is unable to pass electron to NADP+ the electron passes to cytb6 and cytf and then to PS I. Thus here electron is cycled back. In this only one PSI operates therefore no $NADPH+H^+$ is formed and Co_2 fixation is curtailed this results in decline in quantum yeild.

But when shorter wave length is given simultaneously PS II also comes in operation and photoxidation of water relases H+ which reduces NADP+ to $NADPH+H^+$ and photosynthetic enhancement take place.

6.5 Dark Reaction or Light independent biochemical reaction or dark fixation of Co_2

Dark reaction is purely enzymatic and does not require light. The site of dark reaction is stroma of chloroplast. Various enzymes required for fixation of Co_2 are present in the stroma of chloroplast.

The Co_2 absorbed by the plants from the environment combines with certain compounds in sequential steps to form intermediate compound and ultimately results in the formation of sugar and starch.

There are three pathway of Co_2 fixation.

(1) Calvin cycle or C_3 cycle.

(2) hatch-slack pathway or C_4 cycle.

(3) CAM cycle.

6.5.1 Calvin Cycle or C_3 cycle :- It was discovered by calvin. He used 14C and green alga chlorella and scendesmus and discovered C_3 cycle of Co_2 fixation using radioactive tracer technique. Sixmolecules of Co_2 combine with six molecules of ribulose 1,5 diphosphate in presence of water to form 12 molecules of 3-phosphoglyceric acid in presence of enzyme carboxydismutase. 3-phosphoglyceric acid (PGA) is first stable compound of calvin cycle which is 3 carbon compound.

The 12 molecules of PGA react with 12 ATP molecules to produce 12 molecules of 1, 3-Diphosphoglyceric Acid in presence of Phosphoglycerokinase, enzyme.

The 12 molecules of diphosphoglyceric acid is reduced to 12 molecules of phosphoglyceraldehyde by 12 molecules of $NADPH_2^+$. 12 $NADPH^+$ and 12 H_3Po_4 regenerated in the process in presence of enzyme 3-phosphoglyceraldehyde dehydrogenate.

The 5 molecules of 3-phosphoglyceraldehyde get isomerised to form dihydroxy acetone phosphate. The 3 molecules of dihydroxy acetone phosphate combines with 3 molecules of 3-phosphoglyceraldehyde to form 3 molecules of Fructose 1, 6 diphosphate in presence of enzyyme aldolase.

Each molecules of Fructose 1, 6-diphosphate loses one phosphate in presence of enzyme phosphatase to form 3 molecules of Fructose-6 phosphate. One molecule of Fructose 6-phosphate forms one molecule of Hexose sugar.

2 molecules of frustose 6- phosphate react with 2 molecules of 3-phosphoglyceraldehyde to produce 2 molecules of xylulose 5-phosphate and 2 molecules of erythrose-4-phosphate in presence of enzyme Transketolase.

2 molecules of Erythrose-4-phosphate combines with 2 molecules of dihydroxy acetone phosphate to produce 2 molecules of sedoheptulose-1, 7, diphosphate in presence of transaldolase enzyme.

Each molecule of sedoheptulose-1, 7 diphosphate loses one phosphate group in presence of phosphate enzyme to form sedoheptulose-7 phosphate.

2 molecules of sedoheptulose-7 phosphate react with 2 molecules of 3-phosphoglyceraldehyde in presence of enzyme transketolase to produce 2 molecules of Ribose-5-phosphate and 2 molecules of xylulose-5-phosphate.

2 molecules of ribose-5-phosphate are converted to two molecules of ribulose-5-phosphate in presence of phosphoribose isomerase enzyme.

4 molecules of xylulose-5-phosphate are isomerised to 4 molecules of ribulose-5-phosphate in presence of enzyme ribulose phosphate isomerase.

At the end of cycle all the six molecules of ribulose-5-phosphate get converted to ribulose-1, 5- diphosphate.

Thus the whole process of calvin cycle begins with the absoption of 6molecules of Co_2 by 6 molecules of RUBP and ends with the

formation of 1 molecule of hexose sugar with the regeneration of 6 mol. of RUDP.

The energy required in this reaction is supplied by 12 $NADPH+H^+$ and 18 ATP formed in the light reaction of photosynthesis.

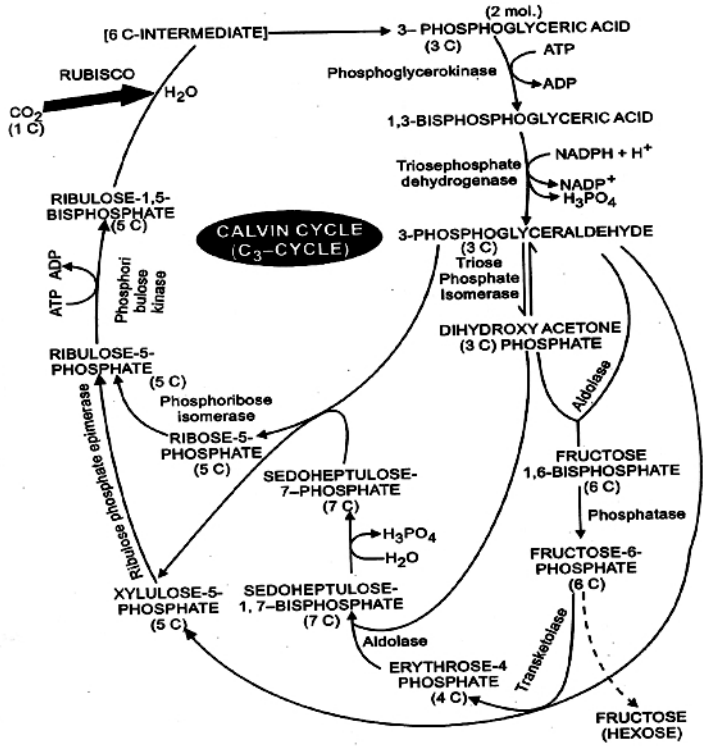


Fig 6.5 Calvin Cycle(C3 cycle)

6.5.2 Hatch-slack Pathway or C_4 cycle :-

This was discovered by Hatch-Slack in tropical and subtropical grasses. Some important C_4 plants are sugarcane, maize, sorghum.

The C_4 plants have different type of anatomy called krantz type which has two different types of chloroplast :-

(1) The bundle sheath has chloroplast which lack grana but has enzymes of calvin cycle therefore in the bundle sheath cell C_3 cycle take place.

(2) The mesophyll cells have chloroplast which has grana but lacks enzyme of calvin cycle. So in the mesophyll cell C_4 cycle take place.

In the mesophyll cells Co_2 is accepted by Phosphoenol pyruvate PEP and Oxaloacetic acid (4Carbon) first stable product is formed.

Oxaloacetic acid is reduced to malic acid in the presence of malic dehydrogenase enzyme using $NADPH+H^+$.

In other categories of C_4 plant oxaloacetic acid is transaminated to aspartic acid by enzyme transaminase present in the cytoplasm.

The malic acid is transported to bundle sheath cells and decarboxylated in presence of malic enzyme to yield Co_2 and pyruvic acid.

The Co_2 produced by decarboxylation of malic acid is accepted by RU1,5 BP and calvin cycle take place in the bundle sheath cell.

The pyruvic acid formed in the bundle sheath enters into the mesophyll cells and forms phosphoenol pyruvate in presence of pyruvate phosphate dikinase enzyme.

In other categories where aspartic acid is produced the path is slightly different. The aspartic acid is converted back to oxalic acid which is decarboxylated to phosphoenol pyruvic acid and Co_2 is released in the bundle sheath.

In other cases the aspartic acid is converted to oxaloacetic acid in the bundle sheath then to malic acid which decarboxylated to pyruvic acid.

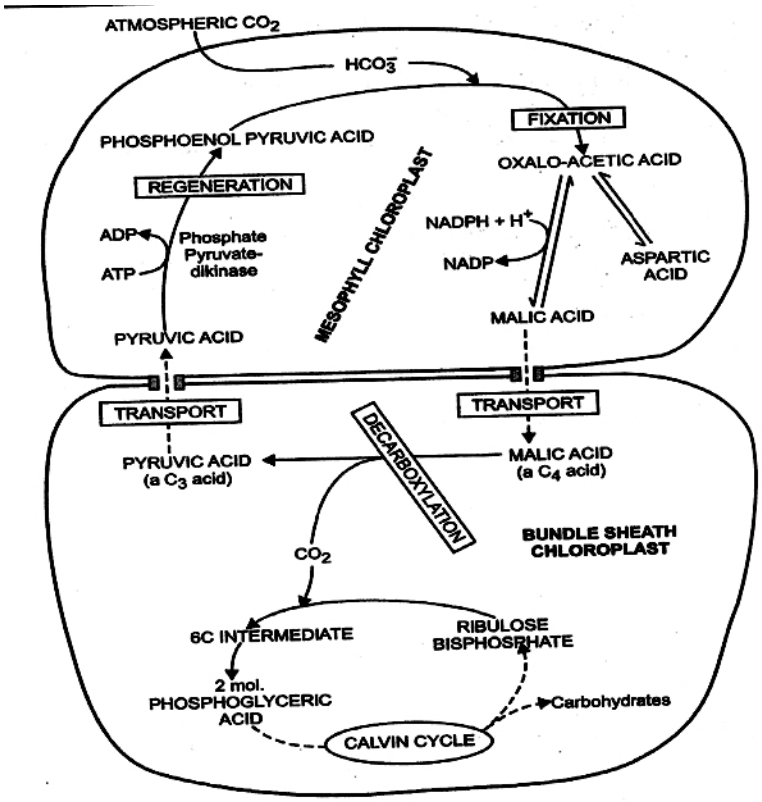


Fig 6.6 Hatch Slack pathway (C4 Cycle)

Significance of C_4 Cycle :-

The C_4 cycle is an adaptation in tropical and subtropical plants for low availability of Co_2 due to partial closure of stomata in the dry climates of tropics and subtropics.

The PEP has more efficiency for Co_2 than RUBP. PEP is not senstive to O_2 also. Thus the C_4 plants are well adopted to grow at low water content, Co_2 and high O_2 in the atmosphere at which C_3 plants can not survive because they can not do photosynthesis.

6.5.3 Crassulacean Acid Metabolism (CAM cycle) or (dark fixation of Co_2 in succulents)

CAM cycle take place in succulent plants which grow under semiarid conditions and fixes atmospheric Co_2 during night. These plants accumulates organic acid in their leaves during night and decrease during day time. This process was first observed in plants belonging to family crassulaceae (eg. Bryophyllum) so it was termed as crassulacean acid metabolism (CAM).

In these plants the stomata remain closed during day time therefore they photosynthesize during day time with the help of Co_2 released from organic acids.

the malic acid synthesized during night with the help of Co_2 released in respiration as well as Co_2 available from the atmosphere through the open stomata accumalates in the vacuoles This malic acid is decarboxylated during day time in presence of enzyme PEP carboxy kinase and produce Co_2 and pyruvic acid. This Co_2 is accepted by RUBP and normal calvin cycle take place and carbohydrate is formed.

The pyruvic acid is converted to carbohydrates. This carbohydrates as well as carbohydrate formed in calvin cycle under go glycolysis and forms PEP which during night accept Co_2 of the atmosphere entering into the plant through open stomata and forms oxaloacetic acid in presence of enzyme PEP carboxylase. The oxaloacetic acid is converted to malic acid in presence of malic dehydrogenase enzyme utilizing $NADPH+H^+$.

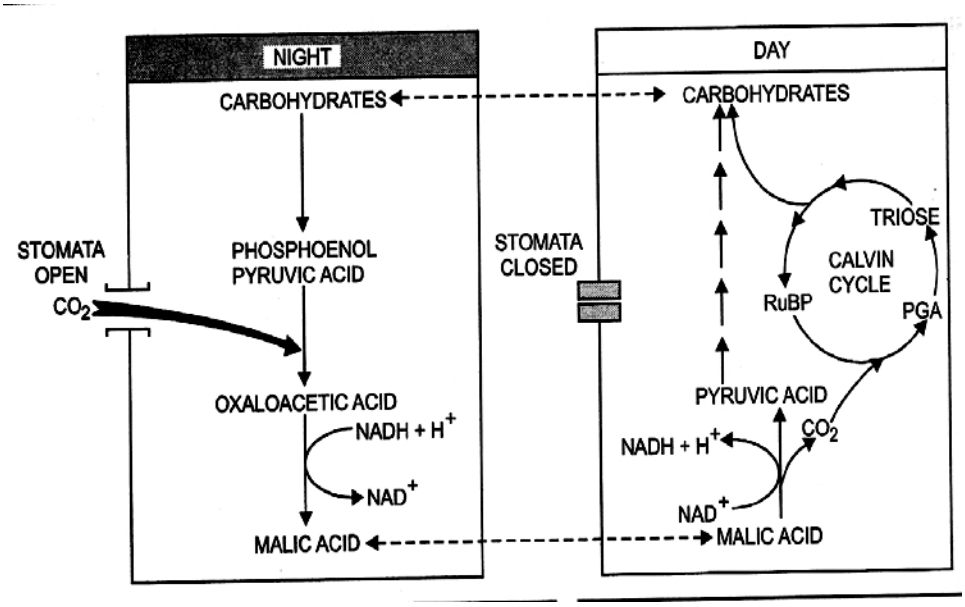


Fig 6.7 CAM Cycle

Significance of CAM

As these plants grow under extreme xerophytic condition and their stomata opens during night and remain closed during day time. Therefore in these plants CAM cycle is an adaptation for photosynthesis. This metabolism enable these plants to survive when other plants would die due to lack of food.

6.5.4 Difference in C_3 and C_4 plant

	C3 plant		C4 Plant
1.	Plant have C3 cycle in all green plant.	**1.**	Plants have Hatch slack cycle in mesophyll cell and C_3 cycle in bundle sheath cell.
2.	Krantz type anatomy is absent.	**2.**	Krantz type anatomy is present. Mesophyll cells have grana but enzyme of calvincycle absent. Therefore C_4 cycle occurs. Bundle sheath lack grana but has enzyme of calvin cycle therefore C_3 cycle occurs.
3.	RUBP and enzymes of calvin cycle are present in all green cell and C_3 cycle occurs in mesophyll cell.	**3.**	RUBP and enzyme of calvin cycle are present in the bunle sheath therefore C_3 cycle occurs.
4.	First stable product is PGA a three carbon compound.	**4.**	First stable product is oxaloacetic acid a 4 carbon compound.
5.	Maximum light intensity for photosynthesis is 1000-1200 foot candles.	**5.**	Can photosynthesize at much higher light intensity even in full sunlight.
6.	There is only one Co_2 acceptor i.e. RUBP.	**6.**	There are two Co_2 acceptor 1. PEP in merophyll cell 2. RUBP in bundle sheath cell
7.	Optimum temperature ranges between 10-25^0C.	**7.**	Optimum temperature ranges between 30-45^0C
8.	C_3 cycle can reduce the Co_2 concentration around plants only upto 50ppm. because RUBP has less affinity for Co_2.	**8.**	It can reduce Co_2 concentration even less than 10ppm because PEP has strong affinity for Co_2.

9.	Less efficient in photosynthesis.	**9.**	More efficient in photosynthesis.
10.	O_2 has inhibitary effect on photosynthesis.	**10.**	O_2 has no inhibitary effect on photosynthesis.
11.	Photorespiration occurs which reduces rate of photosynthesis.	**11.**	Does not occur.

6.6 Summary

In this unit you have learnt that :

- Plant synthesizes their own food from raw material by the process of photosynthesis.
- The photosynthesis is a very important metabolic process which provides food and O_2 to living organism.
- Photosynthesis occurs on chloroplast. Light reaction occurs in grana and dark reaction in the stroma of chloroplast.
- In the light reaction synthesis of ATP (Adenosine triphosphate), NADPH+H+ (reduced Nicotinamide adeninedinucleotide phosphate) and evolution of water take place.
- In the dark reaction fixation of Co_2 take place and final product carbohydrate in formed by C_3 cycle, C_4 cycle and CAM cycle.
- C_3 cycle occurs in C_3 plants, C_4 cycle occurs in C_4 plants and CAM cycle occurs in succulent plants.
- The C_4 cycle and CAM cycle is a kind of adaptation in C_4 and succulent plant respectively.
- Photorespiration or C_2 cycle occurs in C_3 plants therefore photosynthetic yield of C_3 plant is less than C_4 plant.

6.7 Terminal Questions

Q.1 Describe the structure of chloroplast.

Answer:----------

Q.2 Describe the mechanism of light reaction of photosynthesis.

Answer:----------

Q.3 Give an account of calvin (C_3) cycle.

Answer:----------

Q.4 Discuss the mechanism and significance of Hatch-Slack Pathway (C_4 cycle).

Answer:----------

Q.5 Differentiate between C_3 and C_4 plant.

Answer:----------

Short Questions

Q.6 Write short note on :

(1) Emerson Effect

(2) PS I

(3) PS II

(4) Q_{10} or temperature co-efficient.

(5) CAM cycle

Q.7 Multiple choice questions MCQ.

(1) Light reaction of photosynthesis occurs in :

(a) Grana of chloroplast (b) Stroma of chloroplast

(c) Both (d) None of the above

(2) Dark reaction of photosynthesis occurs in :

(a) Stroma of chlorplast (b) Grana of chloroplast

(c) Both (d) None of the above

(3) Oxidation of water is catalysed by :

(a) Photosystem-I (b) Photosystem-II

(c) ATP Synthetase (d) None of these

(4) Photosynthesis is :

(a) Fixation of Co_2 and H_2o

(b) Fixation of carbohydrates

(c) Fixation of sugar

(d) None of these

(5) The O_2 released in photosynthesis comes from :

(a) Co_2 (b) H_2O

(c) Both (d) None of these

6.8 Answer

(1) a (2) a (3) b (4) a (5) b

UNIT - 7

Hormones

Structure

7.1 Introduction

The dormant seed has the miniature of plant body which germinates under favourable environmental and physiological conditions to give rise a differentiated plant body. The growth and differentiation of

plant is controlled by nutritional factors, genetic factors and hormones. The distribution and fate of nutrients in different organs or plants for growth and differentiation is regulated by hormones. Thus plant hormones play an important role in growth and differentiation of plants. The hormones are signal molecules produced within plants, that occur in extremely low concentration and control all aspects of growth and development from embryogenesis, regulation of organ size, pathogen defence, stress tolerance and reproductive development or flowering.

Objectives

After studying this unit you should be able to :

- Know the growth and course of growth.
- The plant hormones like auxin, gibberellins, cytokinins, abscisic acid, ethylene and their role in physiology of plant.
- Physiology of flowering and florigen hormone.
- Short day plant, long day plant, day neutral plant and phytochrome.
- Vernalization and De-vernalization.

7.2 Growth and Course of Growth

Growth is an irreversible change in the volume of a cell accompanied by increase in dry weight.

Site of growth : In unicellular plant the growth occurs as overall growth in the plant body.

In Multi Cellular plants : Growth is restricted to specific regions having meristematic cells - eg. Apical Meristem, Lateral Meristem and Inter Calary Meristem

Growth : Occurs in three phases - (1) Cell division (2) Cell enlargement (3) Cell Maturation.

(1) Cell Division : In the meristematic region cell divides to form new cells.

(2) Cell enlargement : Cell division is followed by cell enlargement. During this phase the young cell absorbs water by osmosis as a result turgor pressure in the cell increases resulting in streching of wall which is irreversible due to plasticity.

Cell Maturation : In this phase secondary walls are laid down and cells are differentiated into permanent tissue.

Course of Growth : If we plot a graph between growth rate and time it shows S-shaped or sigmoid curve.

In the lag phase- growth is initially slow.

In the log phase-Growth gradually becomes more and more rapid.

In the steady phase- Growth slows down and finally stops.

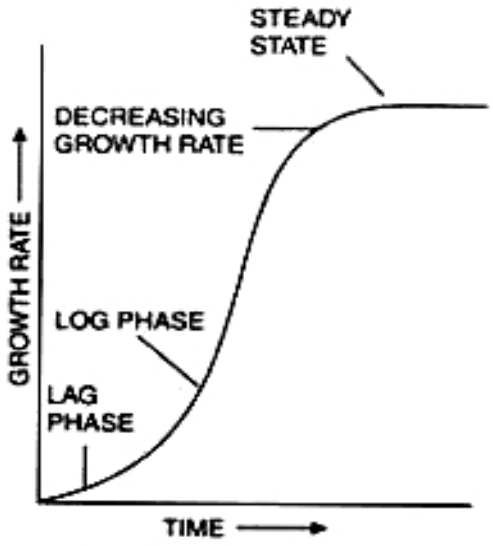


Fig 17.1. Sigmoid curve.

Fig 7.1 Sigmoid curve

In the plants growth is affected by environmental, nutritional, genetic and hormonal factors. Among which hormones are most important internal factor which controls growth and development of the plant.

7.3 Plant hormones

It is defined as - "An organic compound which is produced in one part of the plant body and is translocated to another region where in extremely small amount it induces definite physiological effect."

There is a term phytohormone which is used for the chemical substances synthesized by plant.

A group of plant hormones include Auxin, Gibberellim, ethylene, and abscisic acid. They are also known as growth regulator.

7.3.1 Auxin

Indol- 3 acetic Acid-I AA is the naturally occurring auxin.

Auxin is an organic compound which induce elongation of shoot cell but inhibits elongation of root cell in very low concentration.

Charles Darwin (1881) was first to discover the existence of auxin in the tip of plant.

- Darwin and his son demonstrated the bending of canary grass (Phalaris Canariensis) towards unilateral source of light.
- In another experiment the tip of coleoptile grass was decapitated or covered with black cap. The bending of tip towards light was not observed but when the cut tip was replaced again bending was observed.

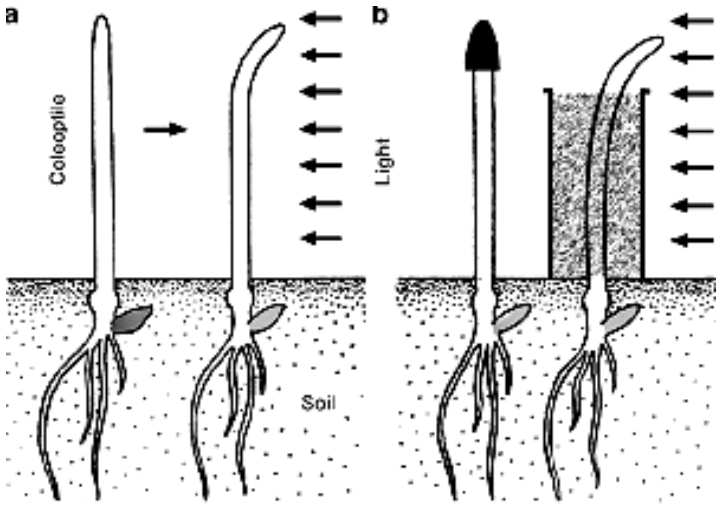


Fig 7.2 Darwin's experiment

Source:https://www.researchgate.net/figure/Charles-Darwin-s-experiments-with-dark-grown-grass-seedlings-a-b-that-led-to-the_fig1_225309609

- Boysen-Jensen (1910-1913) decapitated the tip of Avena and smeared a bit of gelatin on the cut end, replaced the tip on the gelatin and found that coleoptile bend towards the soruce of light. The conclusion was drawn that some substance has diffused from the tip through the gelatin to the cut end and causes growth.

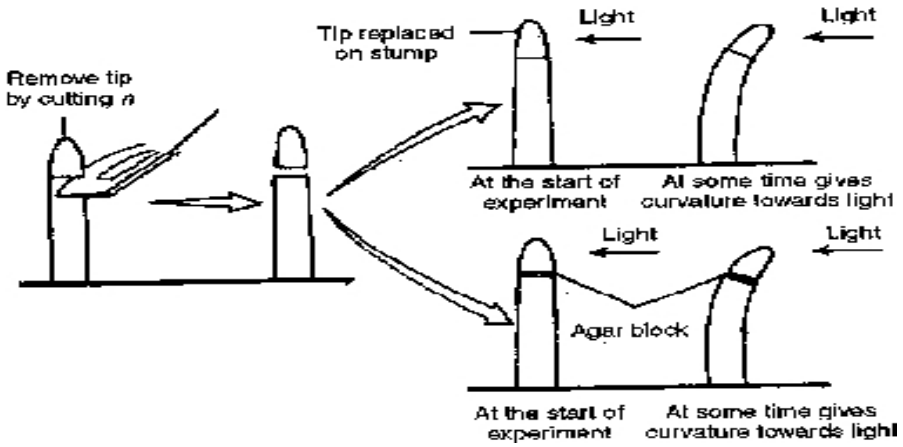


Fig 7.3 Boysen-Jensen experiment.

Source:https://www.entrancei.com/chapter-plant-growth-and-development-class-11/growth-regulators

- Went in 1928 decapitated Avena tips and placed them over a thin block of agar-agar. The agar block was allowed to stay for a brief time. The block was then cut into small pieces, a piece was placed eccentrically on the cut end of coleoptile. The characteristic of bending was observed.

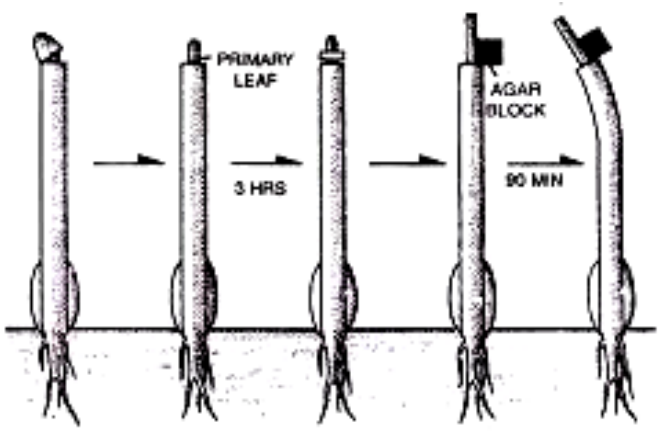


Fig 7.4 Went's experiment

Source:http://www.biologydiscussion.com/plants/growth-of-plants/top-3-plant-growth-promoters-auxins-gibberellins-and-cytokinins/15751

From the above experiments it was concluded that a substance migrates down words shaded side promoting growth curvature to wards light due to more growth on shaded side. The substance produced at the tip was water soluble.

Kogal et al isolated 3 active growth promoting substances from human urine and named them Auxin A, Auxin B and hetero auxin which is now called I AA

The I AA is the principal naturally occurring auxin in all the higher plant generally synthesized at growing tips of stem, root, leaves and buds and is transported from tip to the base.

There are **some synthetic compounds** which also act as auxin:-

NAA - β Napthalene acetic acid

2.4-D- 2.4 dichlorophenoxy acetic acid

IBA- Indol butryric acid.

Role of Auxin

1. **Cell elongation :-** Auxin promotes elongation in stem cells but inhibits in root.

2. Role of Auxin in Phototropism :- Exposure of shoot apex to unilateral light leads to transport of auxin towards shaded side of the plant. Thus accumulation of more auxin on shaded side causes more growth on that side hence stem bends towards the source of light.

3. Role in Geotropism : In horizontally placed plant the geotropic curvature is caused due to transport of Auxin to the lower side under the influence of gravity.

Root apex curves down words because its growth is inhibited on the lower side due to auxin and shoot bends upwards because of more growth on the lower side due to accumulation of auxin. The auxin promotes growth in stem and inhibits in case of root. Therefore, due to auxin shoot becomes,- vely geotropic and root becomes + vely geotropic.

4. Apical dominance : Auxin stimulates growth of apical bud but inhibits the growth of lateral bud.

5. Initiation of root : Higher concentration of auxin inhibits root growth but it initiates the adventitious roots from the nodes or basal regions of stem. Therefore, synthetic auxins IBA, NAA are used to induce root formation in stem cutting and leaf cuts.

6. Parthenocarpy : Parthenocarpy is the formation of seedless fruits with out fertilization. External application of auxin on flowers causes development of seedless fruits in tomatoes, apples and cucurbits.

7. Prevention of Abscission Layer : Shedding of mature leaves and fruits from the stem is called abscission. In abscission an abscission zone is first formed at the base of petiole. The cells of this zone dissolve and cause separation of plant organ.

Abscission is promoted by plant hormone ethylene but is prevented when the concentration of auxin is higher. Thus a premature abscission in the plant is controlled by auxin-etylene concentration.

8. Spur formation :- Apple and pear fruits are borne on dwarf shoot. If terminal shoots is treated with auxin their elongation is checked and become dwarf shoot.

9. Flower initiation :- Auxin generally inhibits flowering but in pine apple it promotes flowering.

10. Prevention of water lodging :- Many crops of Leguminaceac and Graminae tend to fall down due to excessive softening of cells in the basal internodes of the stem. Application of Auxin prevents it.

11. Dormancy :- Auxin prolong dormancy and has importance in storage of fruits and vegetables. It inhibits sprouting of potato for three years instead of one.

12. Weed Control - As a herbicide :- Many synthetic auxins such as 2.4-D, MCPA-2 methyl 4 Chloro Phenoxy acetic acid are used as a herbicide.

13. Auxin controls differentiation of xylem and phloem.

14. Respiration :- It stimulates respiration in plants by inducing synthesis of various enzymes which increase respiration.

7.3.2 Gibberellins

It is another plant hormone which enhances the longitudinal growth of stem when applied to intact plants.

It was discovered by a Japanese plant pathologist. **Kurosawa :** He observed that some rice plants grew abnormally thin and tall. They called it "Bakane of foolish seedling" disease. These rice plants were infected by *Gibberella fujikuroi* (the perfect stage of *Fusarium moniliformae*) Later on Yabuta and Sumiki isolated and crystallised Chemical substances from *Gibbrella fujikuroi* and found that the substance secreted by fungus was responsible for elongation of plant. This secreted substance named as Gibberellic Acid.

About 62 different Gibberellic acids are known out of which about 25 have been isolated from the fungus *Gibberella funjikuroi*.

Physiological Effects of Gibberellins :

1. **Stem elongation :-** Gibberellin causes elongation of stem and leaf sheath.
2. **Dwarf plant :** Genetically dwarf plants can be converted into tall plant by the action of Gibberellin eg. when rosette plants of sugar beet is treated with Gibberellin (GA3) it undergoes marked longitudinal growth of axis.
3. **Promoting flowering in Long Day plant:-** Gibberellin promotes flowering in long day plants under unfavorable short day conditions.
4. **Substituting cold treatment :** Binnials normally flower only during the second year of growth when they passed through a winter season. These plants when treated with Gibberellin can be made to flower in a year and their whole life cycle is completed in one year.
5. **Parthenocarpic fruits :-** Gibberellins have been found to be more effective than auxins in producing parthenocarpic fruits. In Pome and stone fruits, auxins fail to produce parthenocarpic fruits but Gibberellin successfully produced parthenocarpic fruits.
6. **Cell division in the cambium :** Gibberellin can stimulate cell division in the vascular cambium of many deciduous trees.

7. **Seed germination :-** Lactuca and barely are light senstive seed but can germinate even in complete dark when treated with Gibberellins.

8. **Breaking dormancy :-** Gibberellins have been shown to be effective in breaking the dormancy of potato tuber and tree buds during winter.

9. **Bolting and Flowering :-** In certain plants the growth of internodes is reduced and leaves grow profusely. Such type of growth is called rosette. In these plant internodes grow excessively just before reproduction. Stem elongates 5-6 times than the original height of the plant. This stimulation of internodes growth just before flowering, is called 'Bolting' after this flowering takes place in plant. Actually these plants require specific long day photoperiods or specific cold requirement to bolt and flower. When these plants are treated with Gibberellins during the condition of rosette growth, the plants bolt and flower. The Gibberellins treatment stimulates the cell division and cell elongation in the subapical meristem which causes bolting and subsequent flowering.

7.3.3 Cytokinins (Kinetin)

This hormone induces cell division in the plants. It was discorved by Miller and his co-workers while working on tobacco pitch culture. They named as kinetin.

Physiological effects of cytokinins :-

1. **Cell division :-** Cytokinin promotes cell division in number of lower and higher plants.

2. **Cell enlargement: -** Cytokinin causes cell expansion like auxin and gibberellin.

3. **Morphogenesis :-** Cytokinis play a very important role in the organ formation in culture tissue. The cytokinins and auxins interaction controls the differentiation of shoot and root.

   When the concentration of auxins is higher and cytokinins is lower only roots are produced and when cytokinins is higher and auxins is lower stem buds are produced.

4. **Couenteraction of apical deminance :-** When cytokinins is applied to the plant lateral growth in plant taken place even in the presence of apical bud.

5. **Breaking dormancy :-** It can break dormancy of many seeds.

6. **Initiation of interfacicular Cambium :-** Cytokinins induces formation of inter fasicular cambium in plant.

7. **Richmond long effect or Delay of Senescence:-** In senescence the chlorophyll of leaf disappears and protein degrades. Finally they shed from the plant. When these plants are treated with cytokinins the process of senescence is delayed for few days. This phenomenon of delayed senescence in known as Richmond effect.

7.3.4 Abscisic Acid (ABA)

Certain plants have been found to contain new type of hormone which act as growth inhibiter eg. ABA and ethylene. ABA is synthesized in the leaves and then translocated to stem apex through phloem.

Physiological role of ABA

1. It regulates dormancy of buds and seeds probably by inhibiting the growth process.
2. It accelerates the senescence in leaf and causes ageing and abscission of leaves.
3. ABA inhibits germination of seed as well as gibberellins stimulate growth. It acts as antagonist against gibberellic acid and named as anti gibberellins.
4. Increased production of ABA causes closure of stomata as ABA interferes with the uptake or retention of K^+ ion in the guard cell.
5. ABA inhibits gibberellins induced α-amylase formation in barley aleurone.

7.3.5 Ethylene

Ethylene a well known product of combustion responsible for air pollution is a power full plant hormone. It is a volatile gas and get synthesized in ripening fruits, leaves and flowers.

Physiological effect of ethylene:-

1. It prevents elongation of stem and root in longitudinal direction.
2. Ethylene inhibits growth of lateral bud in pea, thus causes apical dominance.
3. In some plants growth of fruit is stimulated by ethylene. The most remarkable effect of ethylene is stimulation of fruit ripening.
4. Ethylene stimulates formation of abscission zone in leaves flower and fruit. Ethylene stimulates abscission by formation of hydrolases.
5. Flowering is promoted by ethylene in many plants like pine apple and mango.

6. Ethylene stimulates root hair formation.
7. Ethylene breaks dormancy of buds and seeds.
8. Ethylene promotes senescence of leaves.
9. It inhibits basipetal polar and lateral transport of auxin.

7.4 Physiology of Flowering

The physiological changes occurring in plant in response to relative length of day and night is called "photo periodism". This term was first of all used by W.W. Garner and H.A. Allard in 1920. They observed that Mary and Mammoth variety of tobacco failed to flower in summer but when they were placed in green house in winter flowering and fruiting takes place. It was concluded that flowering in tobacco plants were promoted by short day length.

7.4.1 Photoperiod : Plants require a critical photoperiod to induce flowering. If we divide 24 hrs into 12 hrs light and 12 hrs dark then short day plants require less than 12 hrs light for flowering. This will be the critical photoperiod for that plant.

Later on plants were classified into three groups according to their photoperiod:

1. Short day plant (SDP)
2. Long day plant (LDP)
3. Day neutral plant

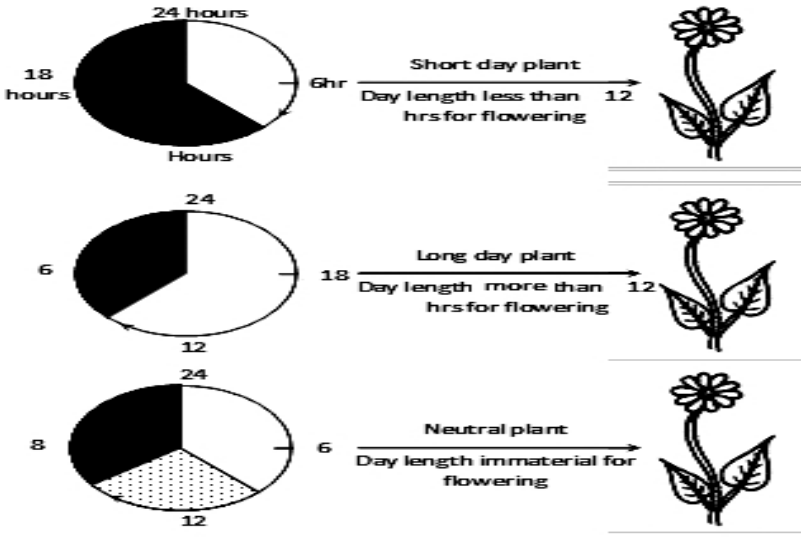


Fig 7.5 Short day, long day and day neutral plants

Source: https://www.studyadda.com/notes/11th-class/biology/growth-and-development-in-plants/physiology-of-flowering-plant/9751

7.4.2 Short Day plant (Long night plant)

Short day plants require a photoperiod of less than 12 hrs for flowering. These plants require relatively long uninterrupted dark period. Flowering is suppressed if the dark period is interrupted in the mid way even by a single flash of light and if dark period is interrupted in the beginning or end then it will not affect photoperiodism. Short day plants can flower even in continuous dark when sucrose is supplied to them. This shows that light is needed for photosynthesis. Under long day conditions flowering can be induced if the dark period is increased by transferring the plant to darkness for short period.

Thus in short day plant, the length of night is more important for flowering therefore, It is better to call them "long night plant".

Example - *Nicotiana tobacum, Glycine max Oryza stiva*.

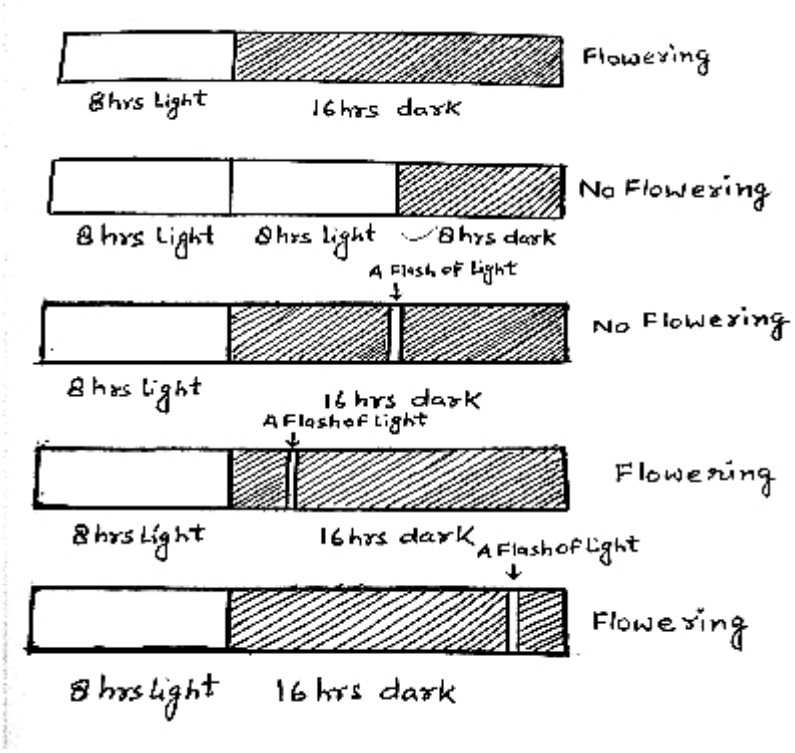


Fig 7.6 Photo period inducing flowering in SDP.

7.4.3 Long Day plant (Short night plant)

Long day plants require a photoperiod of more than 12 hrs. In these plants dark period has inhibitary effect on the flowering of plants. The plants require continuous light and can flower even in absence of darkness.

The long day plants can flower under short day conditions if the short light period is followed by still shorter dark period (8hrs light 4hrs dark in 12 hrs cycle).

Thus, in these plants flowering under short day condition is inhibited because of long dark period and not due to short light period. Therefore, it is better to call then short night plant

eg.- *Triticum, aestivum, Avena sativa, Pisum satiuum.*

7.4.4 Day- Neutral Plants

These plants do not require specific photoperiod for flowering and flowers in almost all the photoperiods. Therefore, they are called day neutral plant.

eg.- Tomato, cucumber, balsam, maize etc.

7.4.5 Flowering hormone or florigen

A flowering hormone florigen exists in plants. The florigen is synthesized in the leaves under favourable photoperiod and then transmitted to the growing point where the flowering takes place.

It is assumed that a special compound (A) required for flowering induction is synthesized from Co_2 during light. The compound A is converted to compound B in the dark period when the dark period is interrupted by a flash of light in the beginning there is no inhibitary effect on the synthesis of the flowering hormone as there is still enough time for the formation of B from A. If the interruption is in the midway the sufficient amount of B may not be formed, therefore flowering will not occur. A compound C is synthesized in the leaf from compound B and this C is believed to be florigen, the flowering hormone. It is then tanslocated to shoot apex where it initiate flowering.

There are evidences in support of flowering hormones :-

1. Photoperiodic stimulus is perceived by leaves.
2. Stimulus may be transmitted from a single leaf through the stem to the apical meristem.
3. Flowering stimulus is same in short day plant and long day plant.
4. The leaf extract of flowering *xanthium* plant induces flowering in vegetative *xanthium* plant.

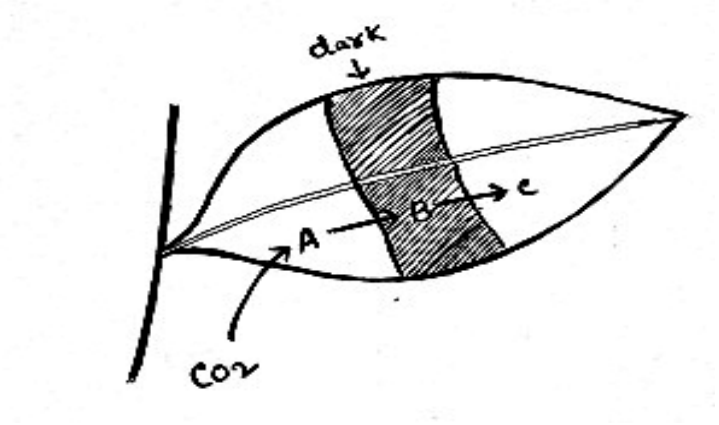


Fig 7.7 Flowering hormone Florigen

7.5 Phytochrome (Reversible photoreaction governing flowering)

In the green plant phytochrome pigment is found which exist in two forms Pr (Phytochrome red) and Pfr (Phytochrome farred). Pr. is blue green and absorbs red light (660nm) where as P_{fr} is light green and absorbs far red light (730nm)

$$P_{red} \underset{730nm}{\overset{660nm}{\rightleftharpoons}} P_{fred}$$

Short day Plant :- In short day plants flowering is promoted by Pr and inhibited by Pfr form.

At the end of light period Pr is converted to Pfr which inhibits flowering. In the continuous dark period Pfr is converted to Pr. which promotes flowering. Therefore, in S.D.P it is the dark period which is more important. When the dark period is interuppted by a flash of light in the mid way, the Pr is again converted to Pfr and flowering is inhibited.

Long day plant : Stimulus of flowering in plants is promoted by Pfr. In long light period Pr is converted to Pfr and flowering takes place when the dark period is longer, Pfr is converted to Pr which inhibits flowering.

7.6 Vernalization

In binneals and perennials flowering is promoted by low temperature. This is called visualization. In these plants in the first year only vegetative growth take place and when plant passes through a winter season then in the next year flowering takes place. The low temperature requirement for flowering was first noticed by klippart in 1857.

This requirement of low temperature in nature can be satisfied artificially in laboratories. If a binneal seed is germinated and is then exposed to low temperature (0^0-5^0C) for few weeks. It will behave as it has gone through a cold winter and complete their life cycle with in a year.

De-vernalization

It is reverse of vernalization if a vernalised seed or plant is kept at high temperature the effect of low temperature treatment is completely removed and flowering occurs when it passes through a winter season.

7.7 Summary

- Growth is an irreversible change in volume of a cell accompanied by increase in dry weight.
- Growth curve is sigmoid or S-shaped.
- In plants growth is controlled and regulated by hormones which are organic substances.
- Auxins or Indol-3 Acetic Acid (IAA) is naturally occurring hormone which induces elongation of shoot cell but inhibits elongation of root cell in very low concentration.
- Gibberellins is another growth hormone produced from *Gibberella fujikuroi*. It also enhance longitudinal growth of stem.
- *Cytokinin* is also known as Kinetin. This hormone induces cell division in the plant.
- Abscisic acid and ethylene are growth inhibitors.
- Abscisic acid causes abscission of leaf and fruit in plants.
- Ethylene is gaseous hormone responsible for ripening of fruits, leaves and flowers.
- Reproductive growth or flowering in the plant is controlled by photoperiod and temperature.
- In annual plant it is controlled by photoperiod where as in binneals and perennials it is controlled by temperature known as vernalization.
- On the basis of photoperiod required for flowering plants are divided into long day plant, short day plant and day neutral plant.
- The flowering hormone in plant is "Florigen".

7.8 Terminal Questions

Long questions :

Q.1 Describe the physiological role of auxins on higher plant.

Answer:----------

Q.2 Write an essay on Gibberellins.

Answer:----------

Q.3 Discuss the physiology of flowering with special reference to photoperiodism.

Answer:----------

Q.4 Describe the physiological role of cytokinins.

Answer:----------

Shorth questions :

Write notes On

Q.5 Abscisic Acid

Q.6 Ethylene

Q.7 Cytokinins

Q.8 Short Day plant

Q.9 Long Day plant

Q.10 Flowering hormone : Florigen

Q.11 Vernalization and de-vernalization.

Multiple Choice questions (MCQ)

Q.1 Auxins have been isolated from :

(a) Cornmeal (b) Matt

(c) Human Urine (d) All of these

Q.2 *Gibberella fujikori* is a :

(a) Fungi (b) Algae

(c) Bryophyte (d) Pteridophyte

Q.3 Cell division hormone is :

(a) Auxins (b) Gibberellins

(c) Cytokinins (d) Ethylene

Q.4 The hormone for abscissions is :

(a) Ethylene (b) Auxins

(c) Gibberellins (d) Absicic acid

Q.5 Ripening hormone is :

(a) Ethylene (b) Auxins

(c) Gibberellins (d) Cytokinins

7.9 Answers (MCQ)

(1) c (2) a (3) c (4) d (5) a

UNIT - 8

Respiration

Structure

8.1 Introduction

The term respiration was first used by animal physiologist to describe the breathing movements of animals, but was subseqently extended to include the chemical reactions by which complex organic substances like carbohydrates, fats and proteins are broken down to release carbondioxide (Co_2), water (H_2o) and energy. Incase of plants the problem of definition is slightly different from animals because :

1. Breathing does not occurs in plant.
2. The gaseous exchange typical of animal is not apparent in plants during day time because of photosynthesis.
3. O_2 is not utilized.
4. Co_2 may not be released in some cases.

Because of this plant physiologist used term respiration for the oxidation of food in living cells. The break down of substrate provide carbon skeleton for the synthesis of a large number of other essential plant products, such as carbohydrates, proteins, fats, nucleic acids, pigments, cytochromes etc.

Objectives

After studying this unit you should be able to :

- Know the process of respiration in plants.
- Aerobic and anaerobic respiration.
- Process of Glycolysis and krebs cycle.
- Electron transport chain and oxidative phosphorylation.
- Process of fermentation.

8.2 Definition of Respiration

Respiration is an energy yielding Catabolic process in which organic foods are broken down in presence or absence of O_2.

Types of Respiration : It is of two types -

1. Aerobic Respiration - Occurs in cytoplasm and Mitochondria
2. Anacrobic Respiration- Occurs in cytoplasm.

8.3 Aerobic Respiration

Occurs in presence of O_2 with complete oxidation of food into Co_2 and H_2o with the evolution of energy, 673Kcal.

$$C_6H_{12}o_6 + 6o_2 \rightarrow 6Co_2 + 6H_2o + 673kcal$$

Mechanism of Respiration- It is completed in two steps - (i) Glycolysis (ii) Krebcycle.

8.3.1 Glycolysis : Various steps of Glycolysis were traced by German Scientist Embden, Meyer half and Parnas so it is also known as EMP path way. It occurs in the cytoplasm and one molecule of glucose is broken into 2 molecules of pyruvic acid through step wise reactions under specific enzymes. This process does not requires O_2. The process is as follows :

- Glucose molecule is phosphorylated in presence of ATP to form glucose-6 phosphate. The reaction is catalysed by enzyme *hexokinase* which requires a divalent Mg^{++} as cofactor.
- Glucose-6-phosphate is isomerized to fructose-6-phosphate in presence of *enzyme phosphogluco isomerase*.
- Fructose-6-diphosphate is then cleaved to two triose phosphates; dihydroxy acetone phosphate and 3-phosphoglycer-aldehyde. The reaction is catalysed by enzyme aldolase. The two trioses are isomeric and they may isomerise to each other in presence of enzyme triosephosphate isomerase.
- 3-Phosphoglyceraldehyde is converted to 1,3-diphosph-oglyceraldehyde in presence of inorganic phosphate (H_3PO_4).

- 1, 3-Diphosphoglyceraldehyde is oxidized to form 1,3-diphosphoglyceric acid in presence of enzyme triosephosphate dehydrogenase and coenzyme NAD^+. The NAD^+ acts as hydrogen acceptor and reduced to NADH+ H^+ in the reaction.
- 1, 3- Diphosphoglyceric acid is then converted to 3-phosphoglyceric acid in presece of enzyme-phosphoglyceric transphosphorylase (Phosphoglyceryl kinase). One molecule of ADP is phosphorylated to ATP in the reaction.
- 3-Phosphoglyceric acid is transformed to 2-phosphoglyceric acid in presence of enzyme-phosphoglyceryo mutase.
- The next reaction involves the dehydration of 2-phosphoglyceric acid to produce 2-phosphoenol pyruvic acid in presence of enzyme-enolase.
- In the next step phosphate is transferred from 2-phosphoenol pyruvic acid to ADP to produce pyruvic acid and ATP in presence of enzyme-pyruvate kinase.

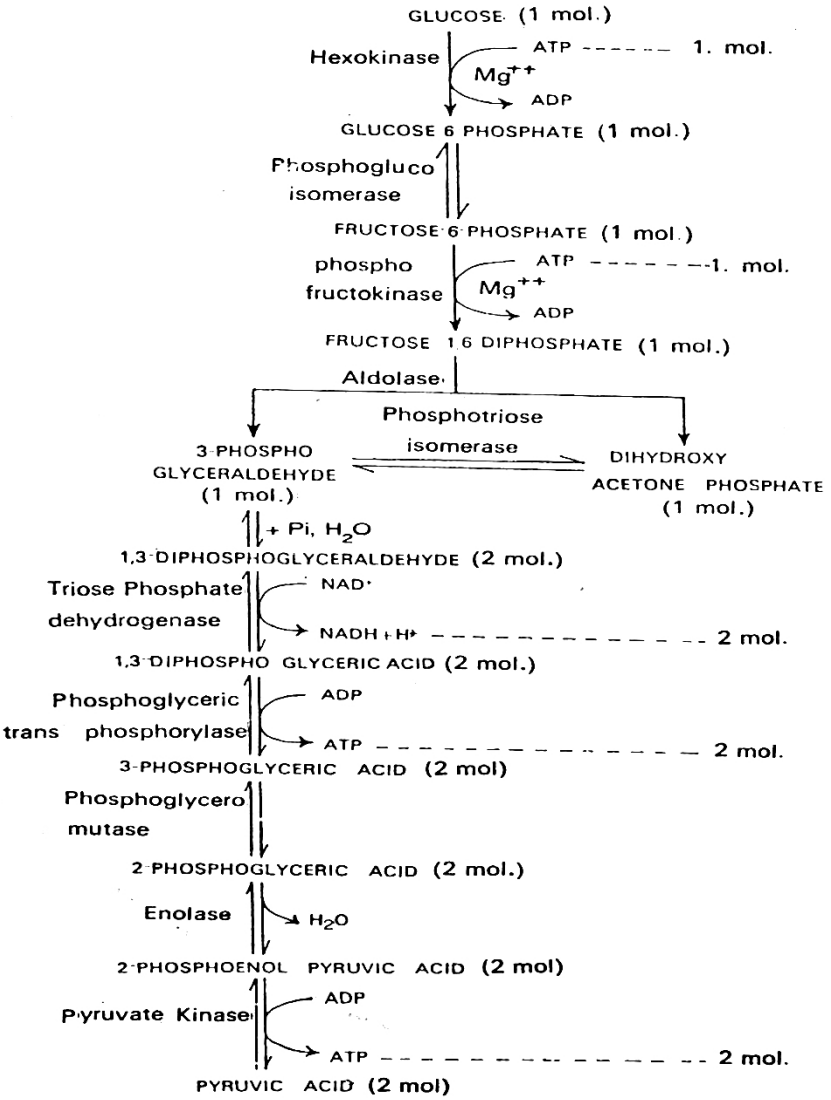


Fig. 8.1 Glycolysis (EMP-Pathway)

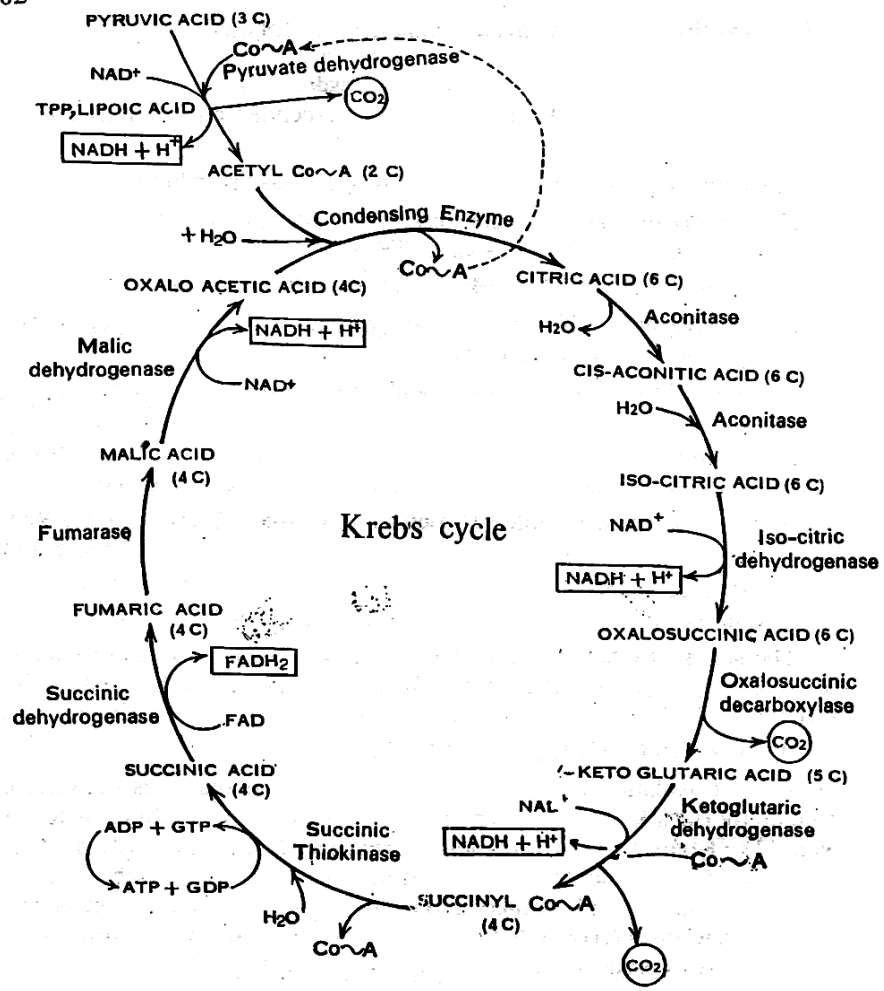
8.3.2 Krebs cycle

It was discovered by famous biochemist sir Hans Krebs (1943) and hence, the pathway was termed as Krebs cycle. The Kreb cycle is also know as tricarboxylic acid cycle (TCA cycle) or citric acid cycle.

The Pyruvic acid produced in Glycolysis enters into mitochondrial matrix and converted to Acetyl-CoA.

Acetyl- CoA is the 'connecting link' between glycolysis and the krebs cycle. Its complete oxidation to Co_2 and H_2o involves a series of reactions of krebs cycle which are as follows :

- The 2-carbon acetyl co-A is added to a 4-cabon oxalo acetic acid to form a 6 carbon citric acid in presence of citrate synthetase enzyme.
- Citric acid is dehydrated to form cis-aconitic acid in presence of enzyme aconitase.
- Cis-aconitic acid reacts with one molecule of water to form iso-citric acid in presence of aconitase enzyme.
- Isocitric acid is oxidised to form oxalosuccinic acid in presence of isocitric dehydrogenase enzyme. At this stage one molecule of NAD+ is reduced to $NADH+H^+$.
- The 6-carbon oxalosuccinic acid is decarboxylated to 5-cabon, α-ketoglutaric acid in presence of oxalosuccinic dehydrogenase enzyme. One molecule of Co_2 is released in the reaction.
- The 5-carbon α-ketoglutaric acid is oxidatively decarboxylated to 4-carbon succinyl coenzyme-A in presence of δ-ketoglutaric dehydrogenase enzyme. In this reaction one molecule of Co-A is used up and one molecule of Co_2 is released. The coenzyme NAD+ is also reduced to $NADH+H^+$.
- Succinyl Co-A hydrolysed to succinic acid in presence of succinic thiokinase enzyme. In this reaction one molecule of H_2o is used up and Co-A is released one molecule of GDP (guanosine diphosphate) in converted to GTP (guanosine triphosphate).
- Succinic acid is oxidized to fumaric acid in presence of succinic dehydrogenase enzyme. The coenzyme-FAD is reduced to $FADH_2$.
- One molecule of H_2o is added to fumaric acid to form malic acid in presence of enyzme fumarase Malic acid is oxidised to oxaloacetic acid in presence of malic dehydrogenase enzyme. One molecule of NAD^+ is reduced to $NADH+H^+$ in the reaction.



Krebs cycle :

Significance of Krebs cycle.

1. Respiration provided energy for the reduction of nitrate to ammonia which is used in the synthesis of aminoacids.

2. α-ketoglutaric acid provides carbon skeleton for the biosynthesis of glutamic acid. Oxaloacetic acid is directly converted to aspartic acid by transamination reaction and alanine is formed from pyruvic acid. Alanine is impotant aminoacid which further give rise other aminoacids by transamination reactions.

3. **Succinyl coenzyme-** A used up for the synthesis of aromatic porphyrins which give rise to cytochromes, phytochromes and chlorophyll pigments.

4. The acetyl coenzyme-A synthesizes fatty acids which by combining with glycerol form fats.

ATP produced in Aerobic Respiration

Each glycolytic $NADH+H^+$ yields 2 ATP molecules when oxidised by E.T.S. Thus 2 molecules of $NADH+H^+$ of glycolysis yield 4 ATP molecules. 4 ATP molecules are also produced in glycolysis by transphosphorylation out of which 2 ATP are consumed. Thus the glycolysis contributes a total of 2+4=6 ATP molecules.

In krebs cycle 2 molecules of ATP are produced by transphosphorylation. Besides this 8 molecules of NADH and 2 molecules of $FADH_2$ are produced in krebs cycle. Each NADH of Krebs cycle yields 3 ATP molecules by oxidative phosphorylation thus total 8x3=24 ATP are produced. Each $FADH_2$ produce 2 ATP molecules by oxidative phosphorylation. Thus 2 $FADH_2$ produce 2x2=4 ATP molecules. The total ATP produced in krebs cycle are = 2+24+4=30 ATP.

Thus the total ATP produced in Respiration are :

Glycolysis + Krebscycle

6 ATP + 30 ATP = 36 ATP

8.4 Oxidative phosphorylation and ETS

8.4.1 Oxidative phosphorylation

The NADH and $FADH_2$ formed in glycolysis are energy rich molecules each contains a pair of electrons having a high transfer potential. When these electrons are used to reduce molecular oxygen to water, a large amount of free energy is liberated, which can be used to generate ATP. In Oxidative phosphorylation ATP is formed as a result of the transfer of electrons from NADH or $FADH_2$ to O_2 by a series of electron carriers. This process, which take place in mitochondria, is the major source of ATP in aerobic respiration.

The respiratory break down of simple carbohydrates in presence of oxygen is an oxidative process. During which many intermediates such as phosphoglyceraldehyde, pyruvic acid, iso-citric acid, α-ketoglutaric acid, succinic acid and malic acid are oxidised. The oxidation of all these is brought about by removal of a pair of hydrogen atoms (2H) from each one of them. The pair of hydrogen is usually picked from the substrate by $NADH^+$ or $FADH_2$ in the following manner.

These coenzymes are reduced by a pair of hydrogen (2H) in the following reactions of aerobic respiration.

NADH or $FADH_2$ released in glycolysis and krebs cycle, finally reduce O_2 to H_2o. The transfer of H^+ and e^- from reduced NAD^+ or FAD to O_2 is not a simple process. The NADH gets oxidised at redox potential of -032V and O_2 is reduced at redox potential of +0.82V. Thus there is a gap of +1.14V in redox potential which is too much. Therefore NADH and $FADH_2$ connot directly combine with O_2 to form H_2O. Many intermediate

cytochromes and other carriers having intermediate redox potential are arranged in a series which transport electrons from reduced NAD^+ or FAD to O_2 and form electron transport system (ETS). As electron transport down to energy gradient through electron transport system results in the formation of ATP (Adenosine triphosphate) from ADP (Adenosine diphosphate) and inorganic phosphate. The ATP produced here is due to oxidation reduction reaction therefore known as oxidative phosphorylation.

8.4.2 Electron Transport System (ETS)

The various components of electron transport system include. Cytochrome b, 2 types of cytochrome c, ubiquinone, flavo protein (FMN or FAD) iron sulphur protein (Fe-S) and enzyme cytochrome oxidase which is untimately associated with cytochrome a and a_3. These components are arranged in a sequence in the inner Mitochondrial membrane. Reduced Cozenzymes transfers their electrons and protons through E.T.S. in following way-

1. Transfer of hydrogen from $NADH+H^+$ (formed in TCA) to FMN (Metaloflavoprotein). The FMN get reduced to $FMNH_2$ and $NADH+H^+$ (coenzyme) get reduced to NAD.

2. Reduced FMN then transfers its electrons to Fe-S protein and two $2H^+$ into the inter membranal space.

3. Reduced Fe-S transfers its electron to ubiquinone (UQ). The UQ takes two electrons one after another from Fe-S and two protons ($2H^+$) from the matrix to become UQH_2.

4. Reduced UQH_2 transfers its lectron to cytochrome b and two H^+ to outerside. $FADH_2$ reduced in kreb cycle also enters into ETS at this stage by transferring its $2H^+$ to UQ and UQ reduced to UQH_2.

   $NADH+H^+$ reduced in glycolysis also enters in ETS. The NADH reduces a flavo protein (FP) (containing NADH-dehydrogense) located on the outer surface of inner mitochondrial membrane. The reduced FPH_2 (flavo protein) enters into main pathway by transferring 2H to UQ. The reduced UQH_2 transfers its electrons to cytochrome b and $2H^+$ to the outer side.

5. Reduced cytochrome b transfers its electrons to Fe-S protein $Fe^{+3} - s \rightarrow Fe^{+2} - s$ it transfer electrons to UQ which also takes $2H^+$ from inner matrix to become UQH_2.

6. The reduced UQH_2 transfers electron to cytochrome C, with the transport of a pair of H^+ outword.

7. Reduced cytochrome C, reduces cytochrome C by transferring electron.

8. Finally electrons from cytochrome C are transferred to O_2 via cytochrome and a_3.

   This step is called terminal oxidation as it is catalysed by cytochrome oxidases (enzyme). The O_2 is reduced to H_2O by transferring electron from cytochrome a_3 and 2H+ from the medium in following way-

$$2cyt(Fe^{+2}) + \frac{1}{2}o_2 + 2H^+ \rightarrow H_2o + 2cy + (Fe^{+3})$$

   The enzyme cytochrome oxidase is tightly bound to the inner mitochondrial membrane and inseparable to cyt a and cyt a_3, polypptides and two cu ions.

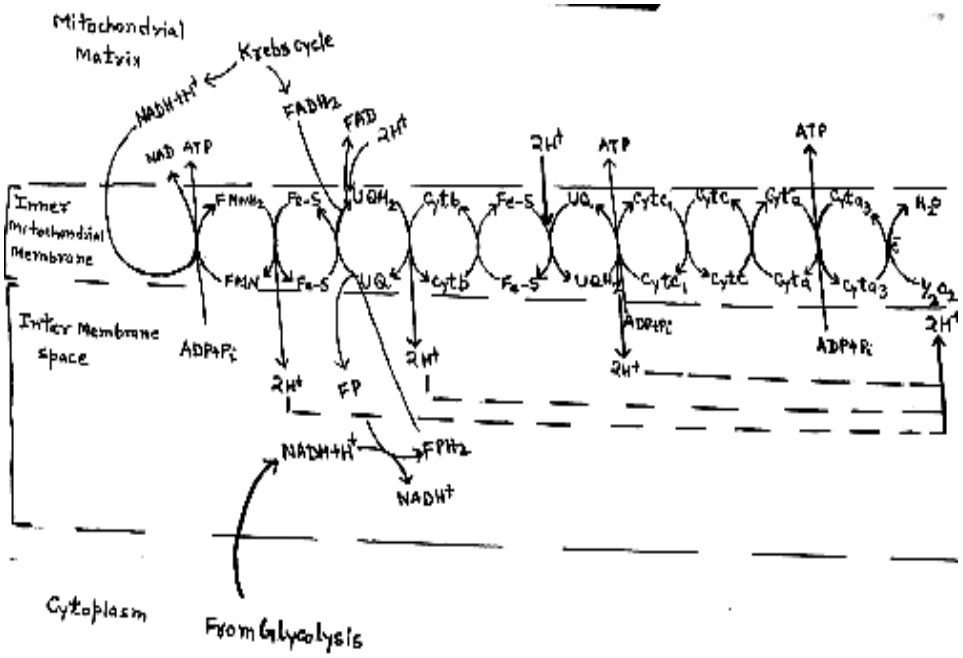


Fig 8.3 ETS cycle

8.5 Anaerobic respiration

$$C_6H_{12}O_6 \rightarrow 2C_2H_5oH + 2Co_2 + 56kcal.$$

Occurs in the absence of O_2 with incomplete oxidation of food with the formation of ethyl alcohol, lactic acid and Co_2 is released.

It occurs in microorganisms, early stage of germination of many seeds before the seed coats are ruptured. In certain fruits like apple grapes in which cutinised and suberised skin does not allow oxygen to reach the respiratory cells.

Fermentation :- The process of fermentation is a type of anaerobic respiration carried out by some micro organism and plants eg. Bacteria and fungi. It is different from anaerobic respiration. The an aerobic respriation is a cellular process where as fermentation is an extracellular process. It occurs outside the living cell with the help of extra-cellular enzymes secreated by micro organisms.

The inhibition of fermentation due to the presence of O_2 is called *Pasteur effect* this effect was further confirmed by meyer hof and warburg.

Later on 1897 German Chemist Buchner also observed that yeast extract converts sugar into ethanol and Co_2 by the process of fermentation.

1. In the process of fermentation the respiration substrate is same as in anerobic respiration.
2. The end products are same $C_2H_5oH+Co_2$
3. Both occurs in absence of O_2.
4. 2mol of ATP are formed.

$$Glu\cos e \xrightarrow{Glycolysis} Pyruvic\ \ acid$$

$$Pyruvic\ acid \underset{Carboxylase}{\xrightarrow{Pyruvic}} CH_3CHo + 2Co_2$$

$$CH_3CHo + 2NADH + 2H^+ \underset{deydrogenase}{\xrightarrow{Alcohol}} C_2H_5oH + 2NAD^+$$

8.6 Summary

- Respiration is an energy yielding catabolic process in which organic foods are broken down in presence or absence of O_2.
- Respiration is of two types, aerobic respiration and anaerobic respiration.
- Aerobic respiration occurs in presence of O_2 and has two process Glycolysis and krebs cycle.
- Glycolysis occurs in the cytoplasm of cell and produces 6 ATP molecules.
- Krebs cycle occurs in the Mitochondria and produces 30 ATP molecules.
- Anaerobic respiration occurs in cytoplasm in the absence of O_2.
- The process of fermentation is similar to anaerobic respiration.

- The only difference is that the fermentation is extracellular process where as anaerobic respiration is a cellular process. Fermentation occurs in some micro-organisms and plant.

8.7 Terminal Questions

Long Questions :

Q.1 Describe the process of aerobic respiration.

Answer:----------

Q.2 Describe electron transport chain.

Answer:----------

Q.3 Describe the process of Glycolysis.

Answer:----------

Q.4 Describe the process of krebs cycle.

Answer:----------

Short questions :

Write short notes on :

(i) Fermentation

(ii) Anaerobic respiration

(iii) Glycolysis

Multiple choice questions (MCQ) :

1. Process of Glycolysis occurs in :

   (a) Cytoplasm (b) Mitochondria

   (c) Chlorophyll (d) Nucleus

2. Process of krebs cycle occurs in :

(a) Cytoplasm (b) Mitochondria

(c) Chlorophyll (d) None of above

3. The end product of Glycolysis in :

(a) Acetic acid (b) Citric acid

(c) Pyruvic acid (d) None of above

4. Net gain of ATP in respiration is :

(a) 36 (b) 38

(c) 32 (d) 33

5. Electron transport chain occurs in :

(a) F_1 particle of Mitochondria (b) Matrix of Mitochondria

(c) Cytoplasm (d) None of the above

8.8 Answers

(1) a (2) b (3) c (4) a (5) a

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