Centre Universitaire Abdelhafid Boussouf Mila

Cours of :
PLANT PHYSIOLOGY

2nd year agronomy

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Plan de cours 45H

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CHAPITRE 02: Nutrition

Plan of chapter

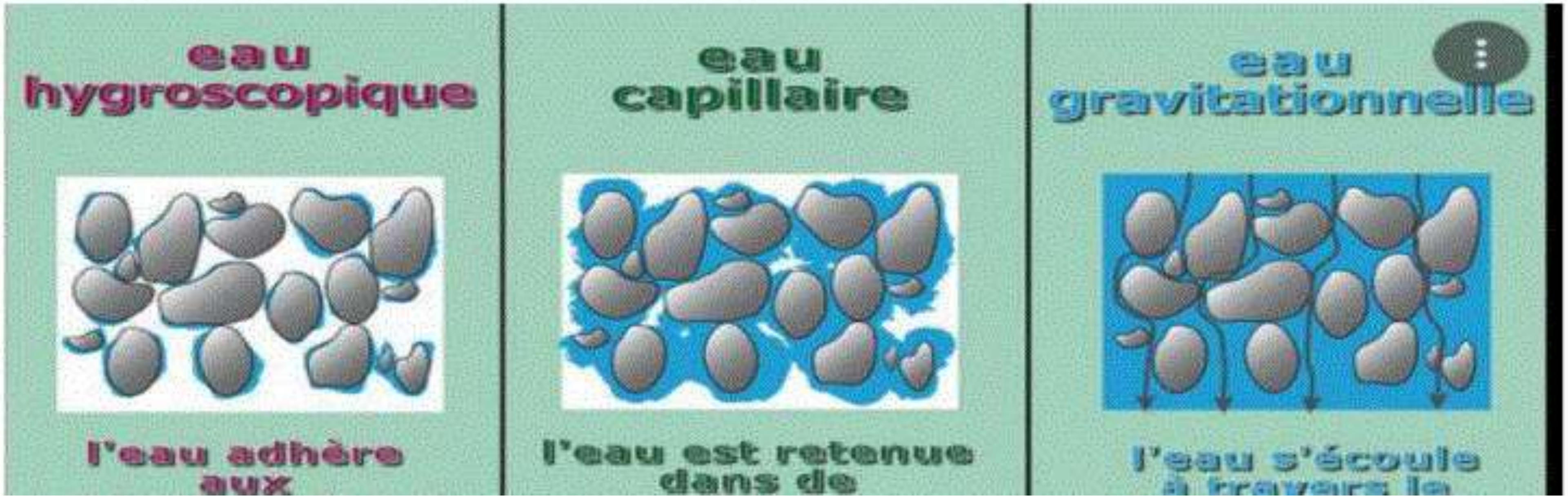
1. Water Nutrition

- Nitrition of green plants is different of animals
- Water is an important factor for plant growth as it helps to fulfill all the vital activities of plants.
- water is essential for life and is the main constituent of the protoplasm comprising 90 to 95% of its total weight.
- Water is a source of hydrogen atoms for the reduction of carbon dioxide in the reaction of photosynthesis and as mentioned earlier that water helps to fulfill different vital activities

1.1. Soil Water

- Generally plants absorb water from soil by their roots. Thus the water present in the soil either in the form of liquid or in vapor/moisture form, is known as —Soil Water
- The water present in the soil may be classified as follows-
- **(i) Gravitational Water:** The water which reaches deeply into the soil after rains due to gravitational force. is not available to plants.
- **(ii) Capillary Water:** The water which remains present in the intercellular spaces of soil particles. This water is available to plants

- **(iii) Hygroscopic Water:** The water which is present around the soil particles in the form of thin vapour layer. This water is also non available water and cannot be absorbed by the plants.
- **(iv) Chemically Combined Water:** The water which remains chemically bound to the soil particle. This water is also non-available to plants.
- **(v) Run- off Water:** The water which run- off drown through slopes after rains is called running water or run- off water. This is also non- available to plants.



Point de flétrissement permanent.

Capacité du champ Eau disponible pour la croissance végétale.

a) Saturation Tous les pores sont pleins. Eau gravitationnelle perdue.

fig 1.Different types of water available in soil

1.2. Water in Plants

- Water in Plants : Transported via xylem (raw sap: water + minerals) and phloem (elaborated sap: water + organic substances).

xylem
(raw sap)

Water in Plants

Phloem
(elaborated sap)

Maintains a balance between water intake (from soil) and loss (transpiration)

1.2.1.Échange de l’eau dans la cellule

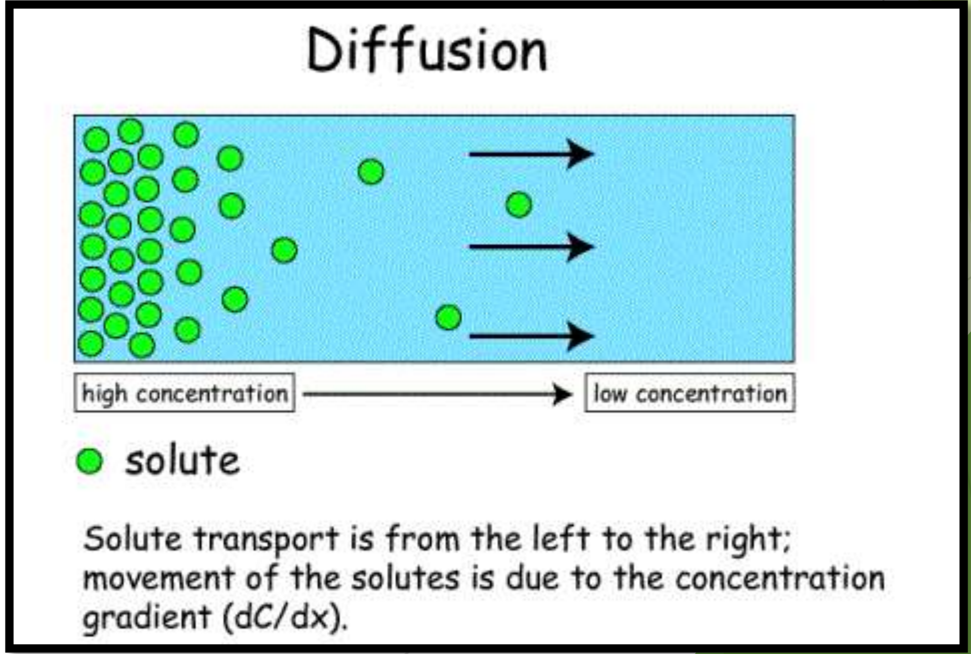
- All living cells contain approximately 60–95% of water, and water is required for their growth and reproduction. Even the dormant cells and tissues also have 10–20% of water. The intercellular or short distance water transport takes place through diffusion, mass flow, or osmosis.

a) Diffusion

It is the movement of molecules or ions of a solute or a solvent from the region of its higher concentration to that of its lower concentration, the net movement stops when a dynamic equilibrium is achieved.

- The molecules move from [hi] to [low], following a concentration gradient. The molecules move from an area of high free energy (higher concentration) to one of low free energy (lower concentration). At equilibrium the molecules continue to move randomly, back and forth from one side of the partition to the other.
- words diffusion is the basic phenomenon of osmosis & imbibition

- In plants, diffusion occurs in stomata to facilitate the exchange of carbon dioxide, oxygen, and water vapors between leaf cells and external atmosphere. Diffusion also plays an important role in gas exchange in lenticels present in the stem. The apoplastic and symplastic pathway of intercellular transport also involve diffusion. Imbibition during seed germination is also a special type of diffusion.



❖ Osmosis :

It is a special type of diffusion which takes place in solvents through semipermeable membrane. Osmosis is a biological process where the solvent molecules move from their higher concentration (lower solute concentration) to lower concentration (higher solute concentration) through a semipermeable membrane.

The rate of osmosis can be increased by the addition of osmotically active substances and can be measured by osmometer.

Osmosis is the process by which water is transported into and out of the cell. The growth, development, and turgidity of the cells are maintained by the process of osmoregulation.

The process of osmosis can be stopped or reversed by applying pressure. This is called reverse osmosis. This process is now commercially used for purifying water.

b) Water Potential:

The chemical potential of water (plant physiologists use the term water potential) is the free energy of water. It is the chemical potential of water. In terms of pressure units water potential is expressed as MPa (megapascal). The lower the water potential of the plant, the greater is its ability to absorb water and vice versa.

It also helps to measure the water deficit and stress in plants. Water potential is not an absolute value and is symbolized by Ψw (psi). Water potential of pure water is maximum and its value is zero (0) at the atmospheric pressure. In a living cell, water potential refers to the sum of the following components:

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

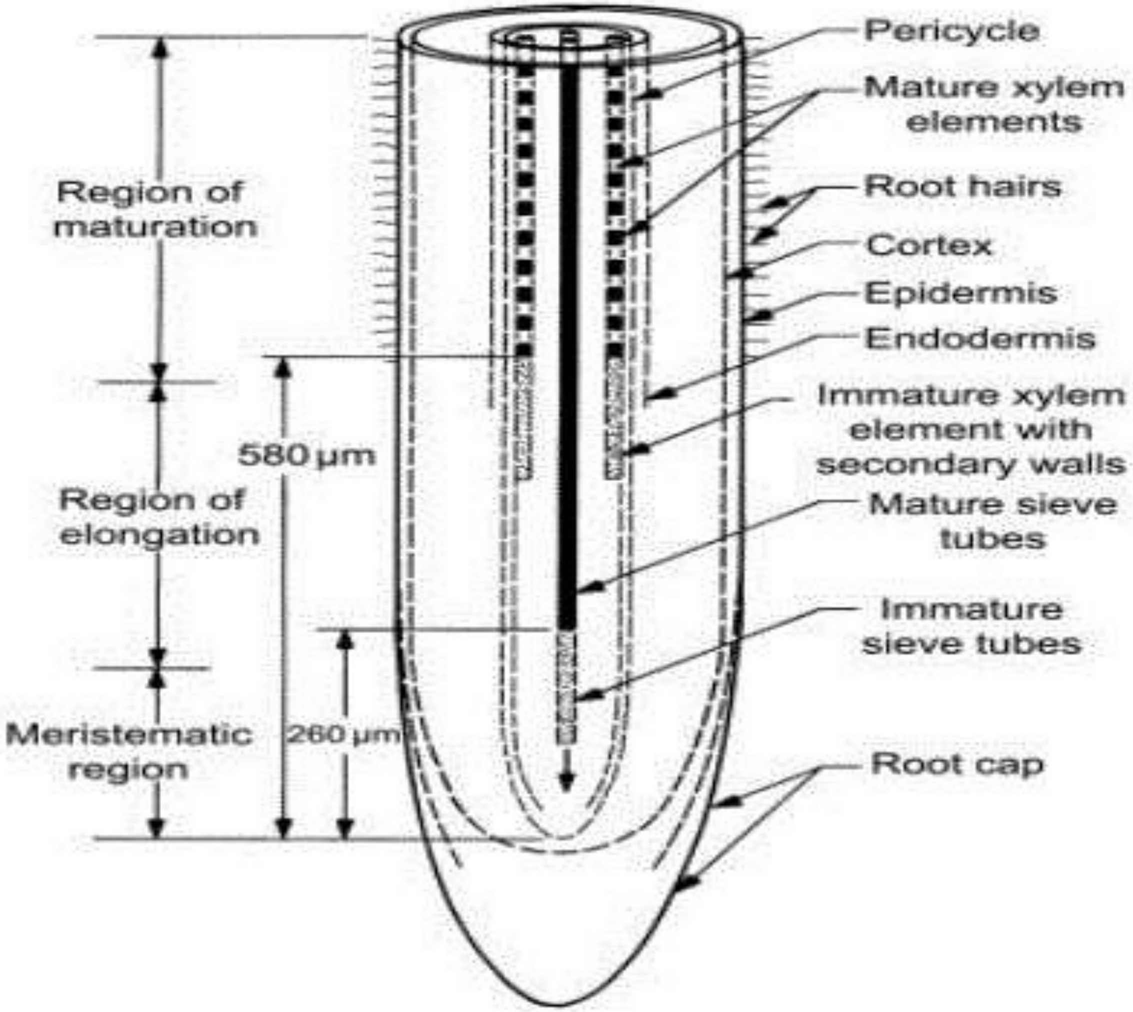
Where:

Ψw is the water potential,
Ψs solute/osmotic potential,
Ψp pressure potential,
Ψg gravitational potential,
and **Ψm** matric potential.

1.3. Mechanism of Water Absorption and Translocation of water

- In general, it is common knowledge that the root system of the plant is mainly responsible for the absorption of water.
- Root system also affects the water absorption. Those plants which possess hairy and well developed root system show higher rates of water absorption comparatively to those which possess very small roots and less number of root hairs.
- Roots: Roots absorb water mainly from its apical region on the basis of apical organization of roots- it shows three clear demarcations or zones

- Zone of meristematic cells.
- ii) Zone of elongation
- iii) Zone of absorption or differentiation
- The depth of roots varies with different species and greatly affected by factors like water, mineral nutrients, O_2 and temperature.
- The absorption of water does not take place from entire surface of root. Only younger portions near the tip are active in absorption of water and mineral substances.



This brings the root hairs continuously come into contact with new supply of water in the soil.

At the extreme tip of root, root cap exists which consists of mass of cells forming a protective sheath around growing point. Most of the water absorption takes place through the root hairs.

A root hair is the tubular extension of epidermal cells. As the root elongates the older root hairs die and new one come up in younger parts of roots. As a result the root hair zone is constantly moving forward farther and farther.

Mechanism of Water Absorption

- Root hairs takes active participation in water absorption as the root hair maintain contact with soil water and in nature it acts as a sole water absorbing organ. Due to diffusion pressure deficit gradient, water diffuses into the root hair.
- The cell sap contains a more concentrated solution than the water present outside the cell. To know the exact mechanism of water absorption two main theories are proposed by the workers-
- i) Active absorption
- (ii) Passive absorption

1. Passive Absorption

It occurs in rapidly transpiring plants during daytime, because of opening of stomata and the atmospheric conditions.

Transpiration pull is responsible for dragging water at the leaf end, the pull or force is transmitted down to the root through water column in the xylem elements.

Roots simply act as a passive organ of absorption. As transpiration proceeds, at the same time water absorption also takes place to compensate the water loss from leaf end.

Most volume of water entering plants is by means of passive absorption.

2. Active Absorption

- It is absorption of water by roots with the help of metabolic energy generated by the root respiration. The force for water absorption originates from the cells of root due to root respiration. The active absorption is carried out by two THEORIES which are:
- (b

(a) Active osmotic water absorption : According to this theory, the root cells behave as ideal osmotic pressure system through which water moves up from soil solution to root xylem. If solute concentration is high and water potential is low in the root cells, water can enter from soil to root cells. If the xylem sap has a higher osmotic potential than that of the soil solution water can move from the soil into the xylem by osmosis. Hence, absorption of water is indirectly an active process in a plant's life.

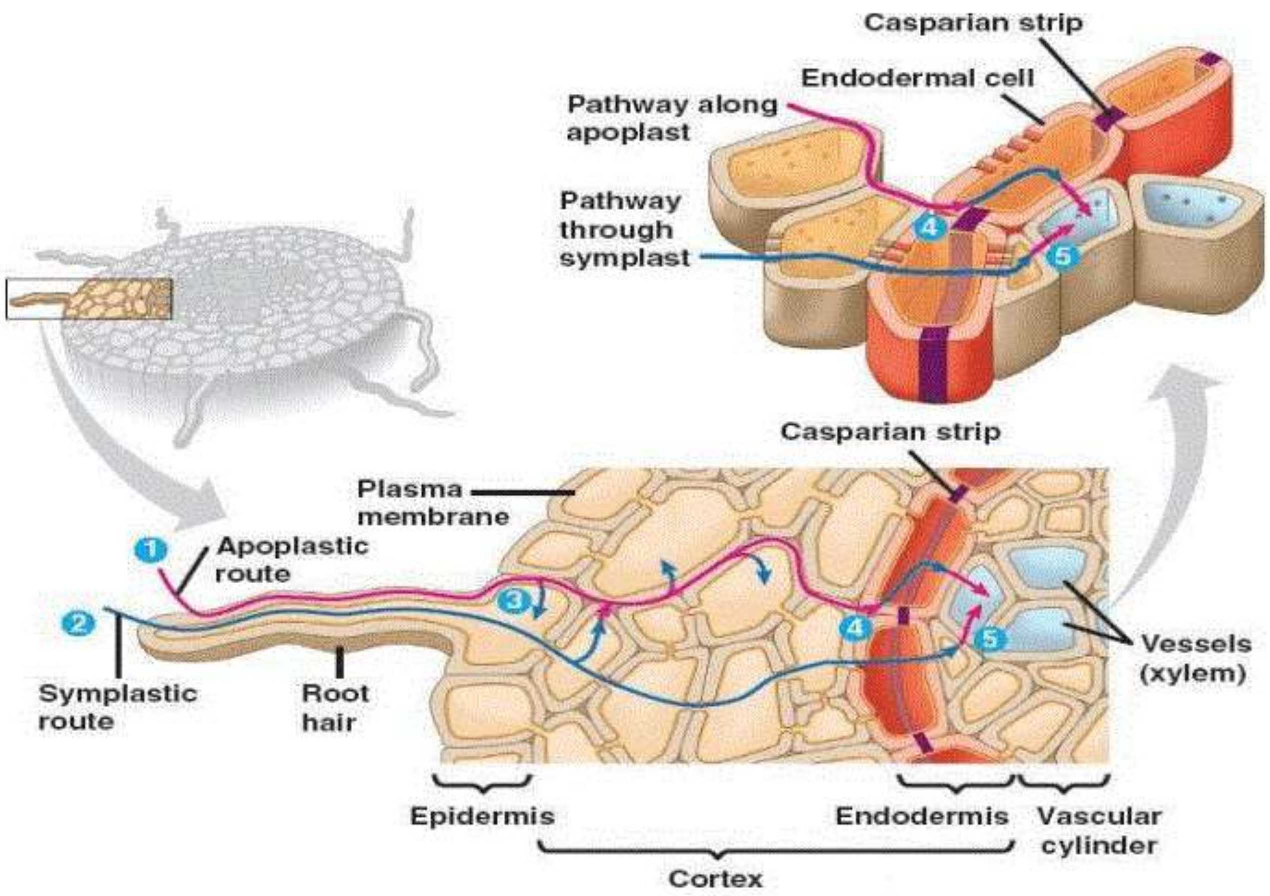
b) Active non-osmotic water absorption

According to the theory, sometimes water is absorbed against concentration gradient.

Translocation of water (Ascent of Sap)

- The movement of water from root to upper foliar parts of the plant requires integration of many levels of transport. The long-distance transport of water in xylem is supplemented by short-distance transport of water from the root to cortex and ultimately to the xylem. Basically, there are three levels of water transport in plants.

The first level of water transport refers to the entry of water from the soil into the root cells, through the plasma membrane. At this level, the selective permeability of the plasma membrane regulates the movement of solutes and the solvent between the cell and extracellular solutions. The molecules tend to move down their concentration gradient. In addition to active and passive transport, proteins present in the membrane speed up the movement across the membrane.



The second level of transport is from root epidermal cells to the innermost layer of the cortex. This is referred as short-distance transport, and it includes apoplast, symplast, and transcellular pathways including transporters, channels, and plasmodesmata. The short-distance transport also includes water transport from xylem in the leaf veins to substomatal cavity.

The third level of transport is the long-distance transport in xylary elements.

Water moves up a plant due to three main processes:

- 1. As water continues to move into the plant by osmosis it pushes the water up the stem; this is known as Root Pressure.

  Plants that develop root pressure frequently produce liquid droplets on the edges of their leaves, a phenomenon known as guttation. Guttation is most noticeable when transpiration is suppressed and the relative humidity is high, such as at night.

- 2. As water is lost from the top of the plant by evaporation, or transpiration, more water is drawn up to replace it ; this is known as Transpiration Pull.

Porins are a class of membrane proteins that are found in cell membranes of all living organisms. These protein units in plants, the aquaporins are membrane protein channels which control the selective movement of the water. Aquaporins can be open or closed to regulate the movement of water across the membrane

- 3. Water would not move up the plant in a continuous stream if water molecules were not inclined to stick together; this is known as Cohesion.
- The fact that columns of water moving up the xylem are under tension due to the pull of transpiration has lead to the system of water movement up the plant being know as the Cohesion Tension theory

1.2. Perspiration and water balance

Transpiration is the evaporation of water from the aerial part of the plants. Water vapor leaves the air spaces of the plant via the stomata.

1.2.1. Highlighting:

Experiment demonstrating plant transpiration. A plastic bag has been secured over the branches of a pot plant. The inside of the bag has condensation on it from water transpired from the plant's leaves. Transpiration is the evaporation of water from pores called stomata in leaves. The pores open to allow carbon dioxide to enter the plant for use in photosynthesis. https://www.alamyimages.fr

Fig : highlighting of transpiration (https://www.alamyimages.fr)

1.2.2. Location and measurement transpiration

- Stomata
- Power Measuring the water absorbed using the Vesque potometer

The stomata are microscopic and bordered by two specialized epidermal cells called guard cells, which control the opening and closing of the stomata. The surrounding wall of the guard cells inside the epidermal cells is thick and inelastic

while the outside walls of the guard cells is thin, elastic and permeable.

Each guard cell has a cytoplasmic lining and central vacuole containing nucleus and number of chloroplast, often poorly developed and incapable of photosynthesis. The guard Transpiration through cuticle cells are surrounded by specialized epidermal cells called subsidiary cells, supports the movement of guard and the number of cells vary from plant to plant.

1.2.3. Variation de la transpiration

- The rate of transpiration is affected by the plant water status, its morphology, as well the environmental factors.

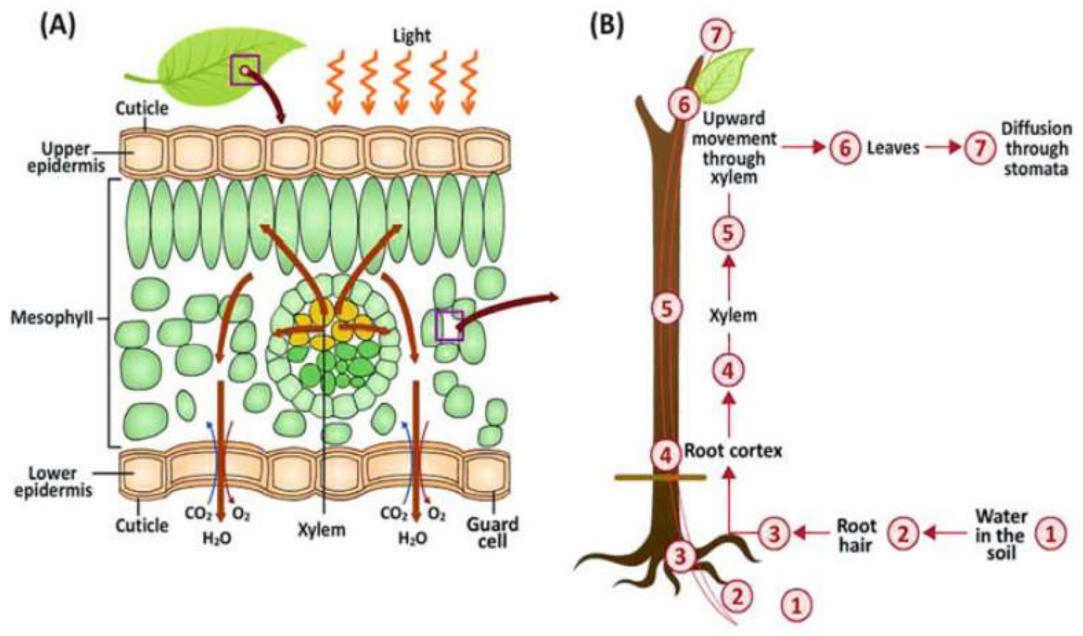


Fig. 1.9 (**a**) Evaporation of water from leaf surface. Water from xylem enters into air spaces of spongy parenchyma and diffuses out through stomata present on the lower epidermis. Gas exchange takes place when stomata open up. Carbon dioxide is taken in and oxygen is released. (**b**) Transpiration from leaf creates a continuous water stream up to the soil

Stomata open up during the day for gaseous exchange. At night when transpirational pull is almost negligible, roots actively absorb solutes. Water passively enters into roots and creates pressure. Due to this pressure, water is forced out of the leaf tips through structures called as hydathodes by a process called guttation.

a. effect of morphology of plant

- Internal Factors One of the most important factors affecting transpiration rate is leaf-shoot ratio.
- The magnitude of transpiration will be more in leaves with greater leaf area.
- However, the rate of transpiration has no correlation with leaf size when per unit leaf area is considered.
- The leaf structure is very important in regulating the rate of transpiration. Leaf adapts man=y strategies to reduce transpiration.
- Stomatal frequency (number of stomata present in per unit area of leaf), pore size, and distribution show tremendous variation in plants growing in different habitats.

b. effect of environnement factor

- The most important environmental factors are humidity, light, temperature, wind velocity, and availability of soil water. Some of the factors are as follows:

a) Temperature: Temperature is the prime factor which directly affects the rate of transpiration. As increase in temperature increases the rate of transpiration by increasing the rate of evaporation of water from cell surface and decreases the humidity of the external atmosphere

b) Humidity of Air : The relative humidity of the atmosphere affects the rate of transpiration. It shows inverse effect on rate of transpiration i.e. rate of transpiration increases with the increase in the humidity of the external atmosphere.

c) Light: Comparatively to temperature, light has no direct effect on the rate of transpiration but indirectly it affects the rate in two ways

i) By controlling the stomatal opening and
ii) By affecting the temperature.

Increase in intensity of light the rate of transpiration increases because the stomata get opened and the temperature rises. Light also has directly effects on transpiration rate as it increases markedly in light and decreases in dark. There is a close relationship between the opening of stomata and presence of light. . Light is Promotes stomatal opening through potassium ion activity.

- **d) Wind Velocity**: Velocity of wind has direct effect on rate of transpiration and the increase in the wind also increases the rate of transpiration. During high wind velocity, stomata close. Therefore, the rate of transpiration also drops. But wind at low velocity increases the rate of transpiration. As wind disperses the air around the leaf and reduces the vapor pressure in the immediate vicinity of stomata, it increases the rate of transpiration
- **e) Atmospheric Pressure**: The reduction of atmospheric pressure reduces the density of the external atmosphere and hence permitting more rapid diffusion of water.

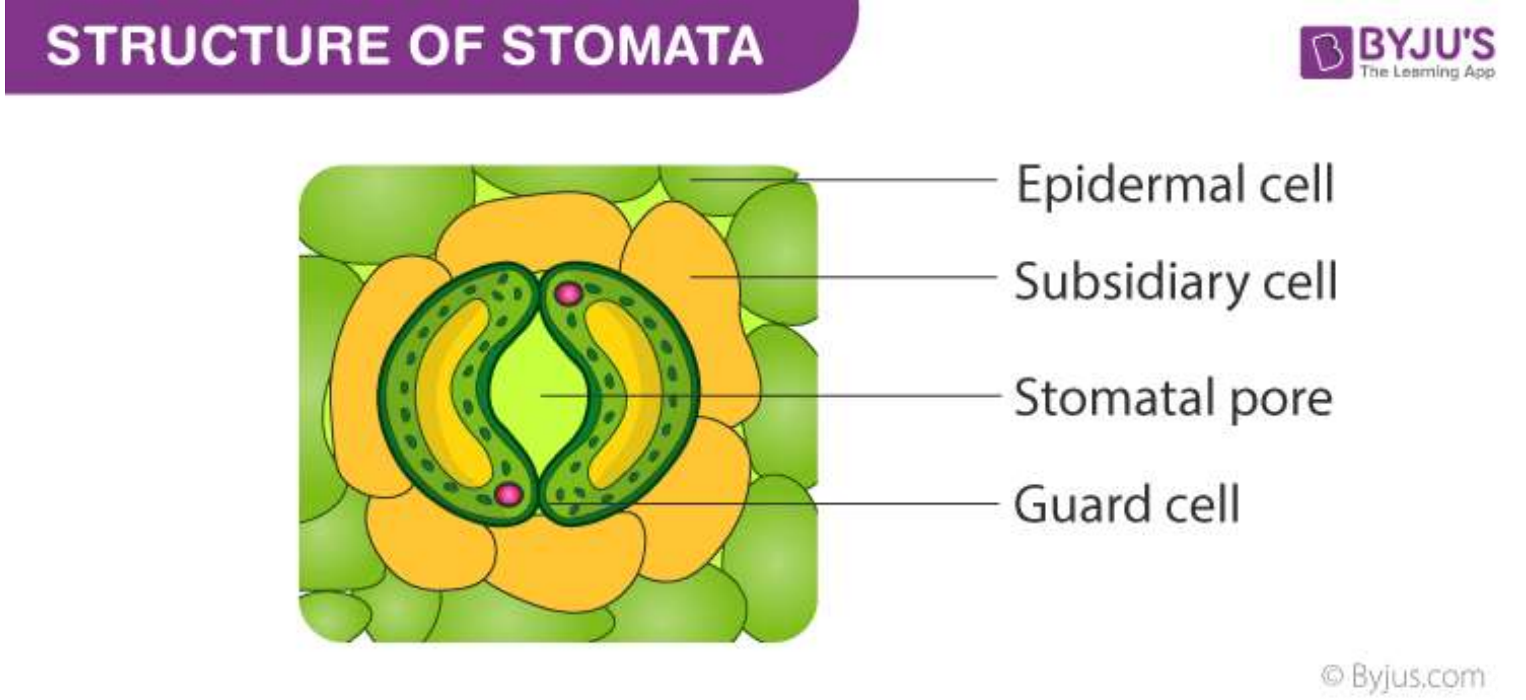
f) Water Supply: Rate of transpiration decreases with the deficiency of water in soil indirectly by decreasing the rate of water absorption.

g) Vital Activities: Some vital activities of plants may also affect the rate of transpiration e.g. Spray and Dusts: Sprays and dusts affect the rate of transpiration by affecting the permeability of the cuticle and temperature of leaves.

1.2.4. Physiological determinism of transpiration

- Leaf can regulate its stomatal resistance by opening and closing of the stomatal pore.
- This biological control is exerted by a pair of specialized epidermal cells, the guard cells, which surround the stomatal pore.
- Guard cells are found in leaves of all vascular plants.
- the guard cells are surrounded by ordinary epidermal cells.

- A distinctive feature of guard cells is the specialized structure of their walls.



- The alignment of cellulose microfibrils, which reinforce all plant cell walls and are an important determinant of cell shape, play an essential role in the opening and closing of the stomatal pore.

- When the stomata open, atmospheric CO2 is fixed and transpiration increases. In the event of a water deficit, the stomata close.
- The opening or closing of the stomata is due to a deformation of the guard cells. This deformation depends on the osmotic forces which correspond to variations in the intracellular potassium (K+) concentration, so K+ is essential for the functioning of the stomata.

- The importance of the difference between the turgor pressure of the guard cells (Tg) and that of the neighboring epidermal cells (Te) which determines the state of the stomata:

- ✓ - If (Tg – Te) is less than or equal to zero, the guard cells are compressed and the ostiole closes.
- ✓ - If (Tg – Te) is greater than zero, the guard cells swell and the ostiole opens.

Effect of light: Light is a major factor in the opening of stomata during the day in plants.

1.2.5. water balance of plants

The water status of plant cells is constantly changing as the cells adjust to variations in the water content of the environment or to changes in metabolic state.

The plant water status is dependent on:

- the soil moisture content,
- the capacity for water absorption by roots, and
- the hydraulic conductivity of root and shoot tissues.

Water potential is often used as a measure of the water status of a plant. Plants are rarely fully hydrated.

During periods of drought, they suffer from water deficits that lead to inhibition of plant growth and photosynthesis.

Several physiological changes occur as plants experience increasingly drier conditions. In many plants reductions in water supply inhibit shoot growth and leaf expansion but stimulate root elongation (Ördög, 2011)

- Water in the plant can be considered a continuous hydraulic system, connecting the water in the soil with the water vapor in the atmosphere.
- Transpiration is regulated principally by the guard cells, which regulate the stomatal pore size to meet the photosynthetic demand for CO2 uptake while minimizing water loss to the atmosphere.
- Water evaporation from the cell walls of the leaf cells generates large negative pressures in the apoplastic water.
- These negative pressures are transmitted to the xylem, and they pull water through the long xylem conduits.

- Transpirational water loss from the leaf is driven by a gradient in water vapor concentration. water transport is finely regulated by the plant to minimize dehydration, largely by regulating transpiration to the atmosphere.
- **water balance in plants** is also maintained by transpiration. Plants absorb a lot of water and transpiration is a means by which excess water is removed. Much of the water uptake is used for photosynthesis, cell expansion, and growth.

1.2.6.Importance of transpiration for plants

1. Transpiraton is a means to achieve thermoregulation, because a transpiring plant has temperature 6-7 °C lower than the temperature of a wilting leaf. Overheating could result in chloroplast damaging and to stop photosynthesis.

2. Due to transpiration, continuous water absorption and transport takes place together with the ions of mineral salts dissolved in it.

3. Transpiration results in continuous flow from the roots to the tip of the plant, thus contribution to the formation of an integrated communication system between all plant organs.

Antitranspirants

- Certain substances like colourless plastics, low viscosity waxes, silicon oil, phenyl mercuric acetate, abscisic acid and CO inhibit transpiration by causing stomata closure.
- These are called as antitranspirants.

Guttation

- Guttation When leaves lose water as a liquid phase through special cells called hydathodes it is referred to as Guttation. These guttation "tears" appear at the leaf tips or margin contain various salts, sugars and other organic substances. It occurs through specialized pores present at tip of veins of leaves called hydathodes.
- When absorption of water exceeds, transpiration a positive pressure is developed which forces water into air cavity and then out through hydathodes.

2. Mineral Nutrition

2.1. Macrolements

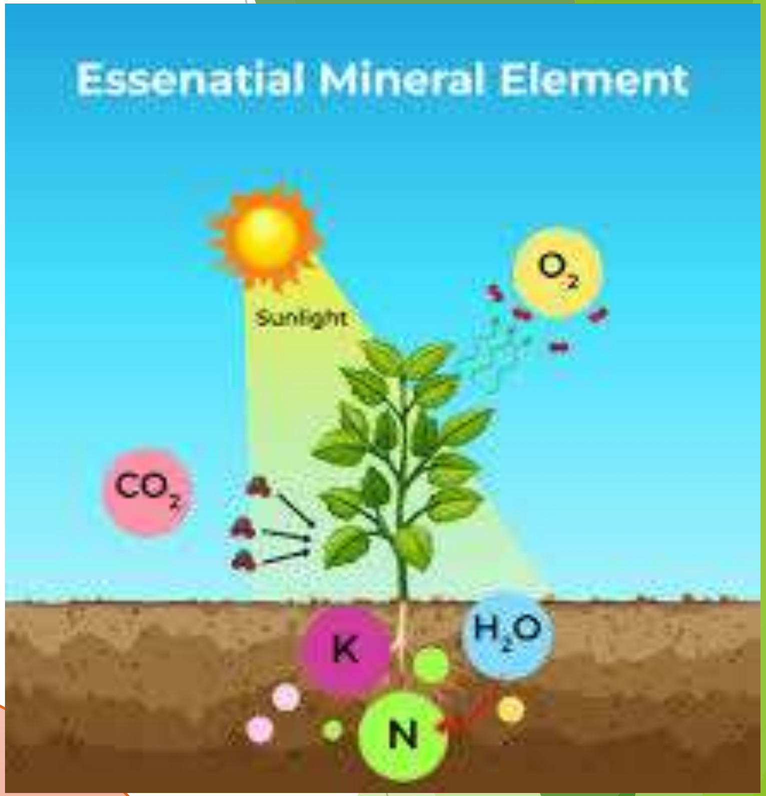
2.2. Microelement

2.3.Nutrient uptake

INTRODUCTION

Plants absorb minerals through their roots from the soils, where they are primarily present in the form of inorganic ions.

MINERAL NUTRITION The process that involves absorption and utilization of mineral elements by the plants for their growth and development.



2.1. Macrolements

- Macroelements are usually involved in the synthesis of organic molecules and development of osmotic potential of the cells.
- About 96% of the dry matter of the plants is formed of carbon, hydrogen and oxygen only Microelements are mostly involved in the functioning of enzymes as cofactors or metal activators.

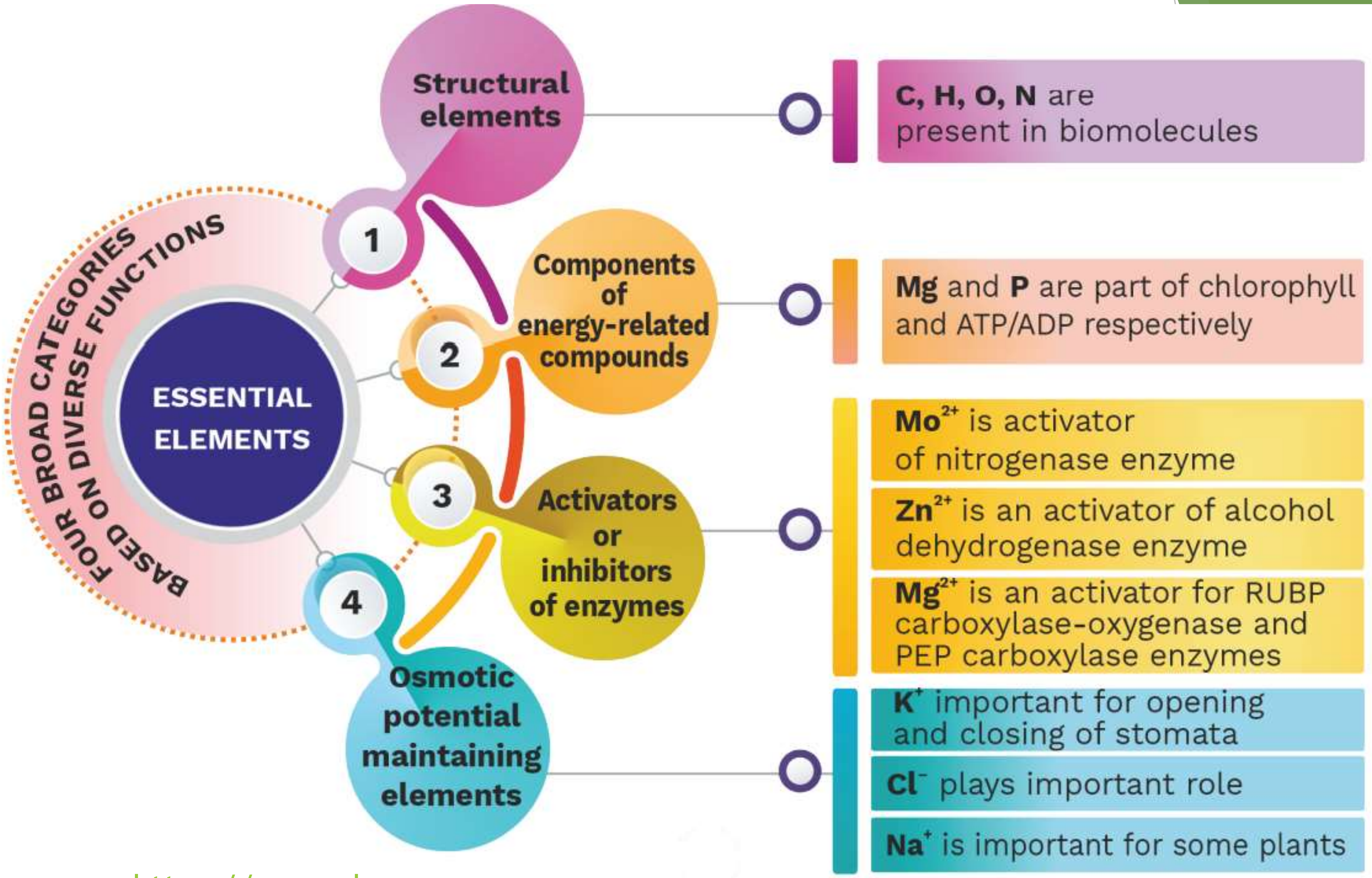
- Essential elements, which are present in easily detectable quantity, (in excess of 10 m mole kg-1 of dry matter).
- ○ Carbon
- ○ Hydrogen
- ○ Nitrogen
- ○ Oxygen
- ○ Phosphorous
- ○ Sulphur
- ○ Potassium
- ○ Calcium
- ○ Magnesium

2.2. Micronutrients

- Micronutrients: Essential elements which are found in plants in traces only (i.e., less than 10 m mole kg-1 of dry matter). They are 8 in number
- ○ Iron
- ○ Manganese
- ○ Zinc
- ○ Copper
- ○ Molybdenum
- ○ Boron
- ○ Chlorine
- ○ Nickle

SOURCES OF ESSENTIAL ELEMENTS FOR PLANTS:

- All elements which enter into plants are derived from the atmosphere, water and soil. Soil a reservoir of essential elements and is rich in ions, inorganic salts, air, water and useful microbes.
- Carbon enters the plants from atmosphere as carbon dioxide.
- Hydrogen is obtained mainly from water.
- Oxygen comes from the air or water and often in the form of inorganic ions.
- Plants absorb nitrogen in compound state from the soil.
- All other elements needed by the plants, are absorbed by the soil
- Essential elements grouped into four broad categories on the basis of their diverse functions.



https://unacademy.com

2.3.Nutrient uptake

- Soil is complex physically, chemically, and biologically. It is a heterogeneous substance containing solid, liquid, and gaseous phases. All of these phases interact with mineral elements.
- The inorganic particles of the solid phase provide a reservoir of potassium, calcium, magnesium, and iron.
- Also associated with this solid phase are organic compounds containing nitrogen, phosphorus, and sulfur, among other elements.

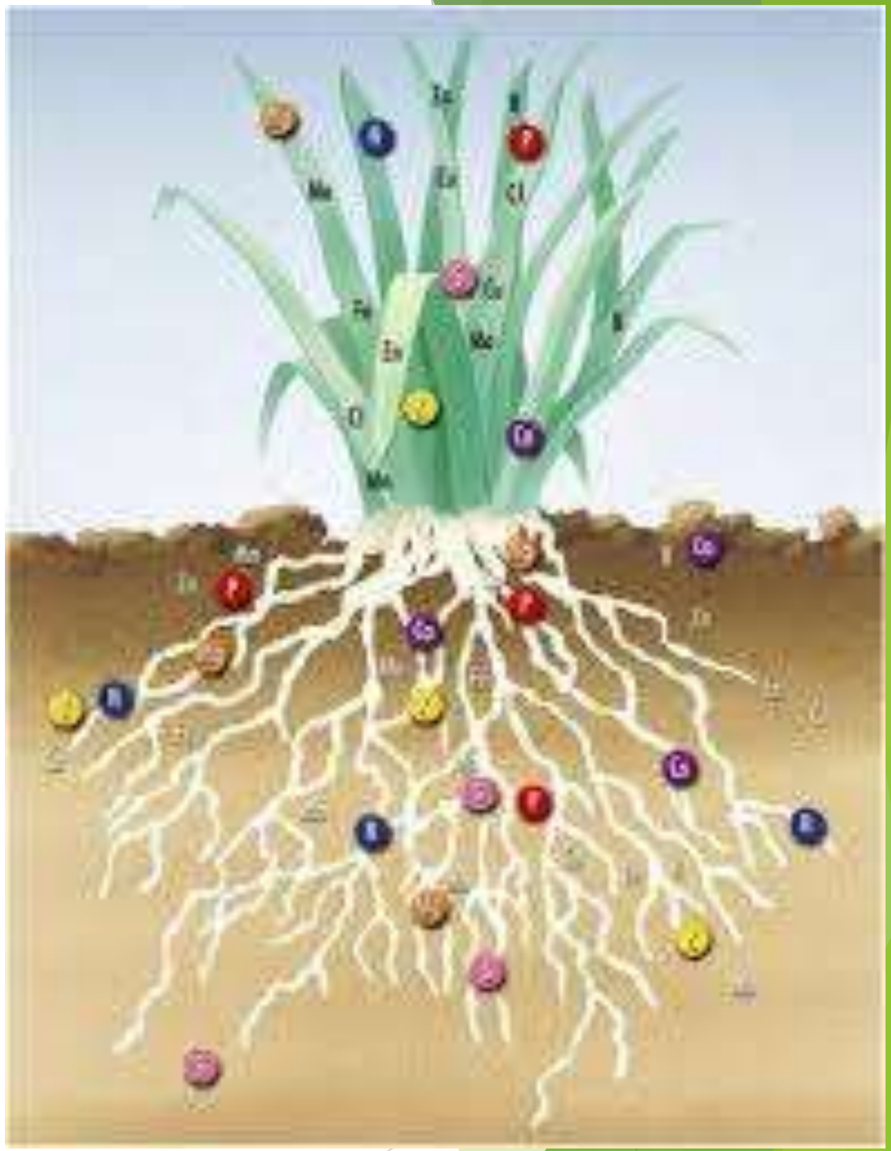
- The liquid phase of soil constitutes the soil solution, which contains dissolved mineral ions and serves as the medium for ion movement to the root surface.
- Gases such as oxygen, carbon dioxide, and nitrogen are dissolved in the soil solution, but roots exchange gases with soils predominantly through the air gaps between soil particles.

2.4. Factors of absorption of ions

- The absorption of ions by plants depends on several factors, including:
- ✓ Negatively charged soil particles affect the adsorption of mineral nutrients
- ✓ Slightly acidic soil solutions are generally favorable for ion absorption by plants. However, the presence of excess calcium, which can alkalinize the soil, may disrupt the uptake of certain nutrients, such as iron.

For example, in apple and grapevines, excess calcium can interfere with iron assimilation, leading to iron chlorosis — a deficiency in chlorophyll synthesis. This results in yellowing of the leaves, a typical symptom of ferric chlorosis.

- ✓ Soil pH affects nutrient availability, excess mineral ions in the soil limit plant growth
- ✓ Plants develop extensive root system
- ✓ Biological Activity in the Rhizosphere: The microbial activity around plant roots (rhizosphere) also plays a role in nutrient uptake.
- ✓ Age and Physiological Condition: The ability of plants to absorb nutrients changes depending on their growth stage and overall health.



2.5. MECHANISM OF ABSORPTION OF MINERAL ELEMENTS

- It occurs in two phases : Initial phase and metabolic phase

- **Initial Phase**

Rapid uptake of ions from the soil into the intracellular spaces of cells or outer space of cells or free space of cells (the apoplast) occurs.

The uptake of ions is passive.

- **Metabolic Phase**

The movement of ions is slow as these move into the cell cytoplasm and vacuole (symplast) then move to other cell.

- It is an active process that requires the metabolic energy.

Note :
The movement of mineral ions - flux.
The inward movement of mineral ions -influx.
The outward movement of mineral ions- efflux.

Passive and Active Transport in Plants

- The movement of an ion from one compartment to another, such as from the soil solution into the cytosol of a root hair, is referred to as passive transport when it occurs in the direction of a decrease in the concentration of that ion.
- Essentially, passive transport follows a concentration gradient, meaning that ions move from areas of high concentration to areas of low concentration.
- On the other hand, active transport occurs when the concentration of the ion is higher in the receiving compartment than in the originating compartment.

Active transport moves ions against their concentration gradient (from low to high concentration) and requires energy.

This energy is typically provided by ATP which powers the transport process.

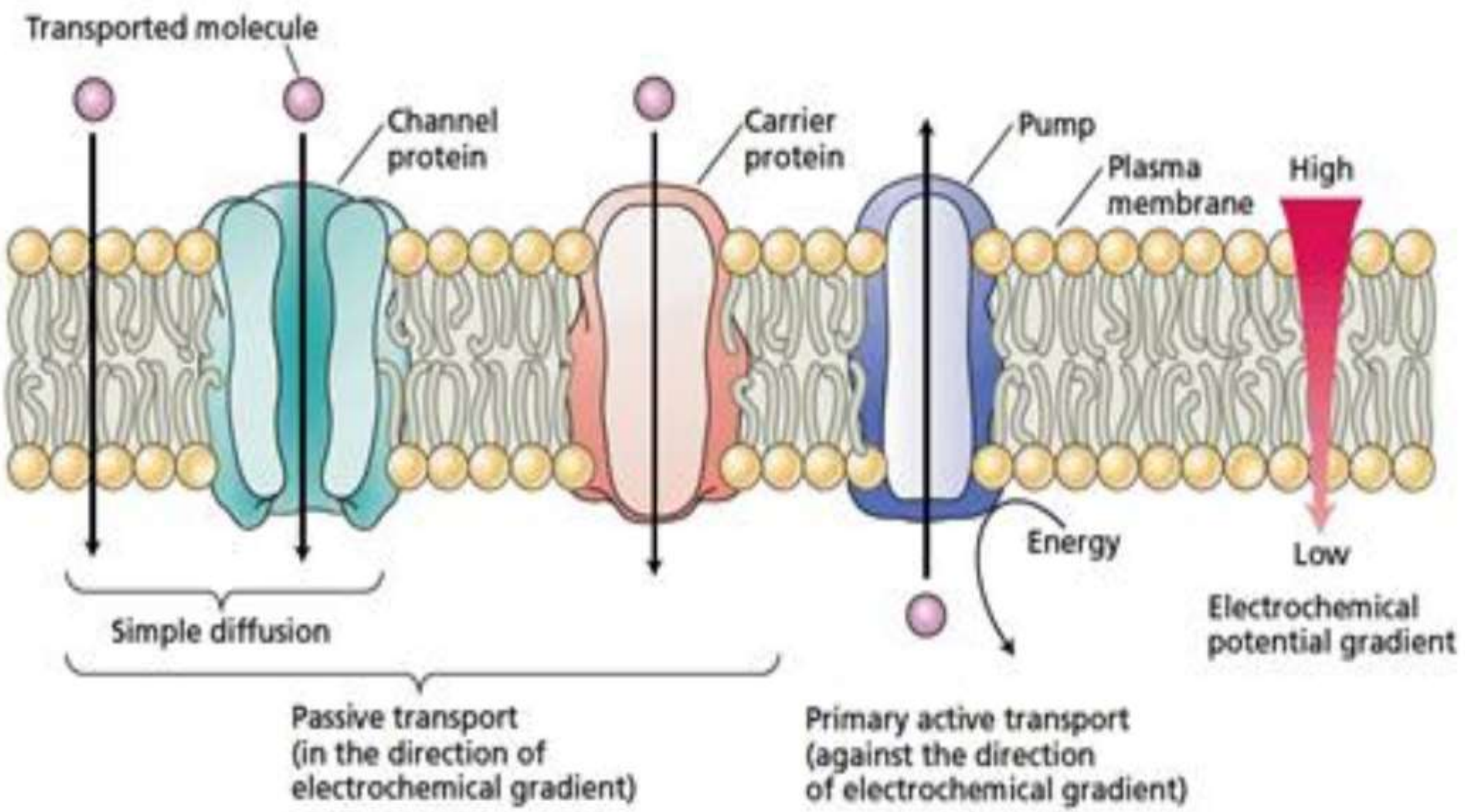


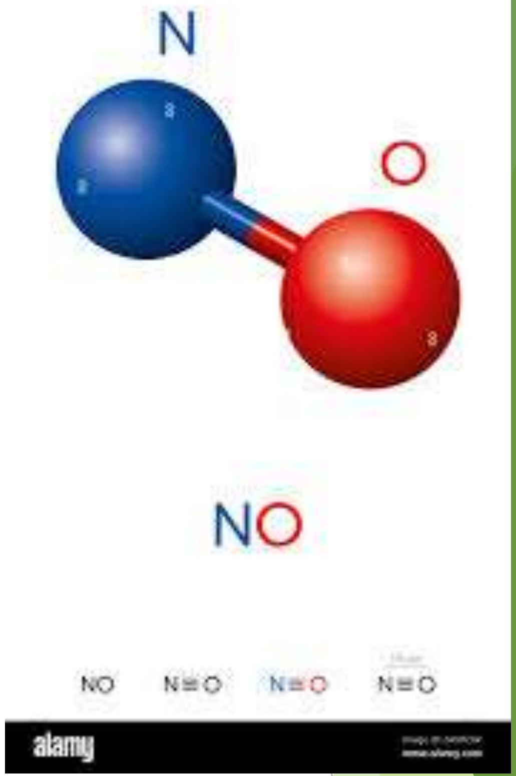
Fig.2: Three classes of membrane transport proteins: channels, carriers, and pumps (source: Taiz L., Zeiger E., 2010)

2.6.TRANSLOCATION OF SOLUTE

The transportation of mineral salts is through the xylem along with the ascending water.

Transpiration pull plays a major role in the movement of mineral salts.

3. Nitrogen nutrition



- NITROGEN (N_2) is one of macro elementes

Absorbed as : Mainly as NO 3

- also taken up as NO2

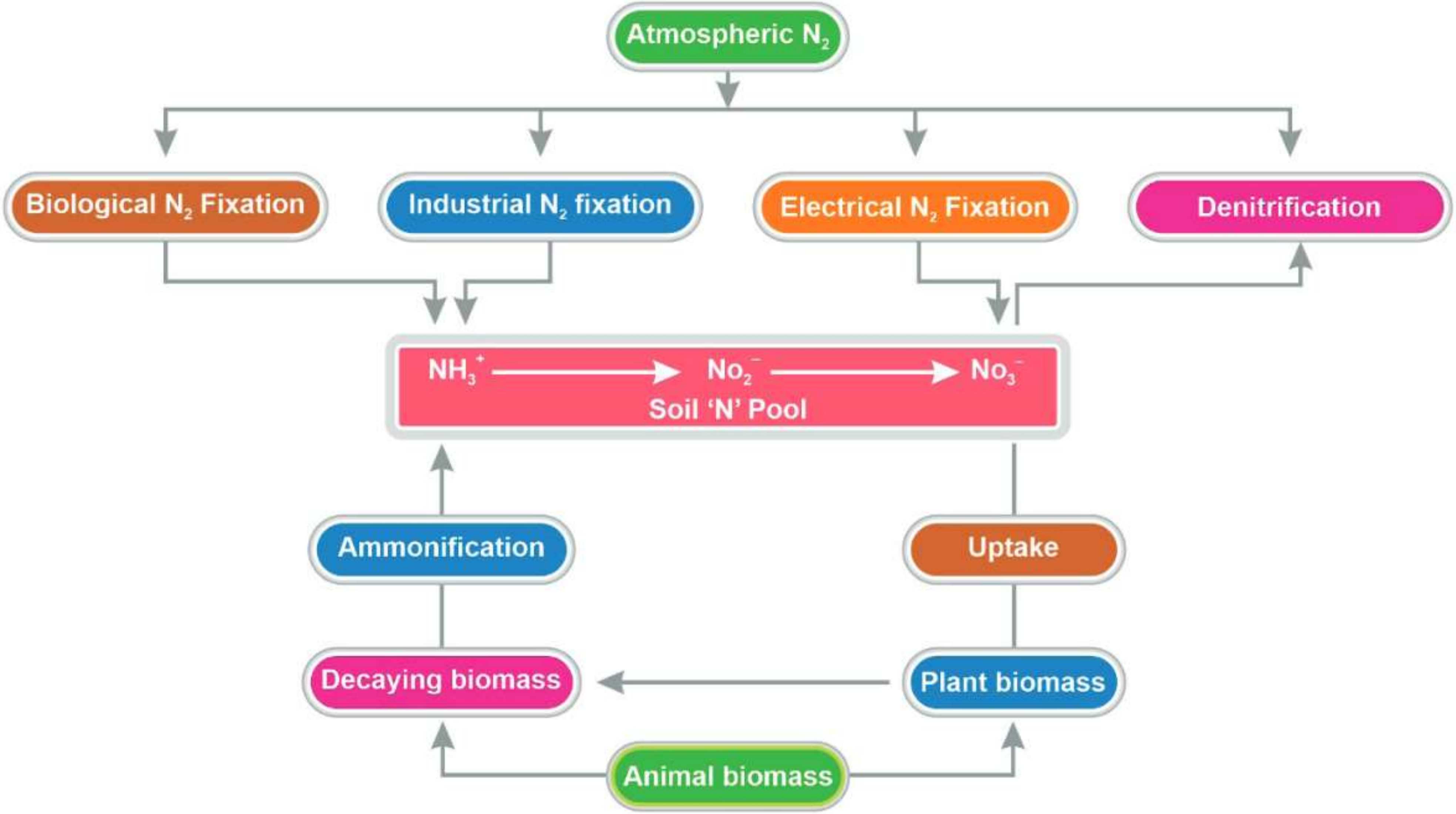
- and NH4+

Functions : Part of proteins, chlorophyll, cytochromes, phytochromes, hormones (auxins, cytokinins), nucleic acids (DNA, RNA), NAD etc; serves as enzymes, promotes vegetative growth.

- Deficiency Symptoms : Stunted growth, Chlorosis, dormancy of causal buds.

3.1.NITROGEN CYCLE

- The molecular nitrogen is not utilized directly by the plants. It has to be fixed i.e., combined with the elements such as carbon, hydrogen or oxygen to form compounds prior to utilization. Nitrogen exists as two nitrogen atoms joined by a very strong triple covalent bond ($N \equiv N$) in nature.



The nitrogen cycle showing relationship between the three main nitrogen pools–atmospheric soil, and biomass

3.2. Nitrogen Fixation

- The process of conversion of nitrogen (N2) to ammonia is termed as nitrogen fixation.
- Methods of Fixation of Nitrogen

○ Physical nitrogen fixation.

○ Biological nitrogen fixation.

- Physical Nitrogen Fixation

takes place by two ways: Natural and Industrial

- Natural Nitrogen Fixation

Atmospheric nitrogen combines with oxygen

under the effect of lightening (i.e., electric discharge) and thunder in the clouds to form Nitric oxide (NO).

- Nitric oxide is then oxidized to form nitrogen peroxide (NO2)
- During rains the nitrogen peroxide combines with water to form nitrous acid and nitric acid which come to ground along with the rains.
- On the ground, the acids react with the alkaline radicals to form water soluble nitrates(NO3-) and nitrites(NO2-).
- The water soluble nitrates and nitrites are directly absorbed by the plants.

BIOLOGICAL NITROGEN FIXATION

- Reduction of nitrogen to ammonia by living organisms is called biological nitrogen fixation.
- The enzyme capable of nitrogen reduction is present exclusively in prokaryotes and such microbes are called N2-fixers.
- In the soil numerous nitrogen fixing microbes are present and Molybdenum is required by the microbes to fix the nitrogen

4. **Carbon nutrition**

- solar radiant energy is converted via endergonic reactions in plants into carbohydrates
- The capture of sunlight energy for transformation into various forms of chemical energy is one of the oldest biochemical reactions on Earth.
- The chloroplast is the place of both the light and carbon reactions of photosynthesis.
- The products of the light reactions, ATP and NADPH, flow from thylakoid membranes to the surrounding fluid phase (stroma) and drive the enzyme-catalyzed reduction of atmospheric CO2 to carbohydrates and other cell components.

- Because the stroma-localized reactions depend on products of the photochemical processes and are also known to be regulated directly by light, they are more properly referred to as carbon reactions of photosynthesis.
- The incorporation of atmospheric CO_2 into organic compounds appropriate for life is accomplished by the Calvin-Benson cycle. There are two major products of the photosynthetic fixation of CO_2:
- starch, the reserve polysaccharide that accumulates transiently in chloroplasts; and sucrose, the disaccharide that is exported from leaves to developing and storage organs of the plant.

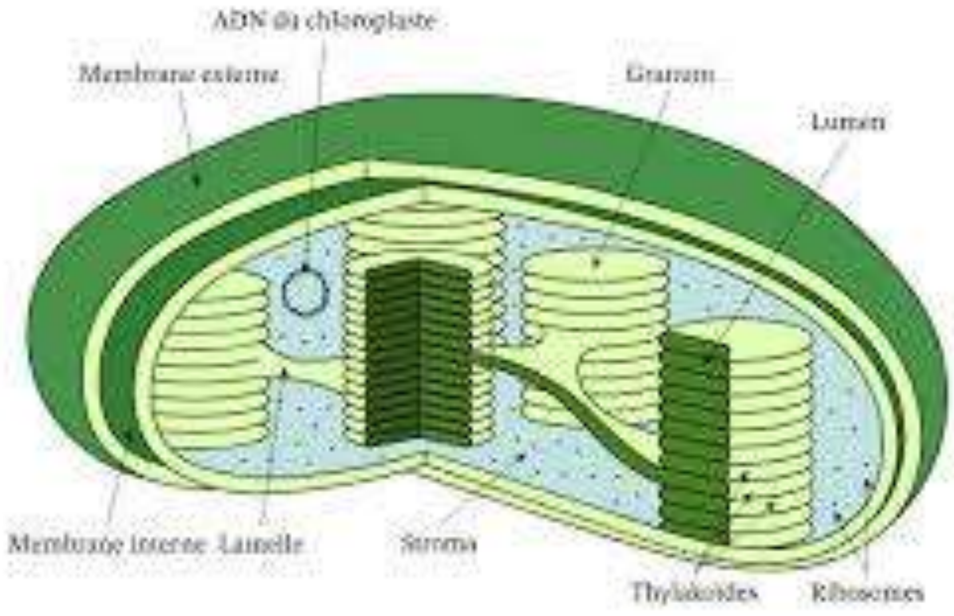
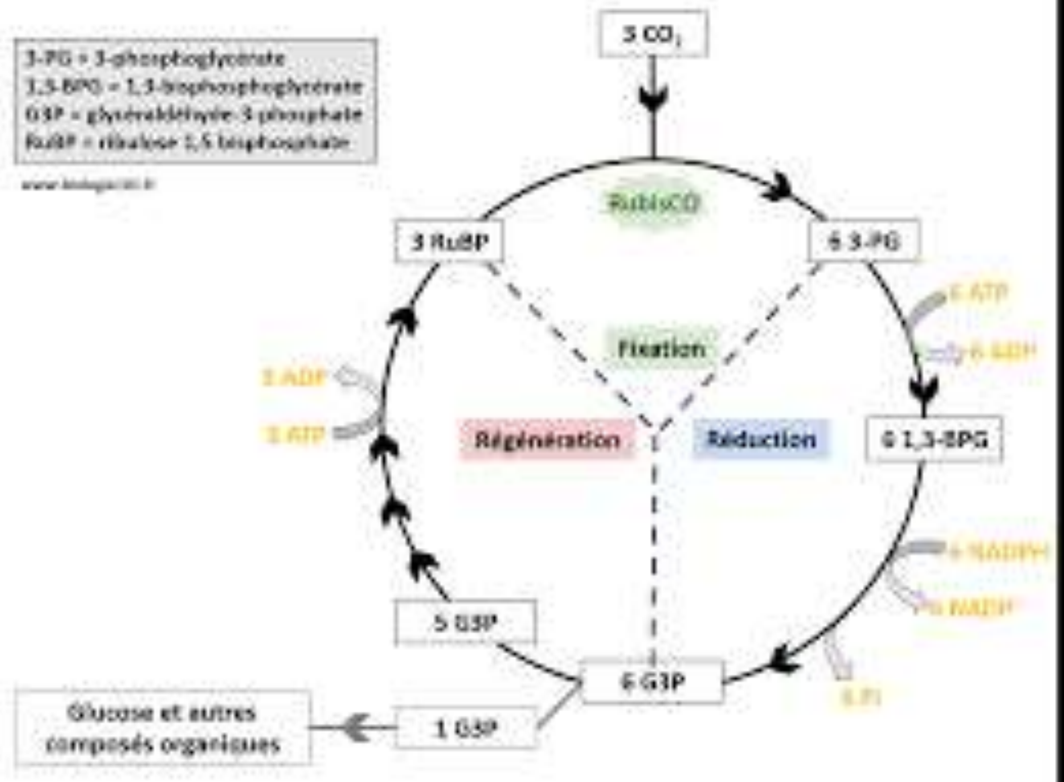


Figure 3: Schéma montrant la structure du chloroplaste, avec les structures essentielles indiquées.

The Calvin-Benson cycle

- The Calvin-Benson cycle is found in many prokaryotes and in all photosynthetic eukaryotes, from the most primitive algae to the most advanced angiosperms. It is also aptly named the reductive pentose phosphate cycle.
- The Calvin-Benson cycle has three stages
- The Calvin-Benson cycle was elucidated by M. Calvin, A. Benson and their colleagues in the 1950s. It proceeds in three stages that are highly coordinated in the chloroplast :
- 1. Carboxylation of the CO2 acceptor molecule.
- The first committed enzymatic step to generate two molecules of a 3-carbon intermediate (3-phosphoglycerate).
- 2. Reduction of 3-phosphoglycerate.
- 3. Regeneration of the CO2 acceptor ribulose 1,5-bisphosphate.


3-PG = 3-phosphoglycérate
1,3-BPG = 1,3-biophosphoglycérate
G3P = glycéraldéhyde-3-phosphate
RuBP = ribulose 1,5 biophosphate
3 CO2
RubisCO
3 RuBP
6 3-PG
Fixation
Régénération
Réduction
6 1,3-BPG
5 G3P
6 G3P
1 G3P
Glucose et autres composés organiques

- **Calvin Benson Cycle Fixing CO_2**
- **The Calvin cycle is a part of the photosynthesis processes responsible for assimilation of atmospheric CO_2 into sugar phosphates used in wider metabolism for plant growth and development.**
- The Calvin cycle takes place in the stroma within the chloroplasts of plant cells.
- This cycle involves eleven enzymes and can be divided into three stages; (i) **carboxylation** carried out by carbon dioxide fixing enzyme ribulose-1,5-bisphosphate carboxylase oxygenase (Rubisco),
- (ii) **reduction** of the C3 acids formed by the carboxylation reaction (the stage of sugar formation), and
- (iii) **regeneration** of ribulose-1:5-bisphosphate (RuBP), the CO_2-acceptor molecule at Rubisco.

Référence bibliographique

- http://retnomastutibiologi.lecture.ub.ac.id/files/2019/01/4-Water-Balance-of-Plants.pdfx