Program	:	B. Pharmacy
Semester	:	1st
Subject /Course	:	Remedial Biology
Subject/Course ID	:	BP106RBT
Module No.	:	04
Module Title	:	Plant nutrition and Photosynthesis
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Learning Outcome of Module-4

LO	Learning Outcome (LO)	Course Outcome Code
1.	Student will learn about types of nutrition and its meaning.	BP106.4
2.	Student will learn about essential elements, their function and deficiency symptoms.	BP106.4
3.	Student will learn about Nitrogen metabolism/ Nitrogen cycle.	BP106.4
4.	Student will learn about complete process of photosynthesis.	BP106.4
5.	Student will learn about C3 and C4 plants anatomy and mode of photosynthesis.	BP106.4
6.	Student will learn about various factors affecting photosynthesis.	BP106.4

Module Content Table

No.	Topic
1.	Nutrition- types/ modes
2.	Essential elements and their function & deficiency symptoms
3.	Nitrogen cycle
4.	Photosynthesis
5.	Light dependent reaction
6.	Dark reaction
7.	Photosynthesis in C4 plants
8.	Factors affecting photosynthesis

PLANT NUTRITION

Nutrients are the components found in our food such as carbohydrates, vitamins, minerals, fats etc. These components are necessary for living organisms to survive. Plants produce their own food while animals and human beings do not produce their own food. We indirectly or directly depend on plants and animals for our food needs.

Modes of Nutrition

The process of obtaining food and utilizing it to grow, stay healthy and repair any damaged body part is known as nutrition. Plants produce their food by taking raw materials from their surroundings, such as minerals, carbon dioxide, water, and sunlight. There are two modes of nutrition:

- Autotrophic – Plants exhibit **autotrophic nutrition** and are called as a primary producer. Plants synthesis their food by using light, carbon dioxide, water, carbon dioxide, or other chemicals.
- Heterotrophic – Both animals and human beings are called heterotrophs, as they depend on plants for their food.

Autotrophic Nutrition in Plants

Photosynthesis

- Plants are able to produce their own food through a process called photosynthesis.
- The chloroplast is the site of photosynthesis.

Heterotrophic Nutrition in Plants

Some plants do not contain chlorophyll and depend on other plants for their food through the heterotrophic mode of nutrition. These type of nutrition in plants are referred to as **Heterotrophic nutrition** in plants, hence are called parasites.

Heterotrophic Plants

Listed below are different types of heterotrophic plants that are mainly classified based on their mode of nutrition:

- Parasitic
- Insectivorous
- Saprophytic
- Symbiotic

Parasitic Nutrition

Some heterotrophic plants depend on other plants and animals for nutrition. Such plants are known as parasitic plants. However, the host is not benefitted from the parasite.

For eg., Cuscuta, Cassytha

Insectivorous Nutrition

Some plants have special structural features that help them to trap insects and are commonly known as carnivorous or heterotrophic plants. These plants digest the insects by secreting digestive juices and absorb the nutrients from them. These plants grow on the soil that lacks minerals.

For eg., Pitcher plant, Venus flytrap

Saprophytic Nutrition

The saprophytic plants derive nutrition from dead and decaying plants and animals. They dissolve the dead and decaying matter by secreting digestive juices and absorb the nutrients.

For eg., mushrooms, moulds.

Symbiotic Nutrition

When two different plants belonging to two different categories show a close association, they are termed as symbiotic. In this, both the plants are benefitted from each other.

For eg., the association of fungi and trees.

Plant nutrients

Approximately 20 macronutrients and micronutrients are deemed essential nutrients to support all the biochemical needs of plants.

Essential Nutrients

Plants require only light, water, and about 20 elements to support all their biochemical needs. These 20 elements are called essential nutrients. For an element to be regarded as essential, three criteria are required:

1. A plant cannot complete its life cycle without the element
2. No other element can perform the function of the element
3. The element is directly involved in plant nutrition

Macronutrients and Micronutrients

The essential elements can be divided into macronutrients and micronutrients. Nutrients that plants require in larger amounts are called macronutrients. About half of the essential elements are considered macronutrients: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. The first of these macronutrients, carbon (C), is required to form carbohydrates, proteins, nucleic acids, and many other compounds; it is, therefore, present in all macromolecules. On average, the dry weight (excluding water) of a cell is 50 percent carbon, making it a key part of plant biomolecules.

Essential Elements for Plant Growth	
Macronutrients	Micronutrients
Carbon (C)	Iron (Fe)
Hydrogen (H)	Manganese (Mn)
Oxygen (O)	Boron (B)
Nitrogen (N)	Molybdenum (Mo)
Phosphorus (P)	Copper (Cu)
Potassium (K)	Zinc (Zn)
Calcium (Ca)	Chlorine (Cl)
Magnesium (Mg)	Nickel (Ni)
Sulfur (S)	Cobalt (Co)
	Sodium (S)
	Silicon (Si)

Figure- **Essential elements required by plants**

The next-most-abundant element in plant cells is nitrogen (N); it is part of proteins and nucleic acids. Nitrogen is also used in the synthesis of some vitamins. Hydrogen and oxygen are macronutrients that are part of many organic compounds and also form water.

Oxygen is necessary for cellular respiration; plants use oxygen to store energy in the form of ATP.

Phosphorus (P), another macromolecule, is necessary to synthesize nucleic acids and phospholipids. As part of ATP, phosphorus enables food energy to be converted into chemical energy through oxidative phosphorylation. Light energy is converted into chemical energy during photophosphorylation in photosynthesis; and into chemical energy to be extracted during respiration.

Sulfuris part of certain amino acids, such as cysteine and methionine, and is present in several coenzymes. Sulfur also plays a role in photosynthesis as part of the electron transport chain where hydrogen gradients are key in the conversion of light energy into ATP.

Potassium (K) is important because of its role in regulating stomatal opening and closing. As the openings for gas exchange, stomata help maintain a healthy water balance; a potassium ion pump supports this process.

Magnesium (Mg) and **calcium** (Ca) are also important macronutrients. The role of calcium is twofold: to regulate nutrient transport and to support many enzyme functions. Magnesium is important to the photosynthetic process. These minerals, along with the micronutrients, also contribute to the plant's ionic balance.

In addition to macronutrients, organisms require various elements in small amounts. These micronutrients, or trace elements, are present in very small quantities. The seven main micronutrients include boron, chlorine, manganese, iron, zinc, copper, and molybdenum.

Boron (B) is believed to be involved in carbohydrate transport in plants; it also assists in metabolic regulation. Boron deficiency will often result in bud dieback.

Chlorine (Cl) is necessary for osmosis and ionic balance; it also plays a role in photosynthesis.

Copper (Cu) is a component of some enzymes. Symptoms of copper deficiency include browning of leaf tips and chlorosis (yellowing of the leaves).

Iron (Fe) is essential for chlorophyll synthesis, which is why an iron deficiency results in chlorosis.

Manganese (Mn) activates some important enzymes involved in chlorophyll formation. Manganese-deficient plants will develop chlorosis between the veins of its leaves. The availability of manganese is partially dependent on soil pH.

Molybdenum (Mo) is essential to plant health as it is used by plants to reduce nitrates into usable forms. Some plants use it for nitrogen fixation; thus, it may need to be added to some soils before seeding legumes.

Zinc (Zn) participates in chlorophyll formation and also activates many enzymes. Symptoms of zinc deficiency include chlorosis and stunted growth.

Deficiencies in any of these nutrients, particularly the macronutrients, can adversely affect plant growth. Depending on the specific nutrient, a lack can cause stunted growth, slow growth, or chlorosis. Extreme deficiencies may result in leaves showing signs of cell death.

Nitrogen Metabolism

The soil has limited amounts of nitrogen. Plants and microbes compete for this nitrogen. Therefore, it is a limiting nutrient for both agricultural and natural ecosystems. Let's understand how this available nitrogen is cycled in the ecosystem a concept known as nitrogen metabolism.

Nitrogen Cycle

The main part of nitrogen metabolism is the Nitrogen Cycle. A molecule of nitrogen is made of two nitrogen atoms held together by a very strong triple covalent bond ($N \equiv N$). There are three main pools of nitrogen – atmosphere, soil and biomass. Nitrogen cycles between these pools in the following manner:

Atmospheric Pool

The process of converting atmospheric nitrogen (N_2) to ammonia (NH_3) is '**Nitrogen fixation**'. Atmospheric nitrogen is fixed in three ways – biological, industrial and electrical.

- 'Biological nitrogen fixation' involves living organisms that reduce nitrogen to ammonia.
- 'Industrial nitrogen fixation' involves industrial combustions, automobile exhausts, forest fires and power-generating stations as sources of nitrogen.
- 'Electrical nitrogen fixation' is when forces of nature such as lightning and ultraviolet radiation provide energy to convert nitrogen to nitrogen oxides.

Soil Pool- The above processes fix atmospheric nitrogen into the soil. This nitrogen is then taken up by plants and animals, consequently.

Biomass Pool- When plants and animals die, the organic nitrogen within them decomposes to ammonia. This process is '**Ammonification'** and it returns nitrogen back to the soil. Some of this ammonia evaporates and re-enters the atmosphere while a major part of it is converted by soil bacteria into nitrate as follows:

(i) First, ammonia is oxidised to nitrite by the bacteria *Nitrosomonas* and/or *Nitrococcus.*

$$2NH_3 + 3O_2 \rightarrow 2NO_2^- + 2H^+ + 2H_2O$$

(ii) Then, nitrite is further oxidised to nitrate by *Nitrobacter*.

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

These reactions are called '**Nitrification**' and the nitrifying bacteria are '**Chemoautotrophs**'. Plants absorb the nitrate thus formed and transport it to the leaves where it is reduced to ammonia. This ammonia forms the amine group of amino acids. Nitrates in the soil are also reduced to nitrogen during '**Denitrification**' by *Pseudomonas* and *Thiobacillus*. In this way, nitrogen keeps cycling in the ecosystem.

Biological Nitrogen Fixation

Only a few prokaryotes can use the atmospheric nitrogen as N_2 and reduce it to ammonia. This reduction of nitrogen to ammonia by living organisms is 'biological nitrogen fixation'. The enzyme it needs for this reaction – nitrogenase is present exclusively in prokaryotes and these microbes are called N_2 – fixers. These N_2 – fixers can be symbiotic or free-living. Some examples of free-living N_2 – fixers are *Azotobacter*, *Bacillus*, *Anabaena*, *Nostoc* etc.

Symbiotic Biological Nitrogen Fixation

The most popular example in this category is the symbiotic relationship between *Rhizobium* and the roots of legumes such as sweet pea, garden pea, lentils. The association is visible as nodules (small outgrowths) on the roots. Another example is the microbe *Frankia* that also produces nitrogen-fixing nodules on the roots of non-leguminous plants.

Nodule Formation

Another form of nitrogen metabolism is nodule formation. Nodule formation involves several interactions between the roots of the host plant and *Rhizobium.*

Fate of Ammonia

What happens to the ammonia generated after nitrogen-fixation? It is protonated to form ammonium ion (NH_4^+) at physiological pH. Although plants can accumulate nitrate and NH_4^+ ions, NH_4^+ ions are toxic to them. Thus, it is in turn, used to synthesize amino acids in plants.

Nitrogen Cycle Definition

"Nitrogen Cycle is a biogeochemical process which transforms the inert nitrogen present in the atmosphere to a more usable form for living organisms."

Furthermore, nitrogen is a key nutrient element for plants. However, the abundant nitrogen in the atmosphere cannot be used directly by plants or animals. Read on to explore how the Nitrogen cycle makes usable nitrogen available to plants and other living organisms.

What is Nitrogen Cycle?

Nitrogen Cycle is a biogeochemical process through which nitrogen is converted into many forms, consecutively passing from the atmosphere to the soil to organism and back into the atmosphere.

It involves several processes such as nitrogen fixation, nitrification, denitrification, decay and putrefaction.

The nitrogen gas exists in both organic and inorganic forms. Organic nitrogen exists in living organisms, and they get passed through the food chain by the consumption of other living organisms.

Inorganic forms of nitrogen are found in abundance in the atmosphere. This nitrogen is made available to plants by symbiotic bacteria which can convert the inert nitrogen into a usable form – such as nitrites and nitrates.

Nitrogen undergoes various types of transformation to maintain a balance in the ecosystem. Furthermore, this process extends to various biomes, with the marine nitrogen cycle being one of the most complicated biogeochemical cycles.

Stages of Nitrogen Cycle

Process of Nitrogen Cycle consists of the following steps – Nitrogen fixation, Nitrification, Assimilation, Ammonification, and Denitrification. These processes take place in several stages and are explained below:

Nitrogen fixation

It is the initial step of the nitrogen cycle. Here, Atmospheric nitrogen (N2)which is primarily available in an inert form, is converted into the usable form -ammonia (NH3).

During the process of Nitrogen fixation, the inert form of nitrogen gas is deposited into soils from the atmosphere and surface waters, mainly through precipitation. Later, the nitrogen undergoes a set of changes, in which two nitrogen atoms get separated and combines with hydrogen to form ammonia (NH4+).

The entire process of Nitrogen fixation is completed by symbiotic bacteria which are known as Diazotrophs. Azotobacter and Rhizobium also have a major role in this process. These bacteria consist of a nitrogenase enzyme which has the capability to combine gaseous nitrogen with hydrogen to form ammonia.

Nitrogen fixation can occur either by the atmospheric fixation- which involves lightening or industrial fixation by manufacturing ammonia under high temperature and pressure condition. This can also be fixed through man-made processes, primarily industrial processes that create ammonia and nitrogen-rich fertilisers.

Types of Nitrogen Fixation

1. **Atmospheric fixation:** A natural phenomenon where the energy of lightning breaks the nitrogen into nitrogen oxides and is then used by plants.
2. **Industrial nitrogen fixation:** Is a man-made alternative that aids in nitrogen fixation by the use of ammonia. Ammonia is produced by the direct combination of nitrogen and hydrogen, and later, it is converted into various fertilisers such as urea.
3. **Biological nitrogen fixation:** We already know that nitrogen is not usable directly from the air for plants and animals. Bacteria like Rhizobium and blue-green algae transform the unusable form of nitrogen into other compounds that are more readily usable. These nitrogen compounds get fixed in the soil by these microbes.

Nitrification

In this process, the ammonia is converted into nitrate by the presence of bacteria in the soil. Nitrites are formed by the oxidation of Ammonia with the help of Nitrosomonas bacterium species. Later, the produced nitrites are converted into nitrates by Nitrobacter. This conversion is very important as ammonia gas is toxic for plants.

The reaction involved in the process of Nitrification is as follows:

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

Assimilation

Primary producers – plants take in the nitrogen compounds from the soil with the help of their roots, which are available in the form of ammonia, nitrite ions, nitrate ions or ammonium ions and are used in the formation of the plant and animal proteins. This way, it enters the food web when the primary consumers eat the plants.

Ammonification

When plants or animal die, the nitrogen present in the organic matter is released back into the soil. The decomposers, namely bacteria or fungi present in the soil, convert the organic matter back into ammonium. This process of decomposition produces ammonia which is further used for other biological processes.

Denitrification

Denitrification is the process in which the nitrogen compounds makes its way back into the atmosphere by converting nitrate (NO_3-) into gaseous nitrogen (N). This process of the nitrogen cycle is the final stage and occurs in the absence of oxygen. Denitrification is carried out by the denitrifying bacterial species- Clostridium and Pseudomonas, which will process nitrate to gain oxygen and gives out free nitrogen gas as a byproduct.

Nitrogen Cycle in Marine Ecosystem

The process of the nitrogen cycle occurs in the same manner in the marine ecosystem as in the terrestrial ecosystem. The only difference is that it is carried out by marine bacteria.

The nitrogen-containing compounds that fall into the ocean as sediments get compressed over long periods and form sedimentary rock. Due to the geological uplift, these sedimentary rocks move to land. Initially, it was not known that these nitrogen-containing sedimentary rocks are an essential source of nitrogen. But, recent researches have proved that the nitrogen from these rocks is released into the plants due to the weathering of rocks.

Importance of Nitrogen Cycle

Importance of the nitrogen cycle are as follows:

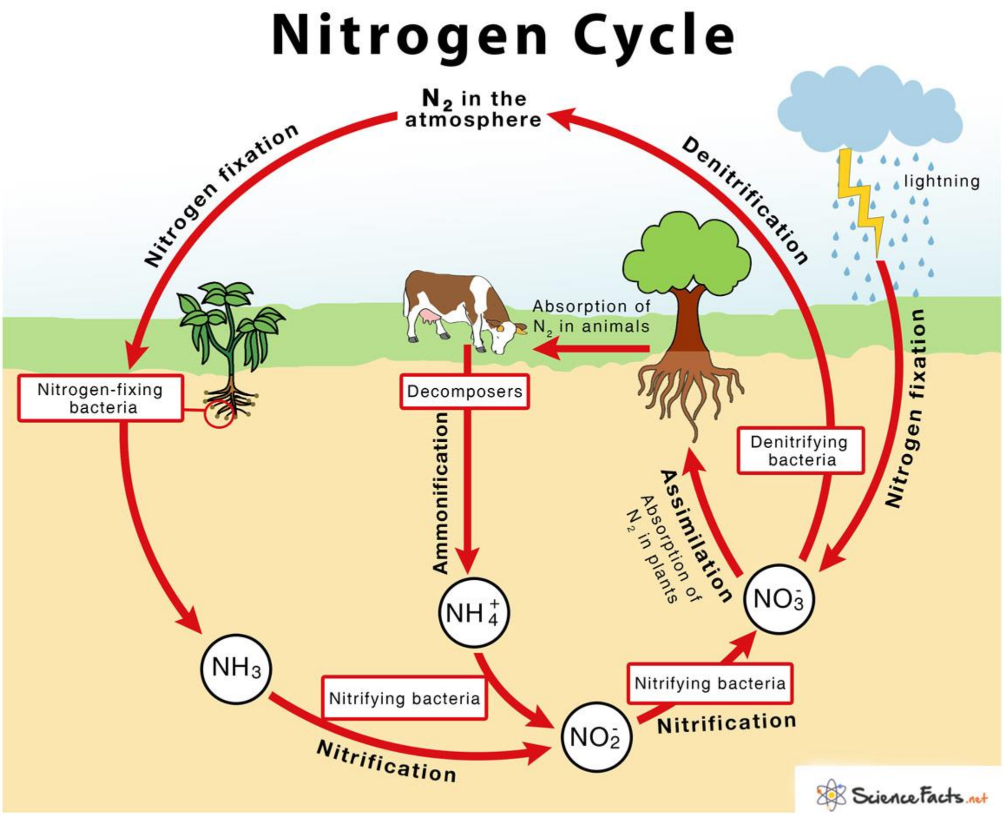
1. Helps plants to synthesise chlorophyll from the nitrogen compounds.
2. Helps in converting inert nitrogen gas into a usable form for the plants through the biochemical process.
3. In the process of ammonification, the bacteria help in decomposing the animal and plant matter, which indirectly helps to clean up the environment.
4. Nitrates and nitrites are released into the soil, which helps in enriching the soil with necessary nutrients required for cultivation.
5. Nitrogen is an integral component of the cell, and it forms many crucial compounds and important biomolecules.

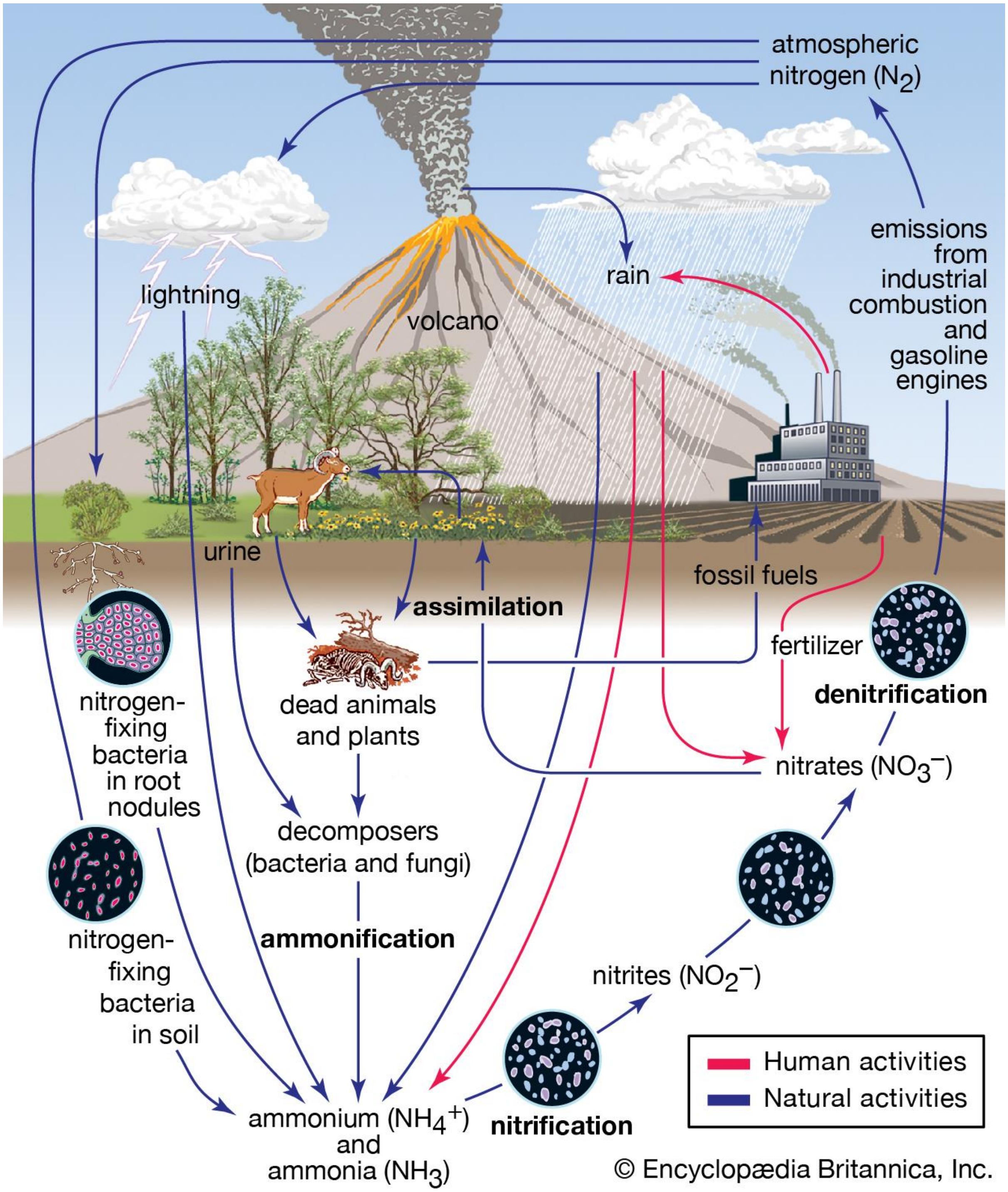
Nitrogen is also cycled by human activities such as combustion of fuels and the use of nitrogen fertilisers. These processes increase the levels of nitrogen-containing compounds in the atmosphere. The fertilisers containing nitrogen are washed away in lakes and rivers and results in eutrophication.

Conclusion

- Nitrogen is abundant in the atmosphere, but it is unusable to plants or animals unless it is converted into nitrogen compounds.
- Nitrogen-fixing bacteria play a crucial role in fixing the atmospheric nitrogen into nitrogen compounds that can be used by the plants.
- The plants absorb the usable nitrogen compounds from the soil through their roots. Then, these nitrogen compounds are used for the production of proteins and other compounds in the cell.

- Animals assimilate nitrogen by consuming these plants or other animals that contain nitrogen. Humans consume proteins from these plants and animals, and then, the nitrogen assimilates into our system.
- During the final stages of the nitrogen cycle, bacteria and fungi help decompose organic matter, where the nitrogenous compounds get dissolved into the soil which is again used by the plants.
- Some bacteria then convert these nitrogenous compounds in the soil and turn it into nitrogen gas. Eventually, it goes back to the atmosphere.
- These set of processes repeat continuously and thus maintain the percentage of nitrogen in the atmosphere.





Frequently Asked Questions

What is plant nutrition?

Plant nutrition is the study of elements and compounds necessary for plant growth, metabolism and external supply. A plant cannot complete its life cycle in its absence.

What is the main mode of nutrition in plants?

The main mode of nutrition in plants is the autotrophic mode of nutrition. The plants have chlorophyll in their leaves which helps them to produce their own food.

What are the different types of heterotrophic nutrition in plants?

Some plants do not have chlorophyll and depend upon other plants for their food. Such plants exhibit a heterotrophic mode of nutrition and are known as heterotrophic plants. For eg., parasitic plants, insectivorous plants, symbiotic plants, and saprophytic plants.

What are insectivorous plants?

Insectivorous plants are the plants that trap insects. Their leaves are modified into special structures which trap the insects and digest it with the help of digestive enzymes to derive nutrition from them.

Can plants prepare food without sunlight?

The seeds of the plants have stored food in the endosperm. They do not require any sunlight to grow. As soon as the first leaf emerges and is exposed to sunlight, they start preparing food by the process of photosynthesis.

What are the important nutrients required by the plants?

The plants require two types of nutrients- macronutrients and micronutrients. Macronutrients include nitrogen, phosphorus, potassium, calcium, magnesium and sulphur. The micronutrients include boron, chlorine, copper, iron, manganese, molybdenum, and zinc.

How are the nutrients absorbed by the plants?

Plants absorb nutrients through their roots. They require nutrients and water up through the stem to the parts that are above ground level.

Why is nitrogen important for life?

Nitrogen constitutes many cellular components and is essential in many biological processes. For instance, the amino acids contain nitrogen and form building blocks that make up various components of the human body such as hair, tissues and muscles.

Why do plants need nitrogen?

Plants need nitrogen as this element is an important component of chlorophyll. Consequently, chlorophyll is vital for the process of photosynthesis, so lack of nitrogen can cause deficiency disorders, stunted growth and other abnormalities.

List the different steps that explain the Nitrogen Cycle process.

- Ammonification
- Nitrification
- Denitrification
- Nitrogen Fixation

What is Ammonification?

Ammonification occurs during decomposition of organic matter, where ammonifying bacteria convert organic nitrogen into inorganic components like ammonia or ammonium ions.

What is Nitrification?

Nitrification is a process that converts ammonia into nitrate by bacteria. Initially, the ammonia is converted to nitrite (NO_2^-) by the bacteria Nitrosomonas, or Nitrococcus, etc. and then to nitrate (NO_3^-) by Nitro Bacterium.

What is Denitrification?

Denitrification is the process of converting the nitrate back into molecular nitrogen by bacterias such as Pseudomonas, Thiobacillus, Bacillus subtilis etc.

What is the function of nitrifying bacteria?

Nitrifying bacteria are a small group of aerobic bacteria, which are mainly involved in the conversion of ammonia into nitrates.

Which part of the plant is involved in nitrogen fixation?

The process of nitrogen fixation is carried out naturally in the soil within nodules in the plant's root systems.

What are the steps involved in nitrogen fixation?

Nitrogen cycle process involves the following steps: Nitrogen Fixation, Nitrification, Ammonification and Denitrification

PHOTOSYNTHESIS

INTRODUCTION

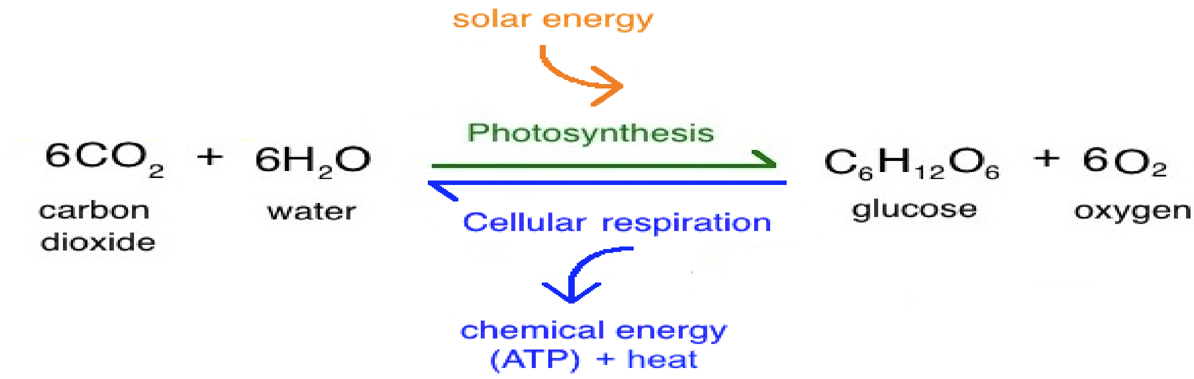
- Photosynthesis, a physico-chemical process by which the green plants use light energy to drive the synthesis of organic compounds.
- Photosynthesis is the process by which the green plants absorb sunlight to produce glucose from carbon dioxide and water.
- Photosynthesis is important due to-
  - ✓ It is the primary source of all food on earth
  - ✓ It is also responsible for the release of oxygen into the atmosphere by green plants.

EARLY EXPERIMENTS ON PHOTOSYNTHESIS

- Joseph Priestley (1733-1804) in 1770 performed a series of experiments that revealed the essential role of air in the growth of green plants.
- Priestley observed that a candle burning in a bell jar, soon gets extinguished and a mouse would soon suffocate in the bell jar because a burning candle or an animal that breathe the air, both somehow, damage the air.
- When he placed a mint plant in the same bell jar, he found that the mouse stayed alive and the candle continued to burn.

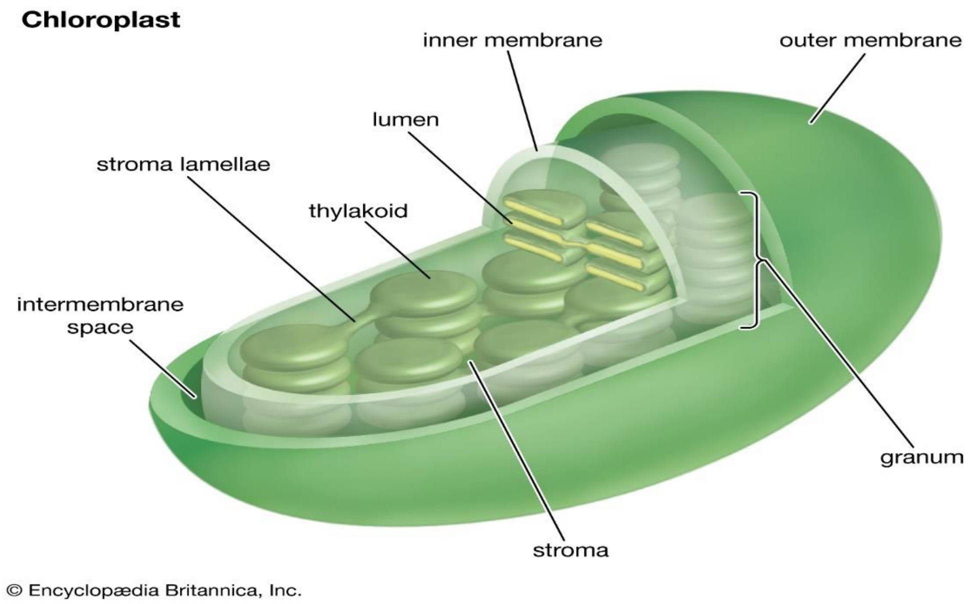
- Jan Ingenhousz, using a similar setup as the one used by Priestley, but by placing it once in the dark and once in the sunlight, showed that sunlight is essential to the plant process that somehow purifies the air fouled by burning candles or breathing animals.
- Ingenhousz with an aquatic plant showed that in bright sunlight, small bubbles were formed around the green parts while in the dark they did not, and later he discovered that these bubbles to be of oxygen.
- Small bubbles which formed were to be of oxygen; hence, he showed that it is only the green part of the plants that could release oxygen.
- Julius von Sachs provided evidence for production of glucose in chlorophyll located in chloroplasts within plant cells and glucose is usually stored as starch.
- W Engelmann used a prism splitted light into its spectral components and then illuminated a green alga, Cladophora, placed in a suspension of aerobic bacteria, which were used to detect the sites of O_2 evolution.
- Engelmann observed that the bacteria accumulated mainly in the regions of blue and red light of the split spectrum, which resembles roughly the absorption spectra of chlorophyll a and b.
- By the middle of the nineteenth century, the key feature of photosynthesis, i.e., plants could use light energy to make carbohydrates from CO_2 and water, was known.
- Cornelius van Niel demonstrated that photosynthesis is essentially a light-dependent reaction in which hydrogen from a suitable oxidisable compound reduces carbon dioxide to carbohydrates.
- In green plants, H_2O is the hydrogen donor and is oxidised to O_2, when H_2S, instead is the hydrogen donor for purple and green sulphur bacteria, the 'oxidation' product is sulphur or sulphate.

Hence, it was inferred that the O_2 evolved by the green plant comes from H_2O, not from carbon dioxide, and the equation of photosynthesis is



SITE OF PHOTOSYNTHESIS

- The mesophyll cells in the leaves, have a large number of chloroplasts, which align themselves along the walls of the mesophyll cells, such that they get the optimum quantity of the incident light.
- Within the chloroplast, there is the membranous system consisting of grana, the stroma lamellae, and the fluid stroma.
- The membrane system is responsible for trapping the light energy and also for the synthesis of ATP and NADPH.
- In stroma, enzymatic reactions incorporate CO_2 into the plant leading to the synthesis of sugar, which in turn forms starch.
- The set of reactions directly driven by light is called light reaction.
- The reactions which are not directly light driven but are dependent on the products of light reactions (ATP and NADPH) are known as dark reactions.



PIGMENTS IN PHOTOSYNTHESIS

- Pigments are substances that have an ability to absorb light, at specific wavelengths.
- The colour of the leaves is due to four pigments such as
  1. Chlorophyll a (bright or blue green in the chromatogram),
  2. chlorophyll b (yellow green),
  3. xanthophylls (yellow) and
  4. carotenoids (yellow to yellow-orange)
- The wavelengths at which there is maximum absorption by chlorophyll a, show higher rate of photosynthesis; hence, we can conclude that chlorophyll a is the chief pigment associated with photosynthesis.
- Other thylakoid pigments, like chlorophyll b, xanthophylls and carotenoids, which are called accessory pigments, also absorb light and transfer the energy to chlorophyll a, and also protect chlorophyll a from photo-oxidation.

Light Reaction-

- Light reactions or the 'photochemical' phase include light absorption, water splitting, oxygen release, and the formation of high-energy chemical intermediates, ATP and NADPH..
- The pigments are organised into two discrete photochemical light harvesting complexes (LHC) within the Photosystem I (PS I) and Photosystem II (PS II).
- The LHC are made up of hundreds of pigment molecules bound to proteins.
- Each photosystem has all the pigments (except one molecule of chlorophyll a) forming a light harvesting system also called **antennae**.
- The single chlorophyll a molecule forms the reaction centre.
- In PS I, the reaction centre chlorophyll a has an absorption peak at 700 nm, hence is called P_{700}, while in PS II it has absorption maxima at 680 nm, and is called P_{680}.

The electron transport

- In photosystem II, the reaction centre chlorophyll a absorbs 680 nm wavelength of red light causing electrons to become excited and jump, which are picked up by an electron acceptor which passes them to an electrons transport system consisting of cytochromes.
- The electrons are passed on to the pigments of photosystem PS I, and the movement of electrons is downhill.
- Electrons in the reaction centre of PS I are also excited when they receive red light of wavelength 700 nm and are transferred to another accepter molecule that has a greater redox potential.
- The electrons then are moved downhill to a molecule of energy-rich $NADP^+$ and the addition of these electrons reduces $NADP^+$ to NADPH + H^+.
- The whole scheme of transfer of electrons is called the **z-scheme**, due to its characteristic shape

Splitting of water

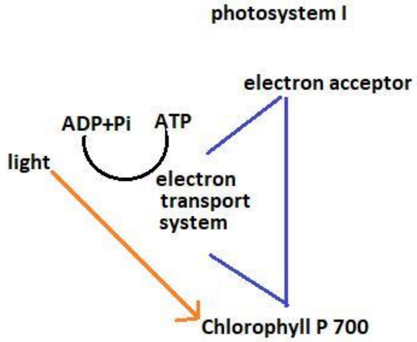
- The process in which water is split into H^+, [O] and electrons is called as splitting of water.
- Splitting of water creates oxygen, one of the net products of photosynthesis.

$2H_20 \rightarrow 4H^+ + 0_2 + 4e^-$

- The water splitting complex is associated with the PS II, which itself is physically located on the inner side of the membrane of the thylakoid.

CYCLIC AND NON-CYCLIC PHOTO-PHOSPHORYLATION

- The process in which ATP is synthesised by cells in mitochondria and chloroplasts is named phosphorylation.
- Photophosphorylation is the synthesis of ATP from ADP and inorganic phosphate in the presence of light.
- When the two photosystems, first PS II and then the PS I, connected through an electron transport chain work in a series, the process is called non-cyclic photo-phosphorylation.
- When only PS I is functional, the electron is circulated within the photosystem and the phosphorylation occurs due to cyclic flow of electrons in the stroma lamellae.
- The stroma lamellae membranes lack PS II as well as NADP reductase enzyme, hence the excited electron does not pass on to $NADP^+$ but is cycled back to the PS I complex through the electron transport chain.
- The cyclic flow results only in the synthesis of ATP, but not of NADPH + H^+.



USE OF ATP AND NADPH

- The phase in which O_2 diffuses out of the chloroplast while ATP and NADPH are used to drive the processes leading to the synthesis of sugar is called biosynthetic phase of photosynthesis.
- Biosynthetic phase does not directly depend on the presence of light but is dependent on the products of the light reaction, i.e., ATP and NADPH, besides CO_2 and H_2
- CO_2 is combined with H_2O to produce sugars.
- The use of radioactive ^{14}C by Melvin Calvin in algal photosynthesis studies led to the discovery that the first CO_2 fixation product was a 3-carbon organic acid.
- Calvin worked out the complete biosynthetic pathway; hence, it was called Calvin cycle.
- The first product identified was 3-phosphoglyceric acid (PGA).
- Another experiment on another plant discovered oxaloacetic acid or OAA as the first stable product of photosynthesis.
- CO_2 assimilation during photosynthesis was said to be of two main types:
- those plants in which the first product of CO_2 fixation is a C_3 acid (PGA), i.e., the C_3 pathway,
- the plants in which the first product was a C_4 acid (OAA), i.e., the C_4

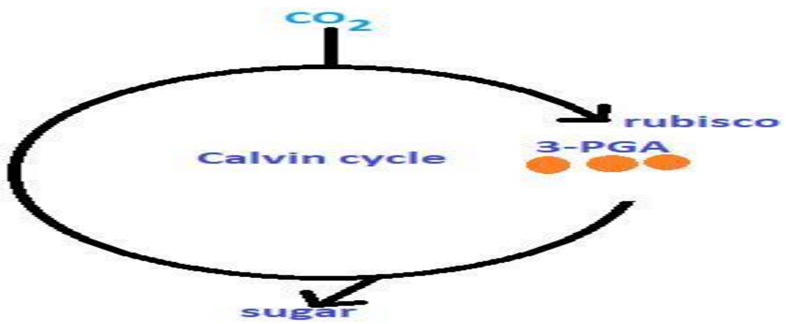


Fig. C3 pathway

THE PRIMARY ACCEPTOR OF CO_2

- The accepter molecule is a 5-carbon ketose sugar, which is ribulose bisphosphate (RuBP).
- Since the first product was a C_3 acid, the primary acceptor would be a 2-carbon compound.
- Scientists spent many years trying to identify a 2-carbon compound before they discovered the 5-carbon RuBP.

THE CALVIN CYCLE

- The Calvin pathway occurs in all photosynthetic plants.
- The Calvin cycle can be described under three stages
  1. Carboxylation
  2. reduction and
  3. Regeneration

Carboxylation is the fixation of CO_2 into a stable organic intermediate, where CO_2 is utilised for the carboxylation of RuBP.

- Carboxylation is catalysed by the enzyme RuBP carboxylase, which results in the formation of two molecules of 3-PGA.
- Since this enzyme also has an oxygenation activity it is called as **RuBP carboxylase-oxygenase** or RuBisCO.

Reduction

- The steps involve utilisation of 2 molecules of ATP for phosphorylation and 2 of NADPH for reduction per CO_2 molecule fixed.
- The fixation of six molecules of CO_2 and 6 turns of the cycle are required for the removal of one molecule of glucose from the pathway.

Regeneration

- The regeneration steps require one ATP for phosphorylation to form RuBP.

- Regeneration of the CO_2 acceptor molecule RuBP is crucial if the cycle is to continue uninterrupted.
- For every CO_2 molecule entering the Calvin cycle, 3 molecules of ATP and 2 of NADPH are required.
- To make one molecule of glucose, 6 turns of the cycle are required.

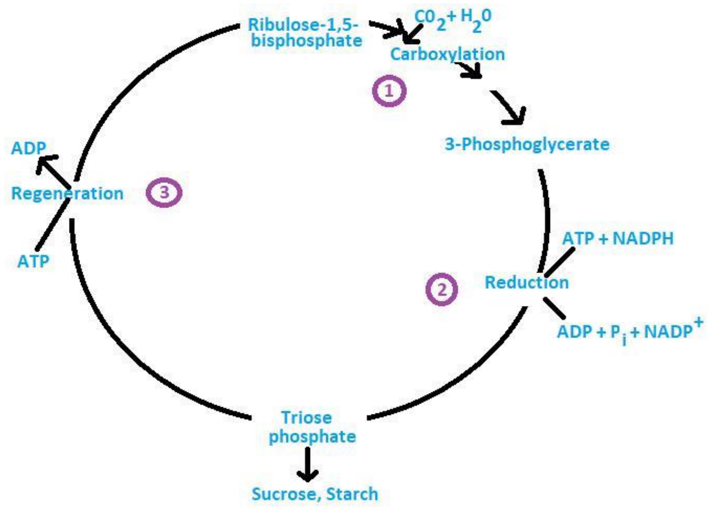
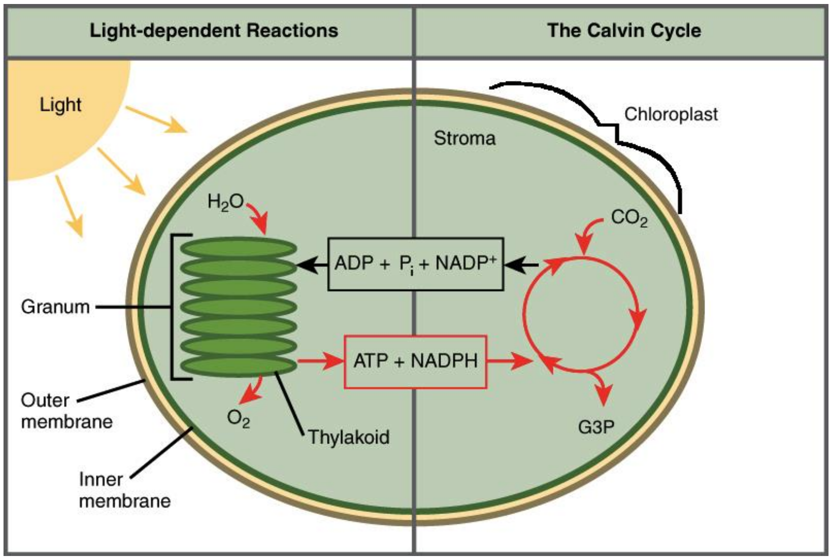


Fig. Calvin cycle



THE C_4 PATHWAY

- Though these plants have the C_4 oxaloacetic acid as the first CO_2 fixation product, plants use the C_3 pathway or the Calvin cycle as the main biosynthetic pathway.

- C4 plants are special because
  1. They have a special type of leaf anatomy,
  2. They tolerate higher temperatures,
  3. They show a response to highlight intensities,
  4. They lack a process called **photorespiration** and have greater productivity of biomass.
- The particularly large cells around the vascular bundles of the C_4 pathway plants are called **bundle sheath cells**, and the leaves which have such anatomy are said to have '**Kranz**' anatomy.
- Kranz' means 'wreath' and is a reflection of the arrangement of cells.
- The bundle sheath cells may form several layers around the vascular bundles.
- Bundle sheath cells are characterised by having a large number of chloroplasts, thick walls impervious to gaseous exchange and no intercellular spaces.
- The presence of the bundle sheath would help to identify the C_4
- The pathway discovered by Hatch and Slack is called **Hatch and Slack Pathway**, which is again a cyclic process.
- The primary CO_2 acceptor is a 3-carbon molecule phosphoenol pyruvate (PEP) and is present in the mesophyll cells and the enzyme responsible for this fixation is PEP carboxylase or PEPcase.
- The mesophyll cells lack RuBisCO enzyme and the C_4 acid OAA is formed in the mesophyll cells.
- It then forms other 4-carbon compounds in the mesophyll cells itself, which are transported to the bundle sheath cells.
- In the bundle sheath cells, these C_4 acids are broken down to release CO_2 and a 3-carbon molecule.

- The 3-carbon molecule is transported back to the mesophyll where it is converted to PEP again, thus, completing the cycle.
- The CO_2 released in the bundle sheath cells enters the C_3 or the Calvin pathway.
- The bundle sheath cells are rich in an enzyme ribulose bisphosphate carboxylase-oxygenase (RuBisCO), but lack PEPcase.
- The Calvin pathway is common to the C_3 and C_4
- In the C4 plants, it does not take place in the mesophyll cells but does so only in the bundle sheath cells.

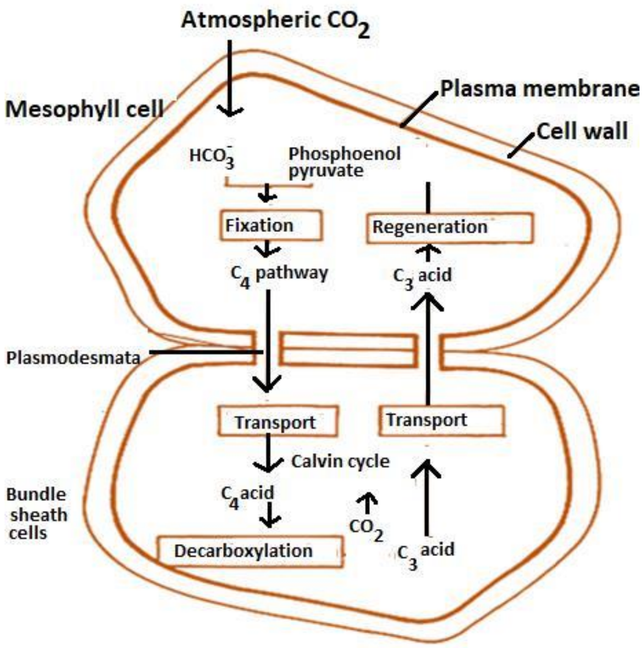


Fig. Hatch-Slack pathway

PHOTORESPIRATION

- The first step of the Calvin pathway is the first CO_2 fixation step.
- Respiration is the reaction where RuBP combines with CO_2 to form 2 molecules of 3PGA, that is catalysed by RuBisCO.

$$RuBP + CO_2 \rightarrow 2 \text{ X } 3PGA$$

- RuBisCO has a much greater affinity for CO_2 than for O_2.
- In C_3 plants, some O_2 do bind to RuBisCO, and hence CO_2 fixation is decreased.
- The RuBP instead of being converted to 2 molecules of PGA binds with O_2 to form one molecule and phosphoglycolate in a pathway called photorespiration.
- In the photorespiratory pathway, there is neither synthesis of sugars, nor of ATP.
- In C_3 plants, some O_2 do bind to RuBisCO, and hence CO_2 fixation is decreased.
- In the photorespiratory pathway, there is no synthesis of ATP or NADPH; therefore, photorespiration is a wasteful process.
- In C_4 plants, photorespiration does not occur because they have a mechanism that increases the concentration of CO_2 at the enzyme site.
- This takes place when the C_4 acid from the mesophyll is broken down in the bundle cells to release CO_2, which results in increasing the intracellular concentration of CO_2.

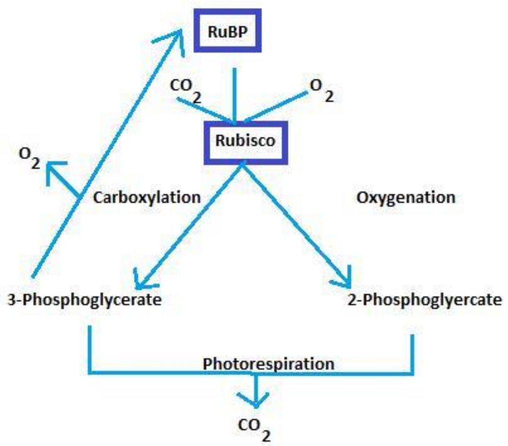


Fig. Photorespiration

FACTORS AFFECTING PHOTOSYNTHESIS

- Photosynthesis is under the influence of several factors, both internal and external.
- The plant factors include the number, size, age and orientation of leaves, mesophyll cells and chloroplasts, internal CO2 concentration and the amount of chlorophyll.

- The external factors would include the availability of sunlight, temperature, CO2 concentration and water.
- When several factors affect any biochemical process, Blackman's law of limiting factors comes into effect, which states that "If a chemical process is affected by more than one factor, then its rate will be determined by the factor which is nearest to its minimal value: it is the factor which directly affects the process if its quantity is changed."

External factors

- Light
- There is a linear relationship between incident light and CO_2 fixation rates at low light intensities.
- At higher light intensities, gradually the rate does not show further increase as other factors become limiting.
- Increase in incident light beyond a point causes the breakdown of chlorophyll and a decrease in photosynthesis.
- Carbon dioxide concentration
- The concentration of CO_2 is very low in the atmosphere.
- The C_3 and C_4 plants respond differently to CO_2
- At low light conditions, neither C_3 nor C_4 group responds to high CO_2 conditions, whereas at high light intensities, both C_3 and C_4 plants show increase in the rates of photosynthesis.
- C_4 plants show saturation at about 360 μlL^{-1}, whereas C_3 responds to increased CO_2 concentration and saturation is seen only beyond 450 μlL^{-1}.
- Temperature
- The dark reactions being enzymatic are more sensitive to temperature than light reaction.
- The C_4 plants respond to higher temperatures and show higher rate of photosynthesis, whereas C_3 plants have a much lower temperature optimum.
- Tropical plants have a higher temperature optimum than the plants adapted to temperate climates.
- Water
- Water stress causes the stomata to close hence reducing the CO_2

- Besides, water stress also makes leaves wilt, thus, reducing the surface area of the leaves and their metabolic activity as well.

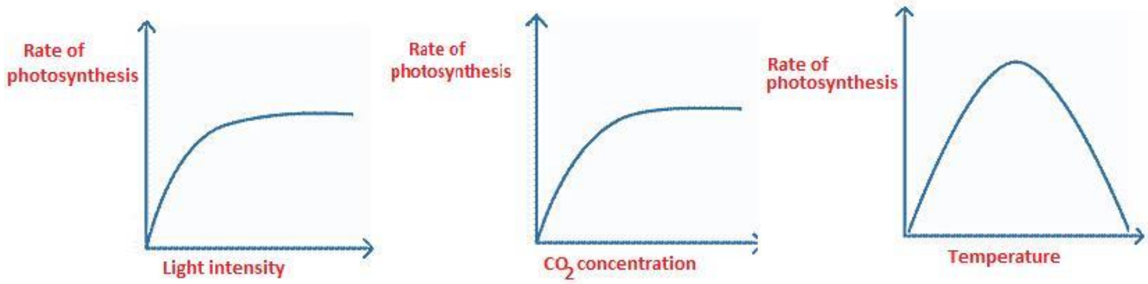


Fig. Factors affecting photosynthesis

Important points to remember

1. Essential nutrients, their role and deficiency symptoms
2. Nitrogen cycle, Biological Nitrogen fixation
3. Photosynthesis- meaning, importance and mechanism
4. Light and dark reaction
5. C4 plants
6. Factors affecting photosynthesis

References for more learning

1. Refer the books suggested for more reading
2. Any NCERT book of Biology
3. You may use website links or you tube links for self-learning

Important questions

2marks

1. Define Nutrition.
2. What do you understand by Essential elements?
3. Enumerate various deficiency symptoms of macro elements in plants.
4. Define Nitrogen metabolism/ Nitrogen cycle.

5. Why Nitrogen is known as Limiting nutrient?
6. What is the role of micro-organism in nitrogen fixation?
7. What is C3 cycle? Give its importance.

5 marks

1. Write a short note on role of essential nutrients in plant growth.
2. What is Biological Nitrogen fixation? Explain its role in Nitrogen cycle.
3. Write in detail various factors that can affect rate of photosynthesis.

10 Marks

1. Define Photosynthesis. Describe its complete process and why it is necessary for us?