7 Plant Growth and Mineral Nutrition

Can you recall?

1. Do you think that the growth is property of living beings only?
2. Is there any difference between plant growth and animal growth?

Growth in plants and animals

Feature	Plant	Animal
Where growth occurs	Mainly at shoot and root tips and in special growth zones like buds	New cells can be made by most tissues
How growth occurs	Size increase often caused by increasing the size of cells by absorbing water into the vacuole	Size increase is brought about by increasing the number of cells
Cell specialisation	Most plant cells can differentiate into different cell types	Only stem cells can differentiate into different cell types. Other animal cell functions remain fixed.

Plant Growth :

- Growth is one of the characteristic features of living organisms.
- Growth as a phenomenon has two aspects viz.
  quantitative and
  qualitative.

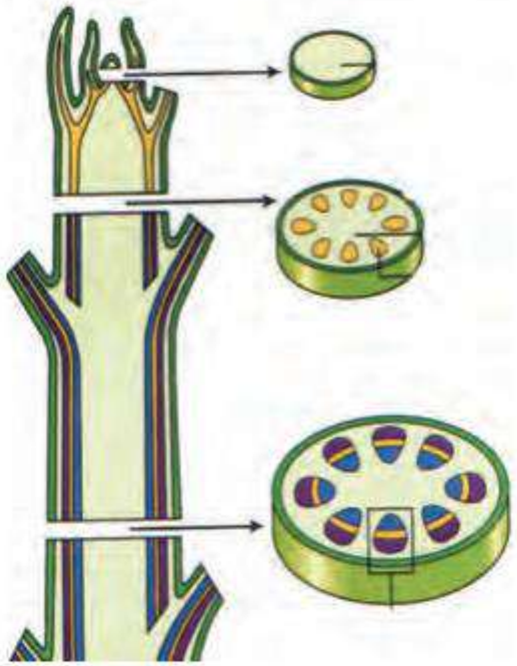
Quantitative aspect :

- speaks for an increase in the length, breadth, size, volume, body mass or dry weight and number of cells.
- Growth as a quantitative change is a final end product of successful metabolism.

Qualitative aspect :

- talks about the change in the nature of growth where development is an ordered change or progress while differentiation leads to higher and more complex state.
- Growth thus can be defined as permanent, irreversible increase in the bulk of an organism, accompanied by the change of form.

- In multicellular (vascular) plants, growth is indeterminate and occurs throughout the **life indefinitely.**
- It is restricted to some specific regions called meristems which are the regions where new cells are constantly and continuously produced.
- Meristems are of three types based on location viz. **Apical, Intercalary and Lateral.**

Figure	Location	Function
	**Apical meristem :** At the tip of the root and stem	Increases the length of the root and stem.
	Intercalary meristem : At the base of the petiole of leaves and of branches.	Growth of branches, formation of leaves and flowers.
	Lateral meristem : Lateral sides of root and stem	Increases girth (diameter) of the root and stem.

Phases Plant Growth :

The cells in the meristem divide, enlarge and get differentiated. Corresponding to these three stages, there are three phases of growth :

A. Phase of cell division/ formation :

- Cells of meristem are thin walled, non-vacuolated having prominent nucleus and granular cytoplasm.
- Meristematic (particularly cambial) cell undergoes mitotic division to form two new cells.
- One cell remains meristematic and the other cell undergoes enlargement and differentiation.
- In this phase, rate of growth occurs at a slower pace (Lag phase).

B. Phase of cell enlargement/ elongation :

- The newly formed cell becomes vacuolated, osmotically active and turgid due to absorption of water.
- The turgidity results in the enlargement of cell - both lengthwise and breadthwise.
- In this phase new wall materials and other materials are synthesized to cope up with the enlargement.
- The growth rate in this phase occurs at an accelerated pace (exponential or Log phase)

C. Phase of Cell maturation/ differentiation :

- The enlarged cell now becomes specialized to perform specific function and attains maturity - both morphological and physiological.
- In this phase, rate of growth slows down and comes to a steady state (stationary phase).

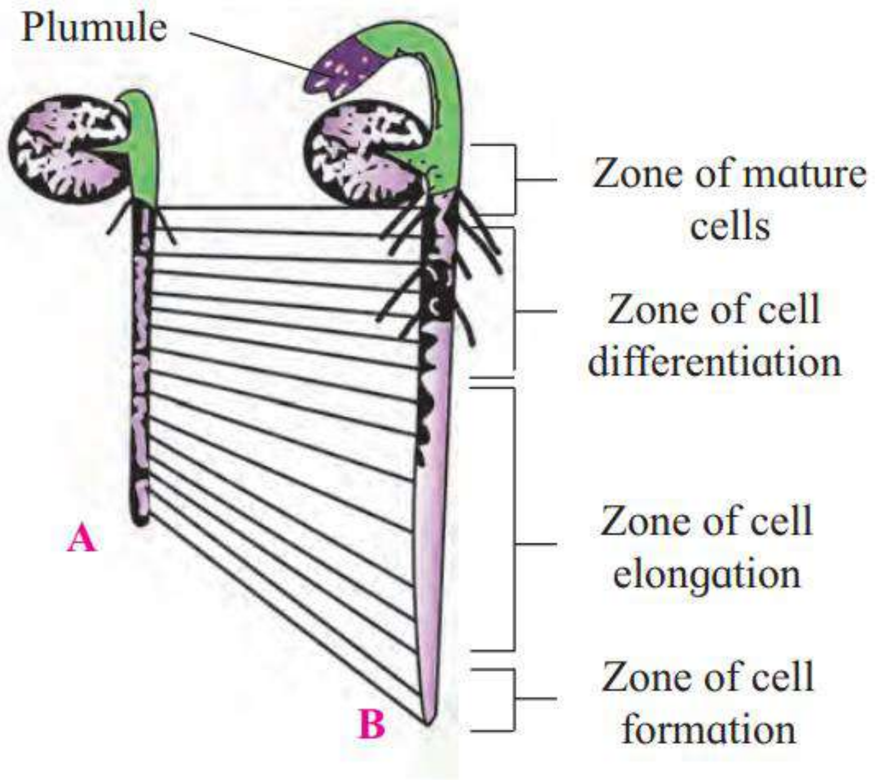


Fig. 7.1 Phases of growth in root - Position of radicle at the begining (A) and at the end (B)

Conditions for Growth :

The different environmental and physiological conditions necessary for the growth include –

- ✓ **Water,**
- ✓ **supply of nutrients,**
- ✓ **temperature,**
- ✓ **oxygen,**
- ✓ **Carbon/ Nitrogen ratio,**
- ✓ **gravitational force,**
- ✓ **light and growth hormones.**

Water :

- is the essential component of protoplasm and maintains turgidity of the cell. It acts as aqueous medium for biochemical reactions.

Nutrients :

- Microelements and Macro elements are nutrients required for the proper growth of the plant.

Temperature :

- Optimum Temperature ranges between 25-350 C.

Oxygen :

- is essential for respiration and the release of energy.

Light :

- is very much essential for germination of seed and photosynthesis.

Gravitational force :

- decides the direction of growth of the shoot and root.

Growth in plants can be measured in terms of....

1. Increase in the number of cells produced - e.g. single maize root apical mesistem can give rise to more than 17,500 new cells/Hour.
2. Increase in surface area of the leaf - e.g. growth of dorsiventral leaf.
3. Increase in length - e.g. growth of pollen tube.
4. Increase in volume of a fruit - e.g. In watermelon flower, the ovary after fertilization increases in its size/ volume by upto 3,50,000 times.
5. Increase in girth of shoot.
6. Increase in dry weight of organ.

Growth Rate and types of growth :

Growth rate :

- ✓ It is the increased growth per unit time. It is also called efficiency index.
- ✓ Rate of growth can be measured by an increase in the size and area of different plant organs like leaf, flower and fruits.
- ✓ The ratio of change in the cell number (dn) over the time interval (dt) is called Absolute growth rate (AGR). Alternatively, it is the measurement and comparison of total growth per unit time.

$$AGR = \frac{dn}{dt}$$

- The AGR, when divided by total number of cells present in the medium, gives Relative growth ratio (RGR).
- Alternatively, RGR refers to the growth of a particular system per unit time, expressed on a common basis or it is the ratio of growth in the given time/ initial growth.

$$RGR = \frac{AGR}{n}$$

Types of growth :

There are two types of growth viz,

- **Arithmetic growth and**
- **Geometric growth.**

a. Arithmetic growth :

- **Here, rate of the growth is constant and an increase in the growth occurs in arithmetic progression. i.e. 2, 4, 6, 8 cms etc.**
- **In this type of growth, the rate of growth is constant.**
- **After mitosis one of the daughter cell continues to divide and the other cell takes part in the differentiation and maturation.**
- **e.g. elongation of root at a constant rate, best explains arithmetic growth.**

It is expressed as,

$$\mathbf{Lt = Lo + rt}$$

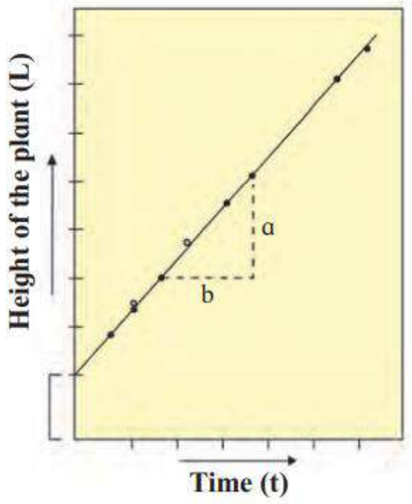
Where **Lt** = Length at time 't'

Lo = Length at time 'Zero'

r = Growth rate

t = Time of growth

When graph of length (L) is plotted against the time (t), a linear curve is obtained as indicated in the diagram.



Graph 7.2 : Constant linear growth

b. Geometric growth :

- Cell divides mitotically into two.
- Here, both the daughter cells continue to divide and redivide repeatedly.
- Such growth is called geometric growth.
- Here, growth rate is slow initially but later on there is a rapid growth at exponential rate.
- Geometric growth can be expressed mathematically by an equation.

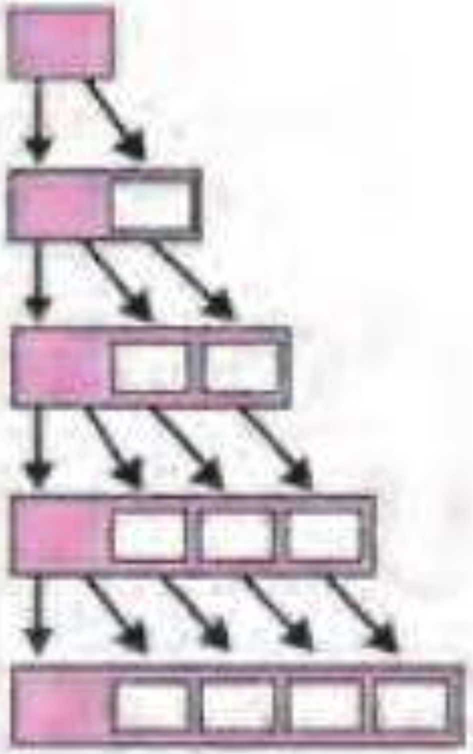
$$W_1 = W_0 e^{rt}$$

W_1 = Final size , W_0 = initial size

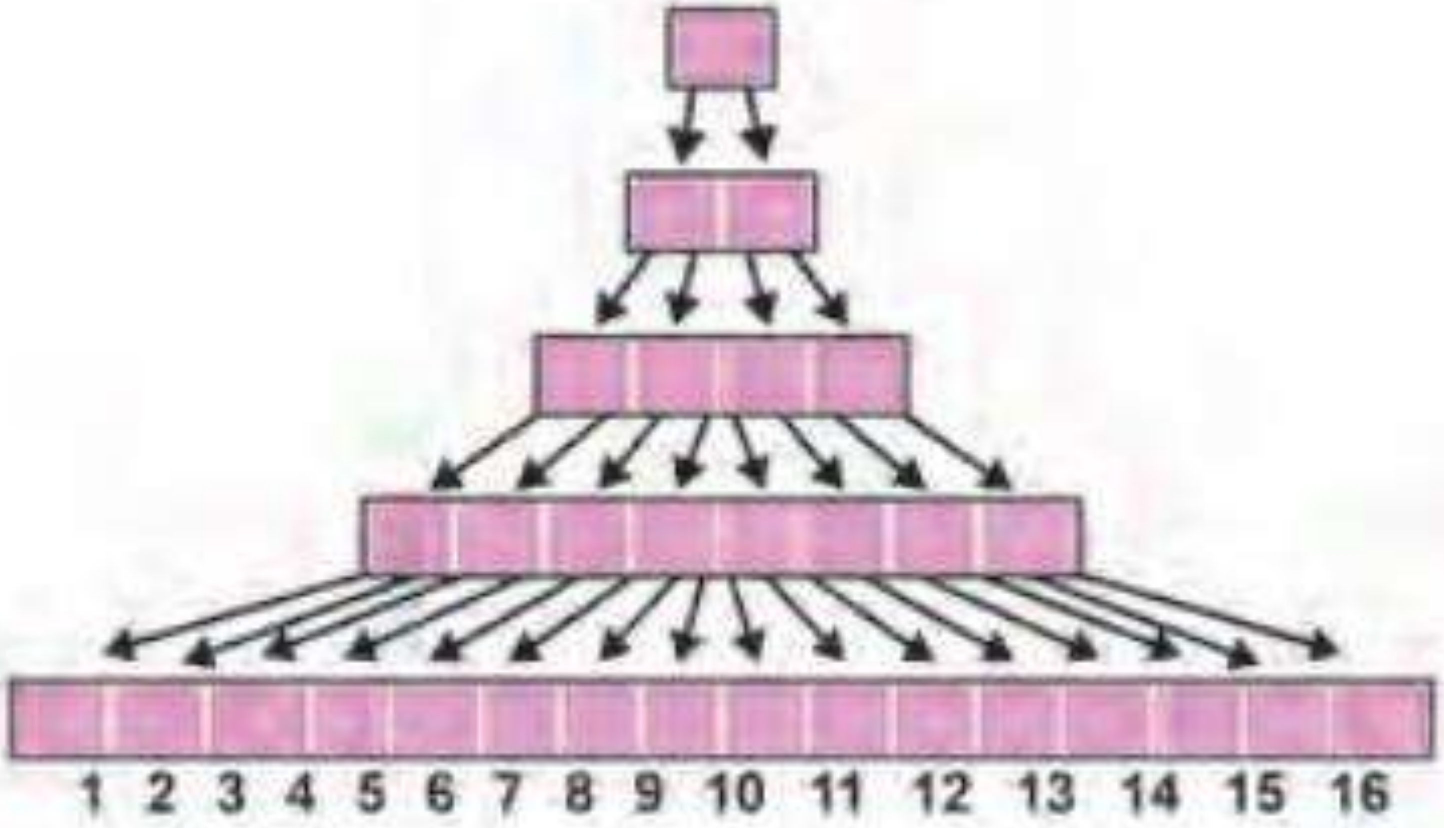
r = growth rate, t = time of growth

e = base of natural logarithm

a. Arithmetic



b. Geometric



Growth rate comparison

- We can also observe quantitative comparison between the growth of living system in two ways.
- Measurement and comparisons of total growth per unit time is called the **Absolute growth rate(AGR) .**
- whereas the growth of the given system per unit time expressed on a common basis per unit initial parameter is called the **Relative growth rate(RGR).**

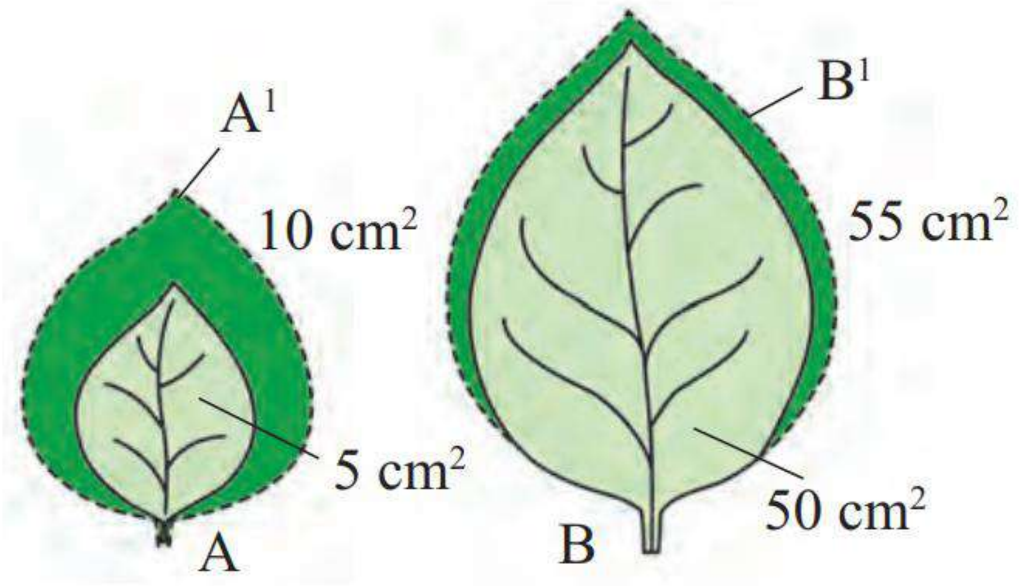


Fig. 7.4 : Growth rate comparison

Growth curve :

"It is a graphic representation of the total growth against time."

There are three types of curves viz,

- **Linear,**
- **Exponential and**
- **Sigmoid.**

Arithmetic growth curve is linear while Geometric growth curve is exponential.

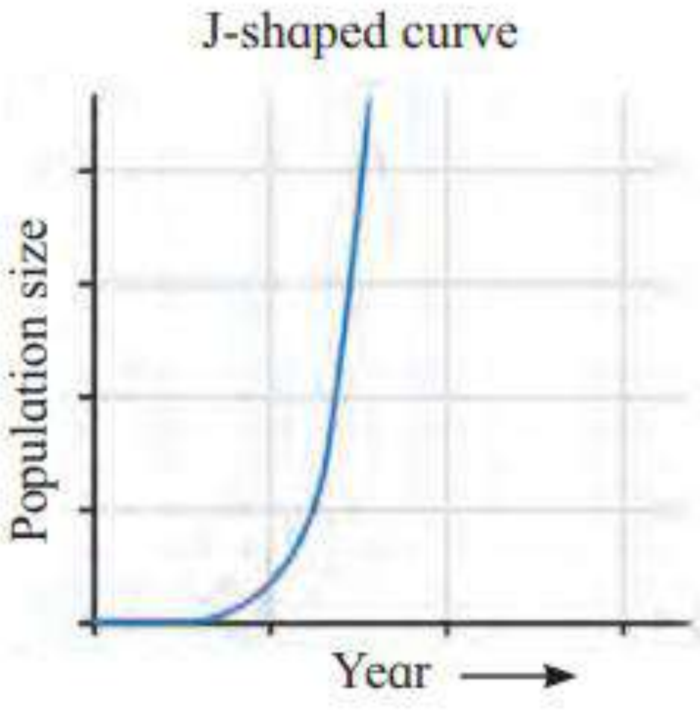
- **Corresponding to three distinct phases of growth, growth rates differ.**

✓ **In Lag phase, growth rate is slow.**

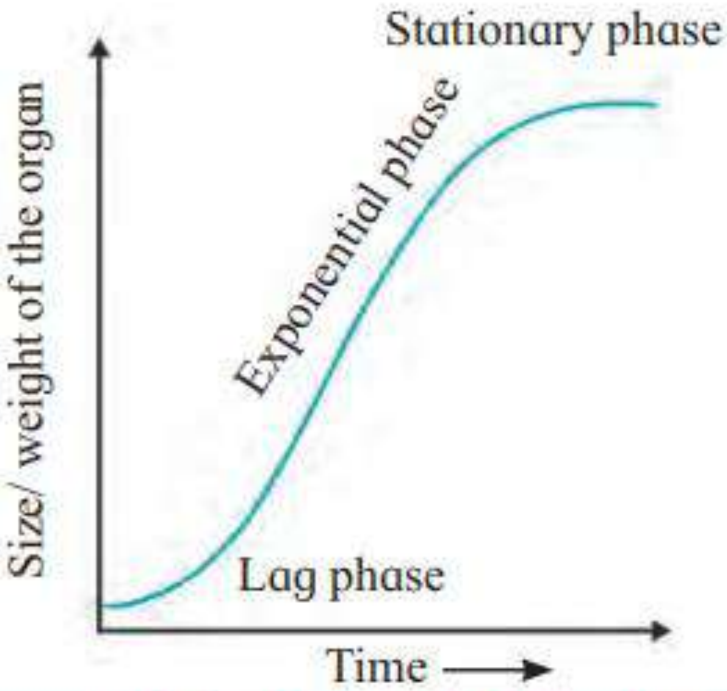
✓ **In Exponential (Log) phase, growth rate is faster and reaches its maximum.**

✓ **In Stationary phase, growth rate gradually slows down.**

When a graph of rate of growth against time is plotted for three phases of growth, a 's' shaped i.e. sigmoid curve is obtained.



Graph 7.5 : Exponential Growth curve



Graph 7.6 : Sigmoid Growth curve

Differentiation, De-Differentiation, Re-Differentiation :

a. Differentiation :

- It is maturation of cells derived from apical meristem of root and shoot. Permanent change in structure and function of cells leading to maturation, is called differentiation.
- During cell differentiation, cell undergoes few to major anatomical and physiological changes.
- e.g. Parenchyma in hydrophytes develops large schizogenous interspaces for mechanical support, buoyancy and aeration.

b. De-Differentiation :

- The living differentiated cell which has lost the capacity to divide, may regain the same as per the need and divide.
- Thus, permanent (mature) cell undergoes dedifferentiation and becomes meristematic
- e.g. interfascicular cambium and cork cambium are formed from parenchyma cells between vascular bundles and inner most layer of cortex, respectively.

c. Re-Differentiation :

- The cells produced by dedifferentiation once again lose the capacity to divide and mature to perform specific function.
- This is called redifferentiation
- e.g. secondary xylem and secondary phloem are formed from dedifferentiated cambium present in the vascular bundle.

Development :

- It refers to the ordered or progressive changes in shape, form and degree of complexity.
- It includes all the changes occurring in sequence from the germination of seed upto the senescence or death during life cycle of plants.
- Thus development includes growth, morphogenesis, maturation and senescence.

Fig. 7.7 Flow chart of development

Plasticity :

- ✓ It is the capacity of being moulded, formed or modeled.
- ✓ It is the ability of plants to form different kinds of structures (i.e. to change) in response to different environmental (external) or internal stimuli, in various phases of life.

In many plants,

- juvenile stage and
- mature stage

- show different forms of leaves in the same plant
- e.g. heterophylly in cotton, coriander, larkspur (Delphinium).
- The environmental heterophylly is shown by Ranunculus flabellasis (butter cup).
- The intrinsic plasticity is found in coriander and cotton.

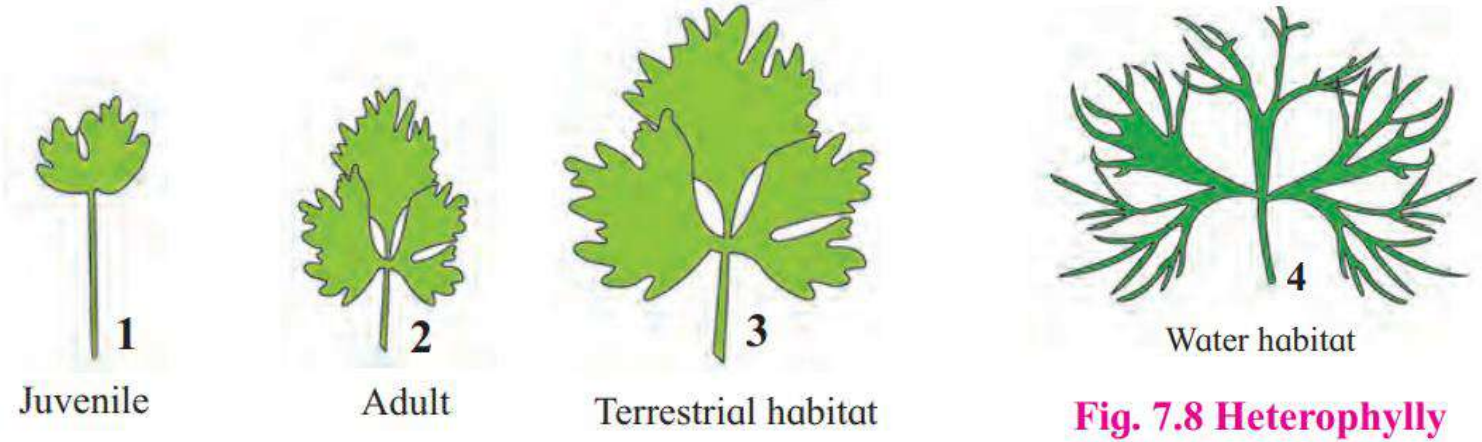


Fig. 7.8 Heterophylly

Growth Hormones :

The term 'hormone' was coined first by Starling (1906) in animal physiology.

- The internal factors that influence growth are called growth hormones or growth regulators as they inhibit, promote or modify the growth.
- Growth promoters
  - are auxins,
  - gibberellins (GA) and
  - cytokinins (CK).
- Growth inhibitors
  - in plants are ethylene and abscissic acid (ABA).
- All phytohormones are growth regulators

a. Auxins (Auxien = to grow):

- Auxin was isolated from urine of a person suffering from Pellagra (Kogl and H. Smit 1931).
- In plants, it is synthesized in growing tips or meristematic regions of plants from where it is transported to other plant parts.
- The most common and important natural auxin is Indole-3-acetic acid (IAA).
- It is the first hormone to be discovered in plants and is primarily responsible for cell elongation.
- Now synthetic auxins like IBA (Indole butyric acid), NAA (Naphthalene acetic acid), 2, 4-D (Dichloro Phenoxy acetic acid), etc. are used

Physiological effects and applications of auxin:

- The primary effect is cell enlargment.
- In most of the higher plants, growing apical bud inhibits the growth of lateral buds.
- This is called as apical dominance.
- Auxin stimulates growth of stem and root.
- Auxin induces multiplication of cells, hence used in tissue culture experiments to produce callus.
- It stimulates formation of lateral and adventitious roots.
- These are marketed as synthyetic herbicides. e.g. 2, 4-D (2,4 dichlorophenoxy acetic acid).
- It kills dicot weeds without affecting monocot crop plants.

b. Gibberellins :

- ✓ It is another growth promoting hormone and is abundant in root tip and developing seeds.
- ✓ It shows non-polar transport through vascular tissue.
- ✓ Gibberellins were first isolated from the fungus Gibberella fujikuroi by a Japanese scientist Kurosawa (1926).
- ✓ He observed that when rice plant was infected by fungus Gibberella fujikuroi, it shows extensive stem elongation called'bakane disease'.
- ✓ The crystalline form of Gibberellins were isolated by Yabuta and Sumiki (1938) from the fungus culture.
- ✓ They named it as gibberellin.
- ✓ It is synthesized in young leaves, seeds, roots and stem tips.
- ✓ These are synthesized from mevalonic acid.
- ✓ More than 150 chemical types are known so far.
- ✓ GA3 (= Gibberellic acid) is most common and biologically active form.
- ✓ Chemically it contains a gibbeane ring- a cyclic diterpene with four isoprene units.

Physiological effects and application of Gibberellins :

- Dormancy of bud can be broken by gibberellin treatment.
- It can promote seed germination in cereals like barley and wheat by synthesizing hydrolysing enzyme amylase to produce sugar.
- The most striking effect of it, is the elongation of stem where internodes increase in length and converting genotypic dwarf to phenotypic tall plant.
- It also promotes bolting
- i.e. elongation of internodes just prior to flowering in plants those with rosette habit e.g. beet, cabbage.

c. Cytokinin :

- It is another growth hormone that promotes cytokinins during cell division.
- Letham coined the term cytokinin.
- The first cytokinin was discovered by Skoog and Miller (1954) during investigation of nutritional requirements of callus tissue culture of Nicotiana tabacum (Tobacco).
- They observed that the callus proliferated when the nutrient medium was supplemented with coconut milk and degraded sample of DNA (obtained from herring sperm).
- They named it as kinetin.
- Chemically kinins are 6-furfuryl amino purine.
- First natural cytokinin was obtained from unripe maize grains by Letham et al.
- It is known as Zeatin.
- 6-benzyl adenine is a synthetic cytokinin hormone.
- Seven different types of cytokinins are recorded from plants.
- Natural cytokinins are also reported from plants like Banana flowers, apple and tomato fruits, coconut milk, etc.

Physiological effects and applications of cytokinin :

- Besides cell division, it also promotes cell enlargment. High cytokinin promotes shooting.
- A low ratio of cytokinin to auxin induces root development but a high ratio causes buds and shoot to develop.
- Cytokinin and auxin ratio and their interactions controls morphogenic differentiation.
- It promotes the growth of lateral buds and controls apical dominance by cell division.
- It delays the senescence or ageing and abscission processes in plant organs.

d. Ethylene :

- It is the only gaseous growth regulator.
- Denny (1924) reported ethylene is effective in fruit ripening.
- Gane (1934) established that plants naturally synthesize ethylene.
- Crocker (1930) proposed that ethylene is the plant hormone responsible for fruit ripening.
- It is a simple gaseous hydrocarbon with essential role in the fruit ripening.
- The most widely used compound as a source of ethylene is ethephon.
- It is synthesized in roots, shoot apical meristem, ripening fruits etc.

Physiological effects and application of ethylene :

- ➢ It promotes ripening of fruits like bananas, apples and mangoes.
- ➢ It stimulates initiation of lateral roots in plants and breaks the dormancy of bud and seed.
- ➢ It accelerates the abscission activity in leaves, flowers and fruits by forming of abscission layer.
- ➢ Ethylene inhibits the growth of lateral buds and causes apical dominance and retards flowering.

e. Abscissic Acid :

- It is a natural growth inhibiting hormone.
- Carns and Addicott (1961-65) observed that the shedding of cotton balls was due to a chemical substance abscisin I and II.
- Wareing (1963) isolated a substance from buds of Acer that can induce bud dormancy and named it dormin.
- These two identical chemical substances were given the common name abscissic acid.
- It is synthesized in leaves, fruits, roots, seeds etc.
- Chemically, it is a 15-carbon sesquiterpenoid and is synthsized from mevalonic acid.

Physiological effects and application of ABA:

- ✓ It promotes abscission of leaves and induces dormancy in many plants.
- ✓ It controls the dormancy in buds and seeds by inhibiting growth processes.
- ✓ It accelerates the senescence of leaves, flowers and fruits.
- ✓ It inhibits and delays cell division and cell elongation and suppresses cambium activity by inhibiting mitosis in vascular cambium.
- ✓ ABA could cause efflux of k+ ions from the guard cells and result in closure of stomata.
- ✓ So, it is known as an antitranspirant.

Photoperiodism :

- Higher plants reproduce sexually by producing special structures called flowers.
- Plants exhibit transition from vegetative growth to reproductive growth during which flowers are produced.
- Like vegetative growth, reproductive growth is also influenced by several environmental and nutritional factors.
- Among the environmental factors - light and temperature exert profound influence on flowering.
- The influence of duration of light is known as Photoperiodism and that of temperature, is Vernalization.

- Light as an environmental factor influences germination of seed, vegetative growth, photosynthesis, etc. Light as a factor has three aspects viz,
  - ✓ Quality,
  - ✓ Intensity and
  - ✓ Duration of light.

It is the duration of light that has profound effect on flowering in higher plants.

<u>Based on the photoperiodic response, plants were classified in three categories viz,</u>

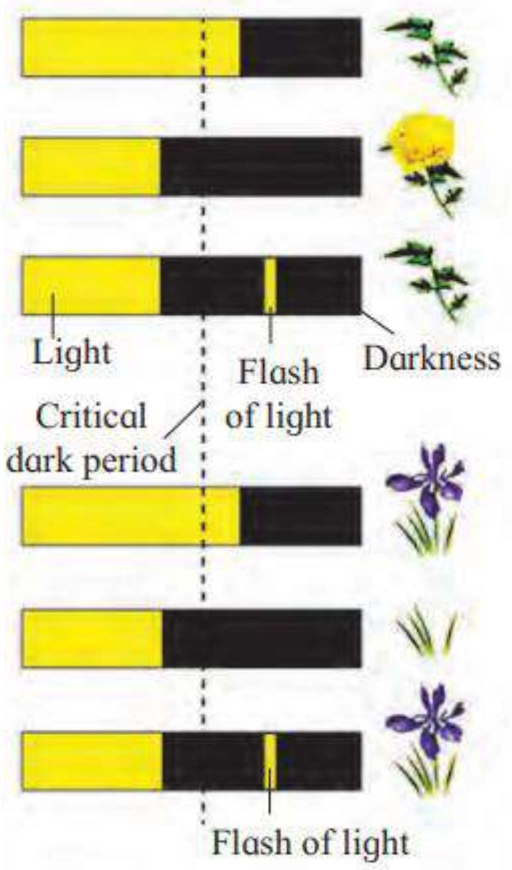
- **Short Day Plants (SDP),**
- **Long Day Plants (LDP) and**
- **Day Neutral Plants (DNP).**

a. Short Day Plants (SDP) :

- ✓ **These plants usually flower during winter and late summer when day length is shorter than the critical photoperiod (critical photoperiod is that length of photoperiod above or below which flowering occurs).**
- ✓ **These are called long night plants because they require long uninterrupted dark period/ night for flowering.**
- ✓ **If dark period is interrupted even by a flash of light, SDP will not flower.**
- ✓ **Some of the short day plants are Dahlia, Aster, Tobacco, Chrysanthemum, Soybean (Glycine max), Cocklebur (Xanthium), etc.**

b. Long Day Plants (LDP) :

- ✓ Plants that flower usually during summer are called long day plants.
- ✓ They require longer duration of light than the critical photoperiod, for flowering.
- ✓ They are called short night plants as they require short dark period.
- ✓ When long dark period is interrupted by a brief flash of light, LD plants can flower e.g. pea, radish, sugar beat, cabbage, spinach, wheat, poppy, etc.



a. Requires a relatively long uninterrupted darkness.

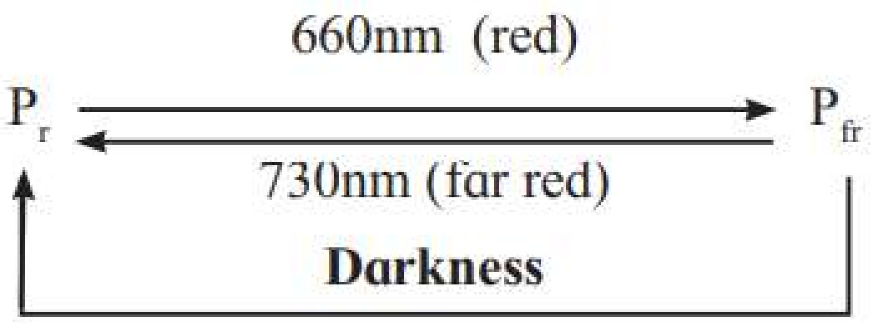
b. Requires a relatively small duration of darkness/ no darkness at all.

c. Day Neutral Plants (DNP) :

- These plants flower throughout the year round, independent of duration of light (photoperiod).
- They do not require specific photoperiod to flower.
- Therefore, they are called Day neutral plants e.g. Cucumber, tomato, cotton, sunflower, maize, balsam, etc.

Phytochrome :

- Hendricks and Borthwick (1952) observed that flowering in SD plants is inhibited, if dark period is interrupted even by a flash of red light of 660 nm.
- If it is immidiately followed by far red light (730 nm), then SD plants will flower.
- This observation led them to conclude that some pigment system in plant receives the photoperiodic stimulus.
- These pigment proteins are called phytochromes.
- The leaves posses light-receiving proteinaceous pigment called phytochrome that induces flowering.
- It exists in two interconvertible forms viz, red (Pr) and far red (Pfr). When Pfr absorbs far red light, it is converted into Pr and vice versa.
- These are located in the cell membrane of green cells.

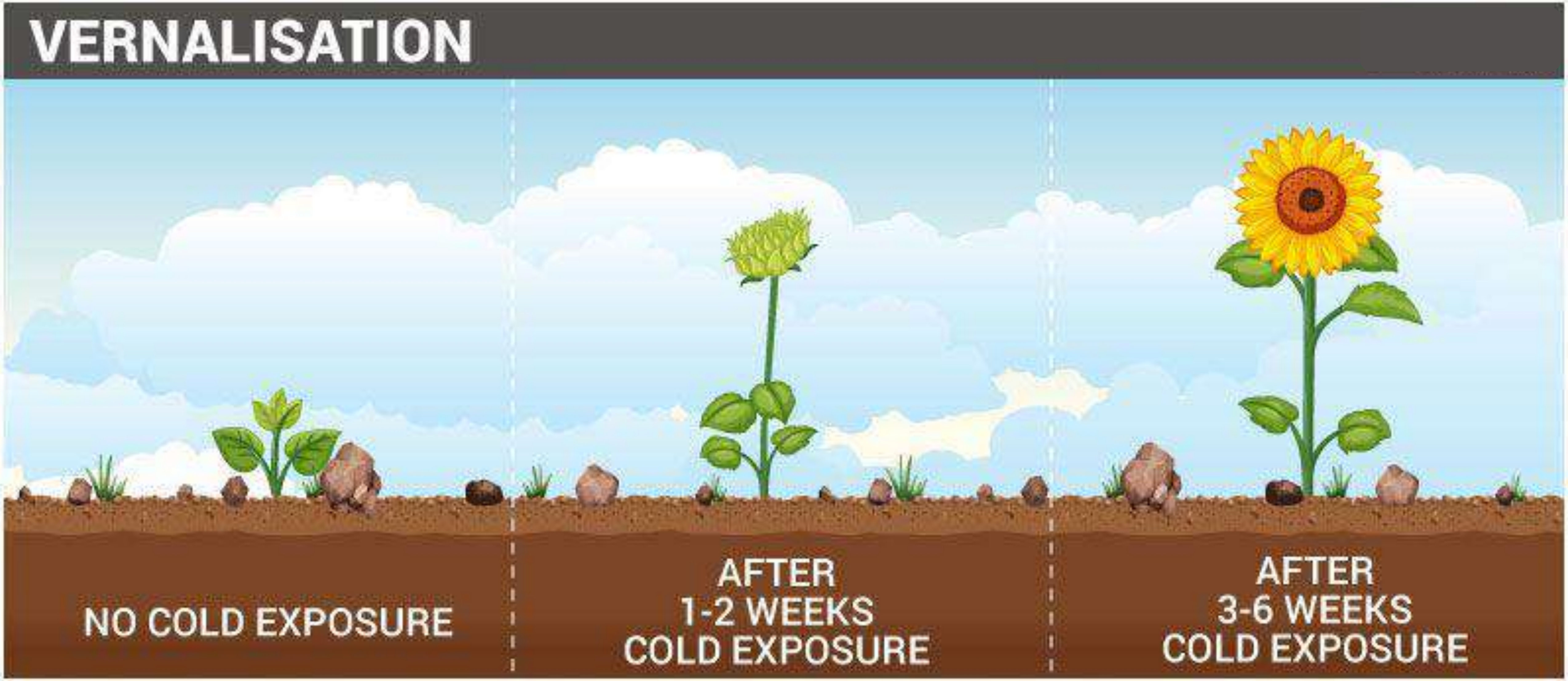


Vernalization (Yarovization) :

- **Temperature as environmental factor influences several physiological processes including reproduction.**
- **Temperature as a factor has three cardinal points viz, minimum, optimum and maximum temperature.**
- **It is an influence of temperature on development and flowering.**
- **Many plants such as cereals, crucifers require a period of cold treatment for flowering.**
- **It is the method of inducing early flowering in the plants by pretreatment to their seeds/ seedlings at low temperature (1-60 C for one to one and half months' duration).**
- **The site of vernalization is believed to be shoot apical meristem.**

Advantages of vernalization :

- Crop plants by shortening juvenile phase attains early flowering.
- Crops can be cultivated in regions where they do not grow naturally.


VERNALISATION
NO COLD EXPOSURE
AFTER
1-2 WEEKS
COLD EXPOSURE
AFTER
3-6 WEEKS
COLD EXPOSURE

Mineral nutrition :

- ✓Plant absorbs water, gases, minerals and nutrients, from surroundings.
- ✓Green plants for the synthesis of their organic food need inorganic substances (elements) which are obtained from soil in the form of minerals.
- ✓ Minerals constitute most commonly occuring solid, inorganic materials obtained from the earth's crust.
- ✓ Chemical analysis of plant ash clearly indicates that plant absorbs mineral elements from surroundings (soil, air and water) for its use.
- ✓ About 36 to 40 different elements of periodic table are used as minerals by the plants.
- ✓ These are absorbed in ionic (dissolved) form as PO4 , CO3 , SO4 , etc.,usually through roots (regions of elongation and growth).

Sources of minerals :

- Plants derive necessary elements from the atmosphere, soil and water.
- Carbon enters the plant as atmospheric carbon-dioxide.
- Source of hydrogen is water and oxygen comes from air and water.
- Carbon, Hydrogen and oxygen are not minerals in origin.
- Source of nitrogen is the soil.
- Plant derives nitrogen from both mineral and non-mineral origin

Classificaion of minerals :

Earlier, on the basis of their requirement minerals were classified as

- essential and
- non-essential.

Essential minerals

- ✓ are those that are indispensible without which plants can not complete their life cycle e.g. C, H, O, N, P, etc.
- ✓ These elements play structural and physiological roles.
- ✓ Their absence can produce/ cause major deficiency symptoms.

The nonessential

- ✓ elements are not indispensable and they do not produce/ cause any deficiency symptoms.
- ✓ This classification is absolete now.

❖ **Based on the quantity requirement, minerals are classified as**

- minor or microelements and
- major or macroelements.

Microelements

✓ are required in traces because they function in the catalytic role e.g. Zn, Cu, Al, Si, Mn, B, Mo, Cl etc.as co-factors.

Macroelements

✓ are required in large quantity.

✓ They mainly play the nutritive and structural roles e.g. C, H, O, P, Mg, N, K, S, Ca and Fe. C, H, O are non mineral major elements.

✓ This classification is not accepted now.

Symptoms of Mineral deficiency in plants :

- **Stunting :** The growth is retarded. The stem appears condensed and short.
- **Chlorosis :** It is the loss or non-development of chlorophyll resulting in the yellowing of leaves
- **Necrosis :** It is the localized death of tissue of leaves.
- **Mottling :** Appearance of green and non-green patches on the leaves.
- **Abscission :** Premature fall of flowers, fruits and leaves.

Table : 7.10 Roles of Mineral Elements in Plants

Element	Region of plant in which required	Functions	Deficiency symptom
Nitrogen NO^-_2 or NO^-_3 or NH^+_4	Everywhere particularly in meristematic tissues	Constituent of proteins, nucleic acids, vitamins, hormones, coenzymes, ATP, chlorophyll.	Stunted growth, chlorosis.
Phosporus $H_2PO^-_4$ or HPO^{2-}_4	Younger tissues, obtains from older, metabolically less active cells	Constituent of cell membrane, certain proteins, all nucleic acids and nucleotides required for all phosphorylation reactions.	Poor growth, leaves dull green.
Potassium K^+	Meristematic tissues, buds, leaves, root tips	Helps in determining anion- cation balance in cells involved in protein synthesis, involved in formation of cell memberane and in opening and closing of stomta; increases hardness; activates enzymes and helps in maintenance of turgidity of cells.	Yellow edges to leaves, premature death.
Calcium Ca^{2+}	Meristematic and differentiating tissues, accumulates in older leaves	Involved in selective permeability of cell membranes, activates certain enzymes required for development of stem and root apex and as calcium pectate in the middle lamella of the cell wall.	stunted growth.

Minerals salt absorption :

- Most minerals in the soil are charged particles hence, they can not pass across cell membrane.
- Hence most of the minerals are absorbed actively with the expenditure energy.
- Minerals can also be absorbed passively without expenditure of energy.
- Mineral ion absorption is independent of water absorption.

a. Passive Absorption :

✓ Movement of mineral ions into the root occurs by diffusion.

✓ Molecules or ions diffuse from a region of their higher concentration to a region of their lower concentration.

✓ The movement of mineral ions into root cells as a result of diffusion is without expenditure of energy is called passive absorption.

✓ Passive absorption can take place by direct ion-exchange, in direct ion-exchange mass flow and Donnan equilibrium.

a. Active Absorption :

- Uptake of mineral ions against concentration gradient, is called active absorption, such movement requires an expenditure of energy by the absorbing cell.
- This energy is derived from respiration and is supplied through ATP.
- When the roots are deprived of oxygen, they show a sudden drop in active absorption of minerals.
- The mineral ions accumulated in the root hair pass into the cortex and finally reach the xylem.

Nitrogen cycle:

7.13 Nitrogen cycle:

It is series of natural processes by which Nitrogen enters successively from air to organisms through soil and back to environment. Plants use photosynthetic product, the sugars to make proteins. To do this, they need nitrogen. Unfortunately, it is very innert (nonreactive). Plants badly need nitrogen in a reactive form usually as nitrate ions.

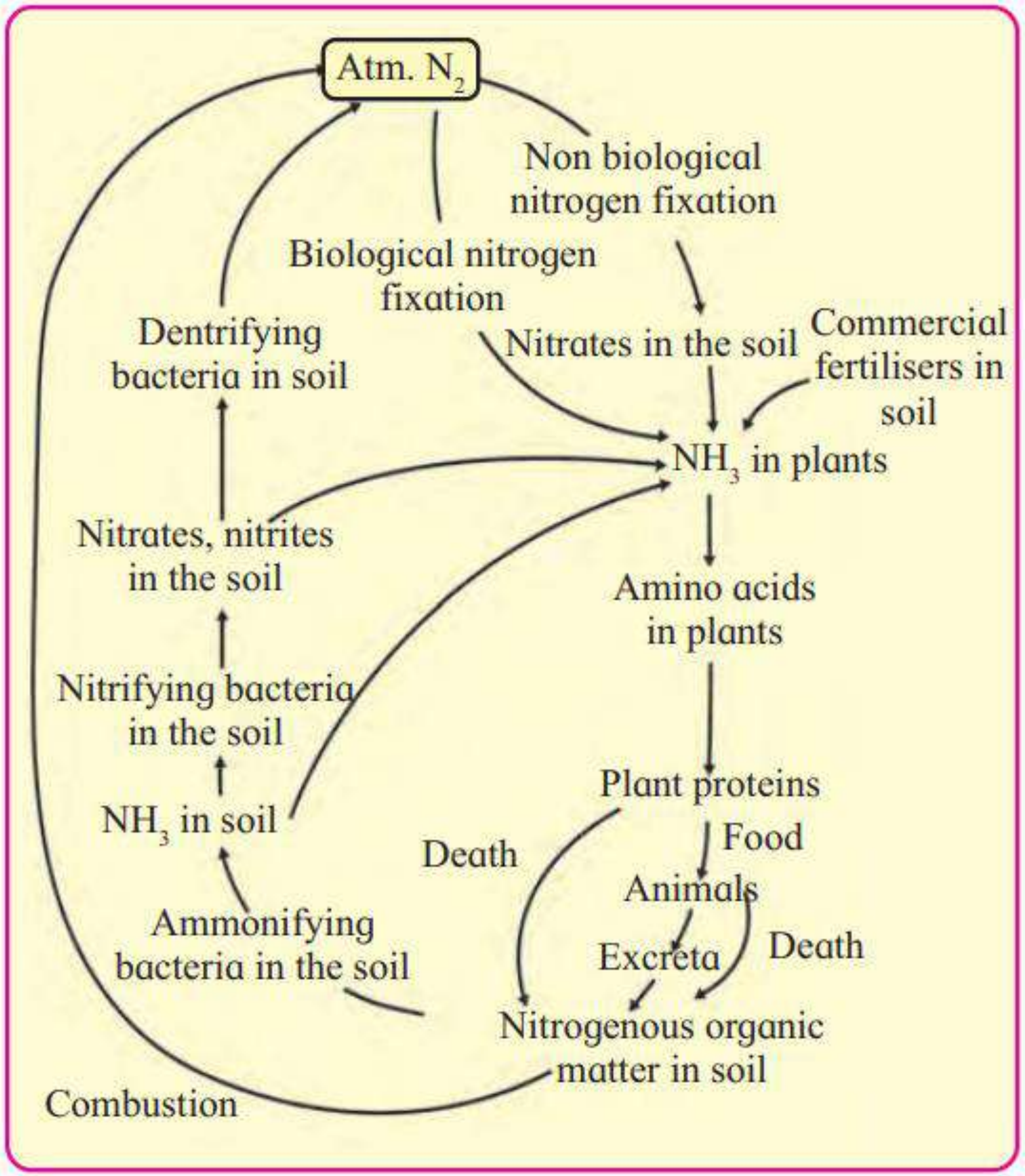


Fig. 7.11 Nitrogen cycle

Nitrogen fixation :

Atmosphere is the source of nitrogen. It can not be used directly. It combines with C, H, N and O to form compounds before being used. Conversion of free nitrogen (N_2) of the atmosphere into nitrogenous salts to make it available for the plants, is called nitrogen fixation. It is of two types : Physical and Biological fixation.

Physical Nitrogen fixation: It occurs in several steps and starts with combination of atmospheric nitrogen with oxygen under the influence of electric discharge and thunder storm produce nitric oxide.

$$\underset{\text{Nitrogen oxygen}}{N_2 + O_2} \xrightarrow[\text{Thunder storm}]{\text{Electric discharge}} \underset{\text{Nitric oxide}}{2\,NO}$$

The nitric oxide is then oxidized to nitrogen peroxide in the presence of oxygen.

$$2NO + O_2 \xrightarrow{\text{Oxidation}} \underset{\text{Nitrogen peroxide}}{2NO_2}$$

During rains, the nitrogen peroxide combines with rain water to form nitrous acid and nitric acid which come to ground along with rains.

$$2NO_2 + \text{Rain water} \longrightarrow \underset{\text{Nitrous Acid}}{HNO_2} + \underset{\text{Nitric Acid}}{HNO_3}$$

On ground, the alkali radicals of soil react with nitric acid to produce nitrites and nitrates.(absorbable form)

$$HNO_3 + \text{Ca or K salts} \longrightarrow \text{Ca or K nitrates}$$

Industrial nitrogen fixation : It occurs by Haber-Bosch nitrate process at high temperature and pressure.

$$N_2 + 3H_2 \xrightarrow[\text{200 atm}]{450^0c} \underset{\text{Ammonia}}{2NH_3}$$

Ammonia is then converted to urea as it is less toxic.

Biological Nitrogen fixation : It is carried out by prokaryotes called as 'Nitrogen fixers' or Diazotrophs'. It accounts nearly 70% of natural nitrogen fixation. Nitrogen fixers are either **symbiotic** or **free living**. The cyanobacteria fix significant amount of nitrogen in specialized cells called **heterocysts**.

Nitrogen fixation is high energy requiring process (endothermic reaction) and nitrogen fixers use 16 molecules of ATP to fix each molecule of nitrogen to form ammonia.

$$N_2 + 8H^+ + 8e^- + 16ATP \longrightarrow 2NH_3 + H_2 + 16ADP + 16Pi$$

Ammonia is then converted into amino acids.

Nitrification :

Nitrification is exothermic reaction. Most of the soil bacteria participate in converting ammonia into nitrate, the form of nitrogen which can be used by plants and animals. This involves two steps performed by two different types of bacteria.

First a soil bacteria convert ammonia into nitrogen-di-oxide (nitrite) eg. *Nitrosomonas*, *Nitrosococcus,* etc.

$$2NH_3 + 3O_2 \xrightarrow[\textit{Nitrosococcus}]{\textit{Nitrosomonas}} 2HNO_2 + 2\,H_2O$$

Then another type of soil bacterium called *Nitrobacter* adds a third oxygen atoms to create nitrate.

$$2HNO_2 + O_2 \xrightarrow{\textit{Nitrobacter}} 2HNO_3$$

Symbiotic N_2 fixation :

The best known nitrogen fixing symbiotic bacterium is *Rhizobium*. This soil living/ dwelling bacterium forms root nodules in plants belonging to family Fabaceae e.g. beans, gram, groundnut etc.

Ammonification :

After the death of plants and animals, various fungi, actinomycetes and some ammonifying bacteria decompose the tissues and convert organic nitrogen into amino acid and then to ammonia and back into the ecosystem. Ammonia (NH_4^+) is now available for uptake by plants and other micro-organisms for growth.

$$\text{Proteins} \xrightarrow[\text{decomposition}]{\text{Microbial}} \text{amino acids}$$

$$\text{Amino acids} \longrightarrow \underset{\text{Ammonia}}{NH_3} + \underset{\text{organic acid}}{ROH}$$

Nitrogen assimilation :

In soil, nitrogen is present as nitrates, nitrites and ammonia (NH_4^+). It is obsorbed by the green plants and converted to nitrogenous organic compounds like amino acids, DNA, etc. This is known as nitrogen assimilation. From plants, nitrogen as biomolecules like amino acids, enters food chain and moves to animals and then to decomposers through the death of animals.

Nitrates are first converted to ammonia but it is highly toxic and immediately used for conversion into amino acids, which are then transported to other parts of the plants for synthesis of proteins.

$$NO_3^- + 2e^- + 2H^+ \longrightarrow NO_2^- + H_2O$$

$$NO_2^- + 8e- + 8H+ \longrightarrow NH_4^+ + 2H_2O$$

Transamination : Amino group of one amino acid (-$CHNH_2$) is transfered to keto position (-CO) of other carboxylic acid.

$$\text{Glutamic acid} + \text{oxaloacetic acid} \xrightarrow[\text{Aminotransferase}]{\text{Glutamate aspertate}} \alpha\text{ - Ketoglutaric acid} + \text{Aspartic acid}$$

Amides :

Ammonia may be absorbed by amino acid to produce amides. The process is called **amidation**. The amides are the amino acids having two amino groups. Extra amino group is attached to acidic group (-COOH) in presence of ATP.

$$\text{Glutamic acid} + NH_4^+ + \text{ATP} \longrightarrow \text{alpha glutamine} + \text{ADP}$$

$$\text{Aspartic acid} + NH_4^+ + \text{ATP} \longrightarrow \text{Aspargine} + \text{ADP}$$

Denitrification :

It is the process in which anaerobic bacteria can convert soil nitrates back into nitrogen gas. Denitrifying bacteria removes fixed nitrogen i.e. nitrates from the ecosystem and return it to the atmosphere in inert form.

Denitrifying bacteria includes *Bacillus spp.*, *Paracoccus spp.* and *Pseudomonas denitrificans*. They transform nitrates to nitrous and nitric oxides and ultimately to gaseous nitrogen.

$$2NO_3 \longrightarrow 2NO_2 \longrightarrow 2NO \longrightarrow N_2$$

Sedimentation : Nitrates of the soil are washed away to the sea or leached deep into the earth along with percolating water.

THANK YOU