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?

7.1 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 successive 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.

Do you know ?

Root and stem show indefinite or indeterminate growth. However, in organs like leaves, flowers and fruits, growth is determinate. i.e. they grow up to certain genetically destined size. In unicellular plants, growth is uniform and determinate.

Do you know ?

Apical meristem : In vascular plants, growth is restricted to the apices of root and shoot. It is responsible for growth in length/ height and the differentiation or cell types. It contributes to the primary growth.

Intercalary meristem : It is located at the node or at the base of internode of stem. It is primarily responsible for increasing length of internodes and also for formation of leaf primordia and lateral buds.

Lateral meristem : It is located laterally along the axis of dicotyledons and gymnosperms. It is located as strip in the vascular bundles of stem of dicots. It is called vascular cambium. It is responsible for increase in the girth of the stem due to addition of secondary vascular tissues.

7.2 Phases of 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 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 fuction and attains maturity - both morphological and physiological. In this phase, rate of growth slows down and comes to a steady state (stationary phase).

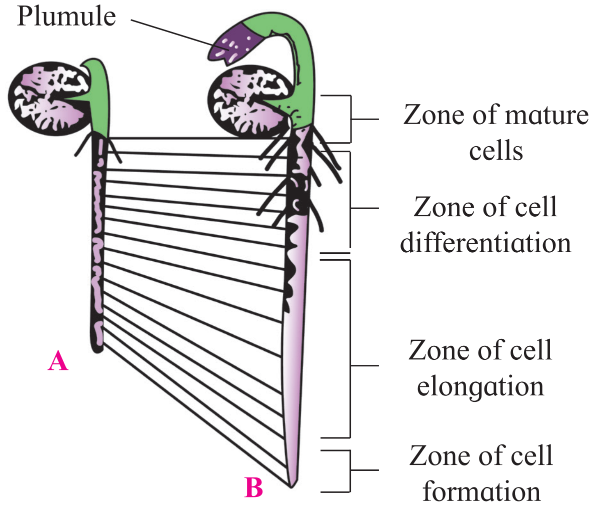


Fig. 7.1 Phases of growth in root - Position of radicle at the begining (A) and at the end (B)

7.3 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. The chief conditions are explained below :

Water is the essential component of protoplasm and maintains turgidity of the cell. It acts as aqueous medium for biochemical reactions. Microelements and Macroelements are **nutrients** required for the proper growth of the plant. Optimum **Temperature** ranges between 25-35^{0}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.

7.4 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.

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, 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.

Various methods for the measurement of linear growth of stem and radicle are as follows:

1. **Direct method :** It can easily be measured with the help of ordinary measuring scale. It is a simple method.
2. **Horizontal microscope :** It is used to measure growth in fields.
3. **Auxanometer :** This equipment is used for precise measurement of linear growth of shoot. There are two types of an auxanometers viz, a) Arc auxanometer b) Pfeffer's auxanometer
4. **Crescograph :** It records primary growth very accurately. It magnifies growth upto 10,000 times giving information of growth per second. It is developed by sir J. C. Bose.

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

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.

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

AGR and RGR are useful in describing the dynamics of cell growth in culture.

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. Linear curve is obtained when growth rate is plotted against the time. Arithmetic growth is expressed mathematically by an equation,

It is expressed as,

$$Lt = Lo + rt$$

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

Lo = Length at time 'Zero'

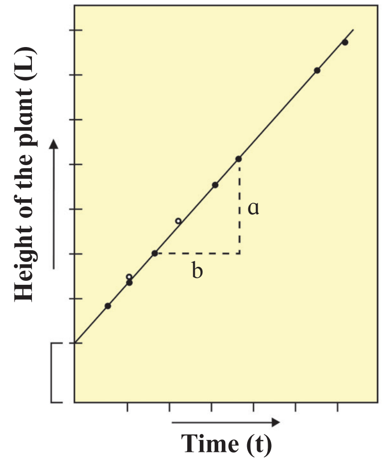
r = Growth rate

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.

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.



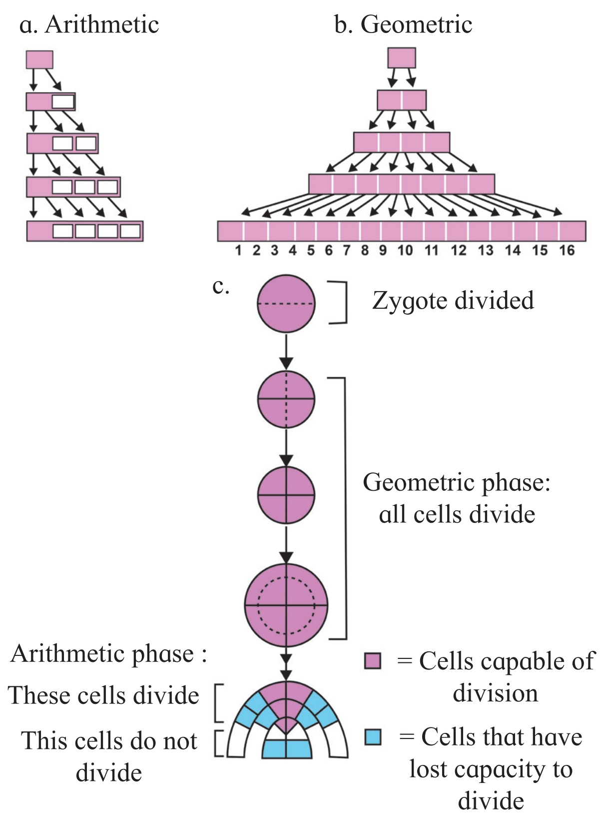
Graph 7.2 : Constant linear growth

$$W_1 = W_o\ e^{rt}$$

W_1 = Final size , W_o = initial size

r = growth rate, **t** = time of growth

e = base of natural logarithm



Digrammatic representation of : **a.** Arithmetic, **b.** Geometric grwoth and **c.** Stages during embryo development showing geometric and arithmetic phases

Fig. 7.3 : Growth rate

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)**.

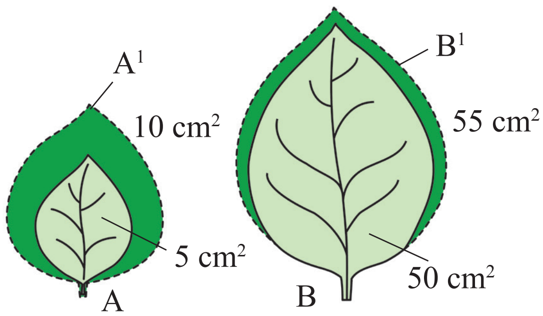


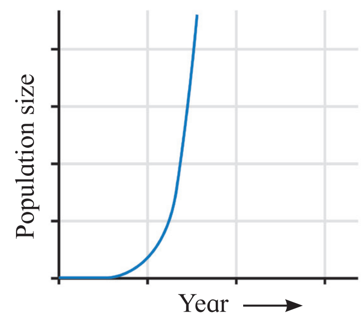
Fig. 7.4 : Growth rate comparison

In the above example, two leaves 'A' and 'B' are of different sizes but show same absolute increase in area in a given time. Both leaves grow and increase their area by 5cm^2 to produce 'A' and 'B' leaves. 'A' leaf of 5cm^2 in size grows 5cm^2/ day then its RGR would be 100%. If the leaf is 50cm^2 in size and the growth rate/day is 5cm^2 then its RGR would become 10%.

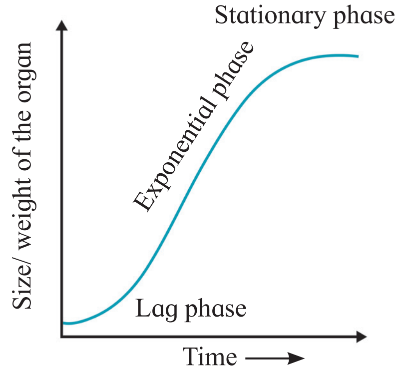
7.5 Growth curve :

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 sigmoid curve is obtained.



Graph 7.5 : Exponential Growth curve



Graph 7.6 : Sigmoid Growth curve

The total time (period) required for all phases to occur, is called **Grand Period of Growth**.

7.6 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. The maturation is at the cost of capacity to divide and redivide.

b. Dedifferentiation :

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. Redifferentiation :

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.

7.7 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.

Seed germination
↓
Meristem
↓
Cell division
↓
Plasmatic growth
↓
Cell elongation
↓
Cell maturation
↓
Mature cell
↓
Senescence
↓
Death

Fig. 7.7 Flow chart of development

7.8 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. Heterophylly is exhibited in the same plant in different growth phases or under different environmental conditions.

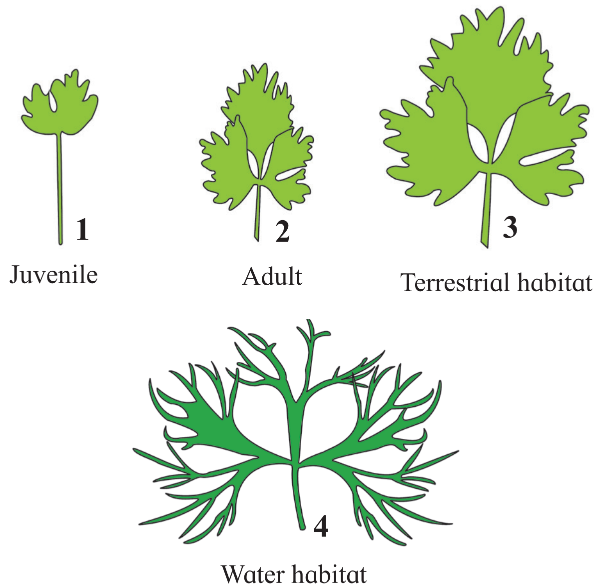


Fig. 7.8 Heterophylly

Can you tell?

1. Is there any relation between phases of growth and regions of growth curve?
2. Which plant organ does show both arithmetic and geometric growth?
3. Differences between arithmetic and geometric growth.

7.9 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.

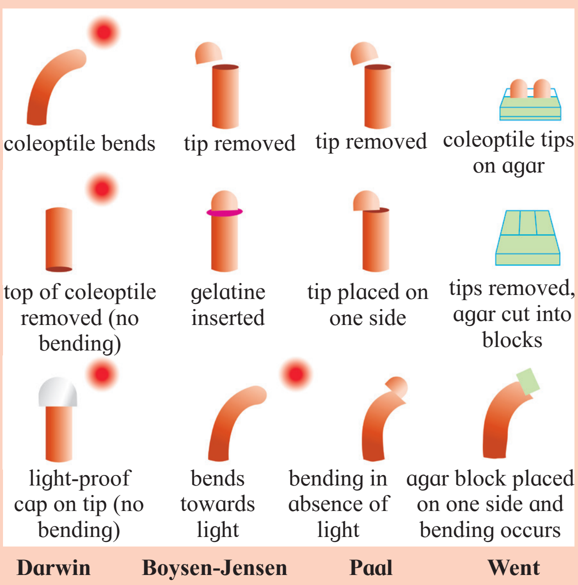
Know the Scientist :

The auxin is the first hormone to be discovered in plants. Discovery of auxins dates back to 19th century when **Charles Darwin** (1886) was studying tropism in plants. He exposed canary grass coleoptile to unilateral light. He concluded that a growth stimulus is developed in the coleoptile tip and transmitted downwards to the growth zone. This has caused bending of the tip towards light.

The Danish plant physiologist Boysen - Jensen (1910) cut off the colepotile and inserted thin plate of gelatin beween the tip and the cut stump. He observed that coleoptile tip still bends towards unilateral light.

Paal (1919) cut off the tip of colepotile and replaced it asymmetrically on the cut coleoptile stump. He observed that the colepotile tip bent away from the side bearing tip even in dark.

F.W. Went (1928) successfully isolated natural auxin from *Avena* coleoptile tips. He cut off the tip and placed them on small agar blocks. Then after certain period of time placed the agar blocks asymmetrically on cut coleoptile stump that caused bending. He demonstrated the presence of substance which could diffuse into agar blocks. Went named this substance as **auxin**.



According to **Thimann** and **Pincus** (1948) "Plant hormones are organic substances produced naturally in higher plants affecting growth or other physiological functions at a site remote from its place of production and active in very minute (optimum) amount". Hormones are transported through phloem parenchyma (Phillips 1971).

a. Auxins (Auxien = to grow):

F. W. Went in 1931, used this term first. 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). Tryptophan is the primary precursor of IAA in plants. It is the first hormone to be discovered in plants and is primarily responsible for cell elongation. It shows polar transport - Basipetal transport in stem. 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.

The seedless fruits like orange, lemon, grapes, banana etc. are produced by application of auxin (i.e. induced parthenocarpy). Auxins promote cell division in cambium and also cause early differentiation of xylem and phloem. It promotes root elongation in low concentration and shooting at higher concentration. It also hastens early rooting in propagation by '**cutting**'.

Foliar spray of NAA and 2,4-D induces flowering in litchi and pineapple. Likewise, it prevents premature fruit drop in apples, pear and oranges, and also prevents formation of abscission layer. Auxins play a role in elongation of cell. It is known to increase rate of respiration. Auxins break dormancy in seed and promote quick germination.

Do you know ?

Agent orange : Mixture of two phenoxy herbicides in ester form. 2, 4-D and 2,4, 5-T (dioxin) is known as agent orange used in Vietnam war for defoliation of forests.

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 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. It also promotes bolting i.e. elongation of internodes just prior to flowering in plants those with rosette habit e.g. beet, cabbage. It causes parthenocarpy in tomato, apple and pear, and flowering in long day plants. It is used to increase the fruit size and bunch length of grapes. When gibberellins are applied on genetically dwarf plants like maize, the stem rapidly elongates and acquires the height of normal tall varities of maize. Application of gibberellins overcomes the requirement of vernalization. Usually, it inhibits growth of root, delays senescence and prevents abscission. It also breaks dormancy of seed and hastens germination. Application of gibberellin causes production of male flowers on female plant.

c. Cytokinin :

It is another growth hormone that promotes 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. This was reported by Richmond and Lang (1957). Formation of interfasicular cambium and expansion of cells are other functions. It also breaks dormancy and promotes the germination of seeds. Cytokinin reverses apical dominance effect. It induces RNA synthesis and formation of interfascicular cambium.

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.

Do you know ?

Ethret / Ethephon is a 2-chloroethyl Phosphoric acid, which releases ethylene after dissolving in water.

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. It is associated with the enhancement of process of senescence of plants organs. It inhibits flowering in most of the plants except pineapple. It causes **epinasty** (drooping) of leaves and flowers. It increases activity of chlorophyllase enzyme causing degreening effect in banana and *Citrus* fruits.

Internet my friend

Degreening: It is the process of decomposition of green pigment in fruits usually by applying ethylene. This method is called trickle degreening. Collect more information about degreening.

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**. It acts as a stress hormone by inducing the plant to bear the adverse environmental conditions. It inhibits flowering in long day plants but stimulates flowering in short day plants.

Do you know ?

Bioassays for :
Auxins - *Avena* curvature test.
Gibberellins - Alpha amylase bioassay.
Cytokinins - Chlorophyll retention test.
Ethylene - Tripple pea test.
ABA - Inhibition of alpha amylase test.

Internet my friend

Collect information of synthetic plant hormones.

Can you tell?

1. Why is auxin called a growth regulator?
2. Effect of Gibberellin application on apple.
3. How can we overcome apical dominance?
4. Which is standard bioassay method for auxins?
5. ABA is called as stress hormone. Why?

7.10 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 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.

The term **photoperiodism** was used by Garner and Allard (1920). They were studying the flowering behaviour in plants - Soyabean and Meryland mamoth variety of tobacco. They found that soyabean plant flowers during late summer and tobacco variety during winter, irrespective of their germination and growing season. They studied effects of different temperatures, nutrition, soil moisture, etc. in respect of flowering. None of these were found to regulate flowering. However, experimentally they found that the exposure to specific duration of light (i.e. photoperiod) had profound influence on flowering. They examined the effect of day length on flowering by using artificial illumination. They concluded that the relative length of the day was most crucial in the growth and development of flowers to which they coined the term **photoperiodism**. Based on the photoperiodic response, plants were classified in three categories viz, **Short Day Plants (SDP), Long Day Plants (LDP) and Day Neutral Plants (DNP).**

Do you know ?

Organs for reception of photoperiodic stimulus - Leaf is the chief organ for receiving the photoperiodic stimulus as demonstrated by Knoff (1934). Defoliated plants will not flower even if the plants are exposed to proper duration of light.

Photoperiodic stimulus - It is a chemical stimulus transported through phloem and is called **florigen** which is hormonal in nature.

Photochemical receptors in the leaves are the biloproteins (pigments) located in the cell membrane. These are called **Phytochromes**.

Blue wavelengths of light influences flowering.

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 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.

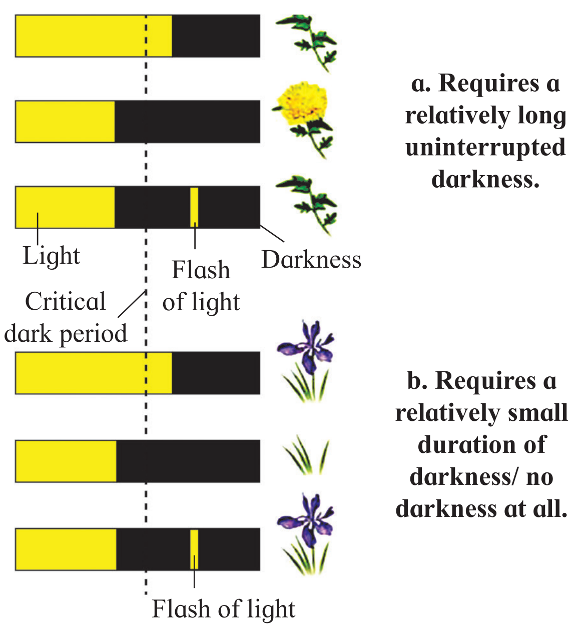


Fig. 7.9 : Photoperiodism

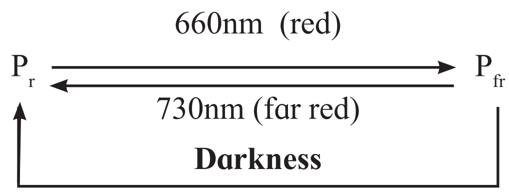
c. Day Neutral Plants (DNP) :

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 produce light-receiving proteinaceous pigment called **phytochrome** that induces flowering. It exists in two interconvertible forms viz, red (P_r) and far red (P_{fr}). When P_{fr} absorbs far red light, it is converted into P_r and vice versa. These are located in the cell membrane of green cells.



During day time, P_{fr} accumulates in the plants. It inhibits flowering in SDP but initiates flowering in LDP. During dark period P_{fr} changes into P_r, it stimulates/ promotes flowering in SDP and inhibits flowering in LDP.

Always Remember

Control of morphogenesis by light and phytochrome, is called photomorphogenesis.

Internet my friend

Melchers proposed that chilling treatment may induce formation of hypothetical floral hormone, vernalin.

7.11 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 a low temperature (chilling) treatment that induces early flowering in plants as was evidenced by Klippart (1918). Chouard (1960) defines vernalization as accelaration of the ability to flower by chilling treatment. The term **vernalization** was coined by T.D Lysenko (1928) for the effect of low temperature on flowering in plants.

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 (1-6^{0}C for one to one and half months' duration). The site of vernalization is believed to be shoot apical meristem. Generally, vernalization is effective at seed stage in annual plants. Vernalization stimulus is also a chemical stimulus named as **vernalin**. This can be transferred through grafting (Melcher 1939).

Know the Scientist :

The low temperature induces early flowering which was first noticed by **Klippart** (1957) while working on two varieties of wheat- 'winter wheat' and 'spring wheat'. The winter wheat sown in winter, produces flowers in the following summer. The spring wheat sown in the spring and produces flowers during summer. However, if winnter variety is sown in spring does not produce flowers during summer but does so in the next year's summer. He observed that if germinated seeds of 'winter wheat' are treated with low temperature, it can behave as spring wheat. He concluded that winter wheat requires low - temperature exposure before the onset of flowering.

The reversion of vernalization by high temperature treatment is called **devernalization**.

Advantages of vernalization :

- Crops can be produced earlier.
- Crops can be cultivated in regions where they do not grow naturally.

7.12 Mineral nutrition :

Plant absorbs water, gases, mineral, nutrients, etc. 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 PO_4, CO_3, SO_4, 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 non-essential 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, 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, etc. C, H, O are non mineral major elements. This classification is not accepted now.

Know the Scientist :

Criteria for Essentiality of elements proposed by Arnon and Stout (1939) : The elements must be absolutely necessary for supporting normal growth and reproduction. These elements must be having specific functions and should not be replaceable by another element. The element must be directly involved in the nutrition of the plant. If an element satisfies all above three criteria, it is considered to be an **essential** element.

Do you know ?

Liebig showed the Essentiality of mineral nutrients and put forth the 'Law of minimum'. According to this law, the yield of crop plant is determined by the amount of essential element that is present (available) in the minimum quantity.

Now a days minerals are classified on the basis of their biochemical functions.

Symptoms of Mineral deficiency in plants :

Any visible deviation from the normal structure and function of the plant, is called **symptom** or hunger sign. The concentration of the essential elements below which plant growth is retarded, is termed as **critical concentration**.

The element is said to be deficient when present below the critical concentration. Certain morphological changes are indicative of the deficiency of particular element. Deficiency symptoms also depend on the mobility of the elements in the plants. The deficiency symptoms appear first in young tissues when elements are relatively immobile e.g. sulphur, calcium.

When the elements are actively mobilized within the plants and exported to young developing tissues, the deficiency symptoms are visible first in the older tissues (senescent leaves). e.g. nitrogen, magnesium, potassium.

Some important deficiency symptoms seen in plants are:

- **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.
Magnesium Mg^{2+}	Leaves, withdrawn from ageing leaves and exported to developing seeds	Activates enzymes in phosphate metabolism, constituent of chlorophyll, maintains ribosome structure.	Chlorosis
Sulphur SO_4^{2-}	Stem and root tips; young leaves remobilised during senescence	Constitutent of certain proteins, vitamins (thaimine, biotin CoA) and Ferredoxin.	Chlorosis
Iron Fe^{3+}	Everywhere carries along leaf veins.	Constituents of ferredoxin and cytochrome, activates catalase required for synthesis of chlorophyll.	Chlorosis
Manganese (trace) Mn^{2+}	Leaves and seeds	Activates certain enzymes (carboxylases)	Chlorosis, grey spots on leaves.
Molybdenum (Trace) MoO_2^{2+}	Everywhere, MoO^{3+} particularly in roots	Activates certain enzymes in the nitrogen metabolism.	Slight retardation of growth.
Boron (trace) BO^{3-} or $B_4O_7^{2-}$	Leaves and seeds	Required for uptake and utilisation of Ca^{2+}, pollen germination and cell differentiation, carbohydrate translocation.	Brown heart disease.
Copper (trace) Cu^{2+}	Everywhere	Activates certain enzymes.	Die-back of shoots.
Zinc (trace) Zn^{2+}	Everywhere	Activates various enzymes especially carboxylases, part of carbonic anhydrase and various dehydrogenases needed for auxin synthesis	Malformed leaves.
Chlorine Cl^-	Everywhere	With Na^+ and K^+ helps to determine solute concentration and anion-cation balance in cells, essential for oxygen evolution in photosynthesis.	Poor growth of the plant

Do you know ?

- **Constituents of protoplasm and cell walls :** C,H,O,N,P,S are important and permanent constituents of the protoplasm and the cell wall.
- **Osmotic potential :** The osmotic pressure of cell is the result of mineral salts and organic compounds dissolved in the cell sap.
- **Catalytic functions :** Many elements like Fe, Cu, Zn, Mg, Mn, Cl, etc. act as catalysts in various enzyme reaction of plant metabolism.
- **Permeability of cytoplasmic membrane:** Permeability of membrane is influenced by the presence of the various 'cations' and 'anions' of the mineral elements in the external medium like ca+, k^+.
- **Components of energy related chemical compounds :** Phosphorus in ATP and Mg in chlorophyll.

Do you know ?

The atmospheric CO_2 is virtually the only source of carbon, which is the basic constituent of all the organic compounds.

Internet my friend

- Collect information about hydroponics and find its use in kitchen garden.
- Collect information on Aeroponics.

Toxicity of Micronutrients :

Mineral ion concentration which reduces the dry weight of tissues by 10%, is considered as toxic. Toxicity of one element may inhibit the uptake of the other e.g. Mn competes with Fe, Mg for uptake, but inhibits Ca translocation to shoot apex. Thus, Mn toxicity develops deficiency symptoms of Ca, Mg and Fe.

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.

Mineral ion absorption can occur in two ways :

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.

b. Donnan equilibrium : It is based on the assumption that certain negatively charged ions, after their entry into the cell, become fixed on the inner side of the cell membrane and can not diffuse outside through the cell membrane. Therefore, additional mobile cations are required to balance these fixed anions. Obviously concentration of cations become more due to accumulation. This kind of passive absorption of anions/ cations from cell exterior against their own concentration gradient in order to neutralize the effect of cations/ anions, is called **Donnan equilibrium.**

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.

The minerals in the xylem are then carried along with water to other parts of the plant along the transpiration stream and are subsequently assimilated into organic molecules and then redistributed to other parts of the plant through the phloem.

Do you know ?

To explain active absorption of minerals Hoagland and Davis (1923) put forth **Carrier hypothesis**. Specific proteins in the membrane of root cells actively pump ions into the cytoplasm of epidermal cells of root. These proteins are called carriers that pump both cations and anions from the soil. According to Bennet and Clarke (1956) protein conjugated with lecithin acts as carrier.

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 need nitrogen in a reactive form usually as nitrate ions.

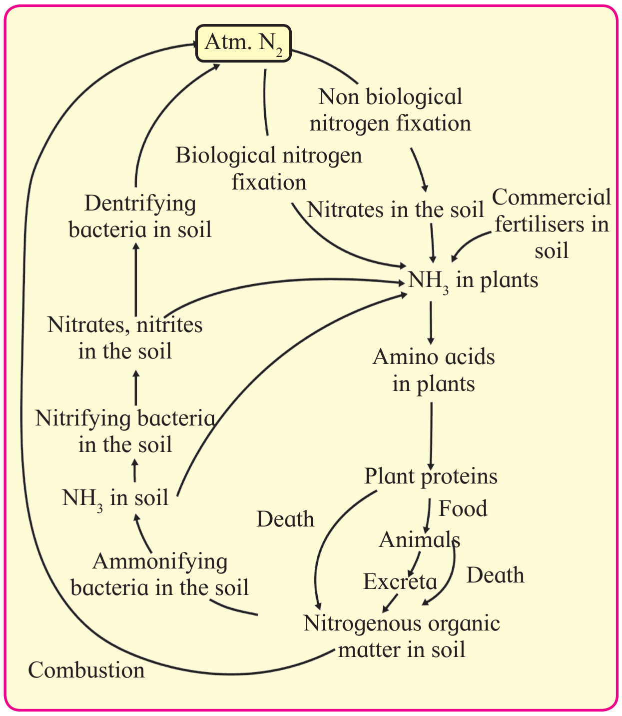


Fig. 7.11 Nitrogen cycle

Nitrogen is a limiting nutrient in the agricultural ecosystems. It exists as nitrogen atoms with a strong triple covalent bond ($N \equiv N$). A regular supply of nitrogen to the plants is maintained through biological and physical process.

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.

Internet my friend

Enlist names of symbiotic and free living nitrogen fixing bacteria.

Always Remember

Today nearly 80% of nitrogen found in human tissues originate from the Haber-Bosch process.

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 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 :

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.

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

These bacteria are chemoautotrophs. By metabolizing nitrogen along with oxygen, they obtain energy to power their own life processes.

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.

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

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

Amino Acid synthesis :

Amino acids are building blocks of proteins. The amino acids are synthesized through :

Reductive amination : Ammonia reacts with alpha ketoglutaric acid to form glutamic acid (glutamate).

α Ketoglutaric acid + NH_4 + $NADPH_2$ $\xrightarrow{\text{Glutamate dehydrogenase}}$ Glutamate + H_2O+ NADP

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

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

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

Aspartic acid + NH_4^++ ATP $\longrightarrow$ Aspargine + ADP

Amides like glutamine and asparagine are formed from glutamic acid and aspartic acid respectively by addition of another amino group to each. Amides are transported to other parts of plants via xylem vessels.

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.

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

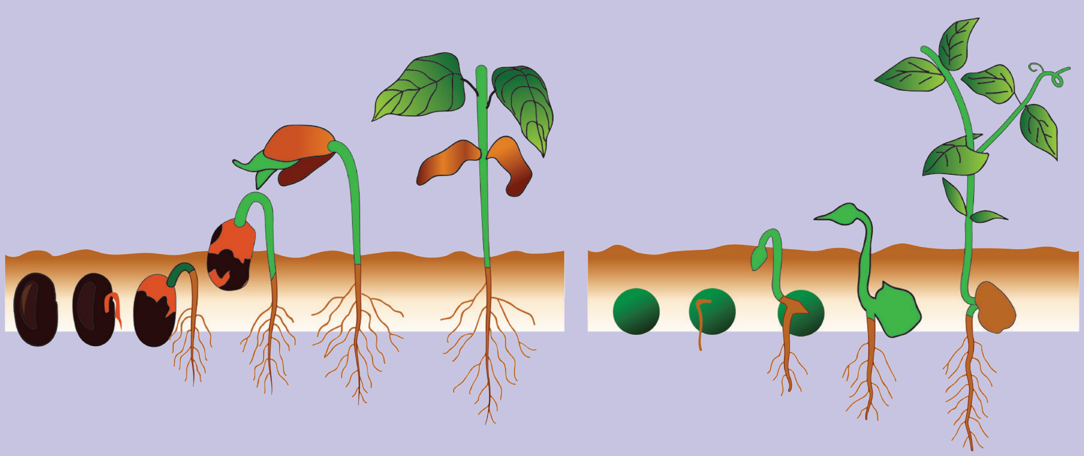
Sedimentation : Nitrates of the soil are washed away to the sea or leached deep into the earth along with percolating water.

Do you know ?

1. Soil nitrogen is replenished by excretion of animals, (as ammonia, urea and uric acid) ammonification and nitrification.
2. Plastids contain nitrite reductase which reduces it to ammonia.

Activity :

Label the following diagrams and identify the types of germination.



Exercise

Q. 1 Multiple choice questions.

1. Which of the hormones can replace vernalization?
   a. Auxin
   b. Cytokinin
   c. Gibberellins
   d. Ethylene

2. The principle pathway of water translocation in angiosperms is ....
   a. Sieve cells
   b. Sieve tube elements
   c. Xylem
   d. Xylem and phloem

3. Abscisic acid controls ....
   a. cell division
   b. leaf fall and dormancy
   c. shoot elongation
   d. cell elongation and wall formation

4. Which is employed for artificial ripening of banana fruits?
   a. Auxin b. Ethylene
   c. Cytokinin d. Gibberellin

5. Which of the following is required for stimulation of flowering in the plants?
   a. Adequate oxygen
   b. Definite photoperiod
   c. Adequate water
   d. Water and minerals

6. For short day plants, the critical period is ....
   a. light b. dark/ night
   c. uv rays d. both a and c

7. Which of the following is day neutral plant?
   a. Tomato
   b. Cotton
   c. Sunflower
   d. Soybean

8. Essential macroelements are ....
   a. manufactured during photosynthesis
   b. produced by enzymes
   c. absorbed from soil
   d. produced by growth hormones

9. Function of Zinc is ....
   a. closing of stomata
   b. biosynthesis of 3-IAA
   c. synthesis of chlorophyll
   d. oxidation of carbohydrates

10. Necrosis means ....
    a. yellow spots on the leaves
    b. death of tissue
    c. darkening of green colour in leaves
    d. wilting of leaves

11. Conversion of nitrates to nitrogen is called ....
    a. ammonification
    b. nitrification
    c. nitrogen fixation
    d. denitrification

12. How many molecules of ATP are required to fix one molecule of nitrogen?
    a. 12 b. 20
    c. 6 d. 16

Q. 2 Very Short Answer Questions :

1. Enlist the phases of growth in plants?
2. Give the full form of IAA?
3. What does it mean by 'open growth'?
4. Which is the plant stress hormone?
5. What is denitrification?
6. Name the bacteria responsible for conversion of nitrite to nitrate.
7. What is role of gibberellin in rosette plants?
8. Define vernalization.
9. Define photoperiodism.
10. What is grand period of growth?

Q. 3 Short Answer Questions :

1. Write a short note on :
   a. Differentiation b. Redifferentiation
2. Differentiate between Arithmetic and Geometric growth.
3. Enlist the role and deficiency symptoms of :
   a. Nitrogen b. Phosphorus c. Potassium
4. What is short day plant? Give any two examples.
5. What is vernalization? Give its significance.

Q. 4 Long Answer Questions :

1. Explain sigmoid growth curve with the help of diagram.
2. Describe the types of plants on the basis of photoperiod required, with the help of suitable examples.
3. Explain biological nitrogen fixation with example.
4. Write on macronutrients and micronutrients required for plant growth.

Project :

1. Grow seed in the deep tray on soil medium and study different stages of germination. Prepare powerpoint presentation with the help of pictures/photographs of the same.
2. Prepare chart differentiating the epigeal and hypogeal germination.
3. Collect the information about the **viviparous germination** in plants growing along seashore.
4. Identify and label the deficiency symptoms in the given diagram.