Basis of Agronomy

Agriculture as art, science and business of crop production

Agriculture

Agriculture

- **Agriculture is derived from two Latin words ager or agri meaning soil and cultura meaning cultivation.**
- Agriculture is an applied science which encompasses all aspects of crop production including horticulture, livestock rearing, fisheries, forestry, etc.
- **Agriculture is defined as an art, science and business of producing crops and livestock for economic purposes**


Agronomy

Agronomy

is derived from a Greek word 'agros' meaning 'field' and 'nomos' meaning 'management'.

Principles of agronomy deal with scientific facts in relations to environment in which crop are produced.

Definition of Agronomy

1. It is defined as an agricultural science deals with principles and practices of crop production and field management.
2. Agronomy is branch of agricultural science, which deals with principles, & practices of soil, water & crop management.
3. It is branch of agricultural science that deals with methods which provide favorable environment to the crop for higher productively,

Agronomy comprises scientific study the physical elements of the climate, soil and land, the biological constituents of the vegetation and soil, the economic opportunities and constraints of markets, sales and profit, and the social circumstances and preferences of those who work the land.

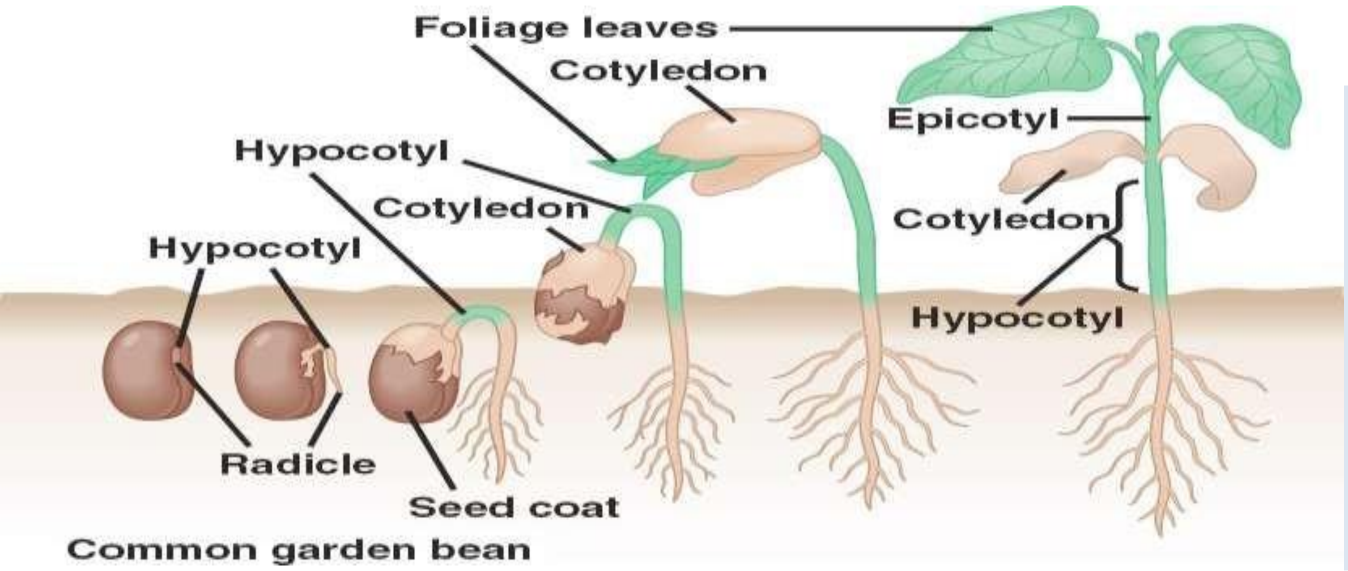
Scope of Agronomy

- **Agronomy is a dynamic discipline with the advancement of knowledge and better understanding of planet, environment and agriculture. Agronomy science becomes imperative in Agriculture in the following areas.**
- Identification of proper season for cultivation of wide range of crops is needed which could be made possible only by Agronomy science.
- Proper methods of cultivation are needed to reduce the cost of cultivation and maximize the yield and economic returns.
- **Availability and application of chemical fertilizers has necessitated the generation of knowledge to reduce the ill-effects due to excess application and yield losses due to the unscientific manner of application.**
- **Availability of herbicides for control of weeds has led to development for a vast knowledge about selectivity, time & method of its application.**

- Water management practices play grater role in present day crisis of water demand
- Intensive cropping is the need of the day and proper time and space intensification not only increase the production but also reduces the environmental hazards.

- **New technology to overcome the effect of moisture stress under dry land condition is explored by Agronomy and future agriculture is depends on dry land agriculture.**
- **Packages of practices to explore full potential of new varieties of crops are the most important aspects in crop production which could be made possible only by Agronomy science.**
- Keeping farm implements in good shape and utilizing efficient manner to nullify the present day labour crisis is further broadening the scope of agronomy.
- Maintaining the ecological balance through efficient management of crops, livestock and their feedings in a rational manner is possible only by knowing agronomic principles.
- **Care and disposal of farm and animal products like milk and eggs and proper maintenance of accounts of all transactions concerning farm business is governing principles of agronomy.**

Plant growth and development



Water, Light and Temperature plays crucial role in plant's growth and development processes

Development is the sum of two processes: growth and differentiation.

During the process of development, a complex body organization is formed that produces roots, leaves, branches, flowers, fruits, and seeds, and eventually they die.

GROWTH

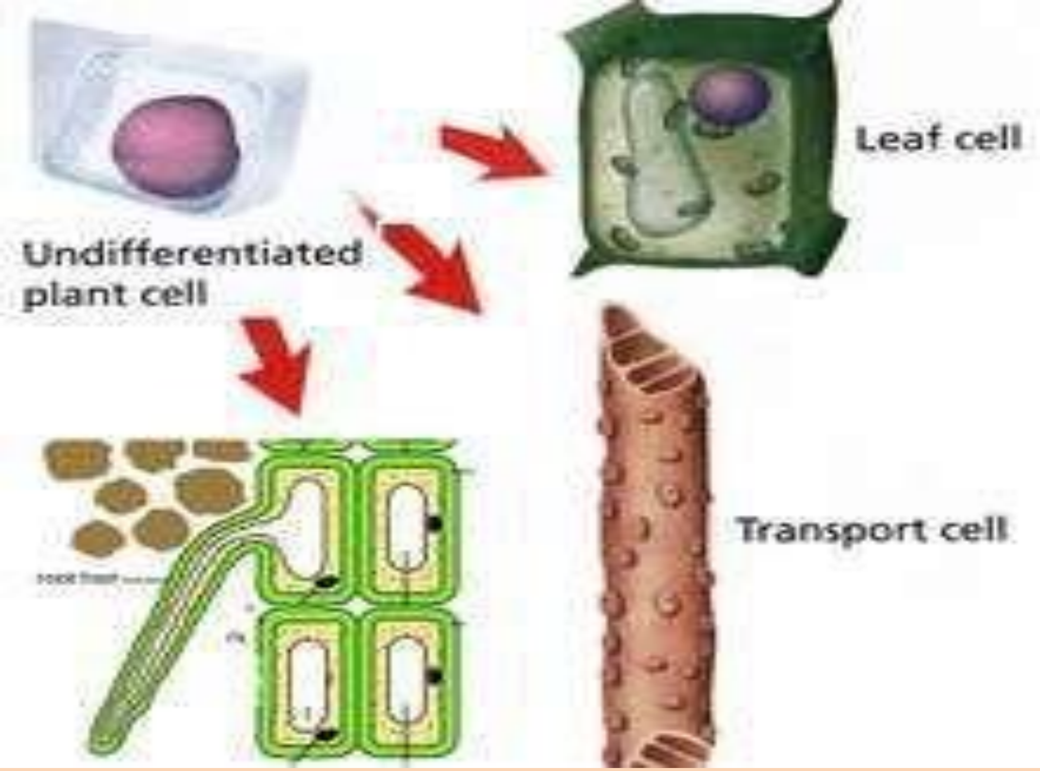
- Growth may be defined as an irreversible permanent increase in size in size, volume or mass of a cell or organ or whole organism.
- Growth is one of the fundamental characteristics of a living being.

- **It is accompanied by metabolic processes i.e. anabolic and catabolic process, that occur at the expense of energy.**
- **Example:- expansion of a leaf, elongation of stem etc.**

- **The main characteristics of growth are :-**
- Cellular growth
- Cell division
- Cell expansion
- Cellular differentiation

- Growth rate can be defined as increased growth per unit time.
- The rate of growth can be expressed mathematically.

- **Cellular differentiation** is the process by which a less specialized cell becomes a more specialized cell type.



- **Cells derived from meristems and cambium** differentiate and mature to perform specific functions which is termed as **differentiation.**

Dedifferentiation is an important phenomenon as cells regress from a specialized function to a simpler state.

An undividable differentiated cell sometimes regains the power of division. This process is called dedifferentiation.

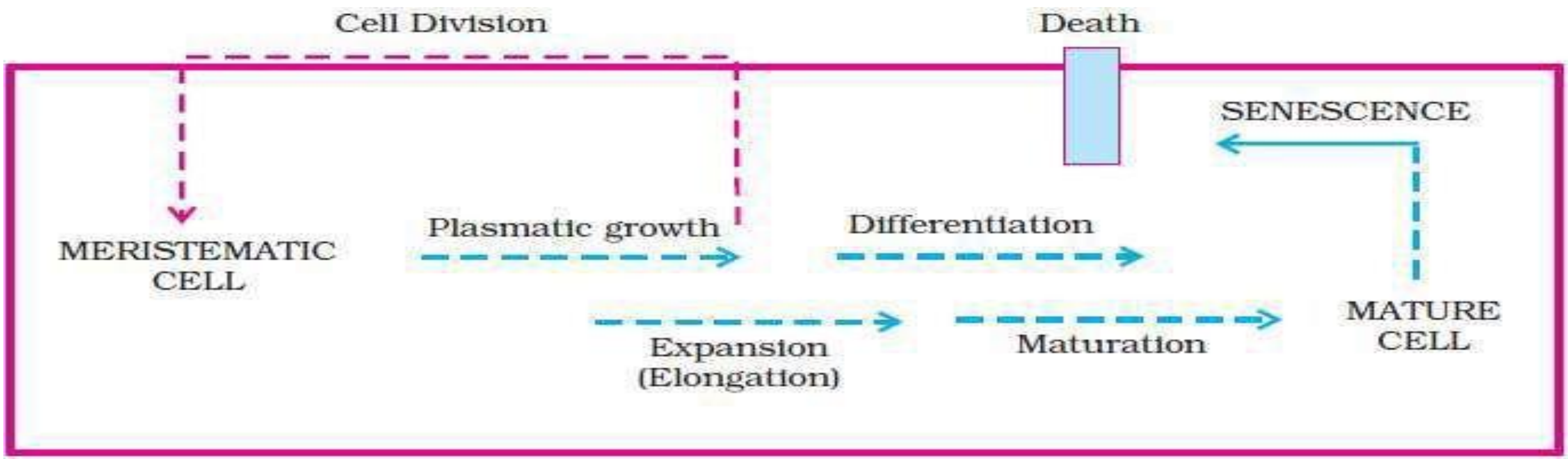
Dedifferentiation is a common process in plants during secondary growth and in wound healing mechanisms.

Factors affecting crop production – climatic – edaphic - biotic- physiographic and socio economic factors

CROP GROWTH

- **INTERNAL FACTORS** (Genetic or heredity)
- **EXTERNAL FACTORS** (Environmental)
  - A. Climatic
  - B. Edaphic
  - C. Biotic
  - D. Physiographic
  - E. Socio-economic

Development includes all changes that an organism goes through during its life cycle from germination of the seed to senescence.



Sequence of the developmental process in a plant cell

Agriculture is grouped in four major categories as,

A. Crop Improvement	(i) Plant breeding and genetics (ii) Bio-technology
B. Crop Management	(i) Agronomy (ii) Soil Science and Agricultural Chemistry (iii) Seed technology (iv) Agricultural Microbiology (v) Crop-Physiology (vi) Agricultural Engineering (vii) Environmental Sciences (viii) Agricultural Meteorology
C. Crop Protection	(i) Agricultural Entomology (ii) Plant Pathology (iii) Nematology
D. Social Sciences	(i) Agricultural Extension (ii) Agricultural Economics

Scope of Agronomy

Agronomy- dynamic discipline with the advancement of knowledge, better understanding of planet, environment and agriculture.

Identification of proper methods of cultivation- to reduce the cost of cultivation and maximize the yield and economic returns

Availability and application of chemical fertilizers

Control of weeds about selectivity, time & method of its application.

Water management practices

Intensive cropping with reduced the environmental hazards.

New technology to overcome the effect of moisture stress under dry land condition

Packages of practices to explore full potential of new crop verities

Keeping farm implements in good shape and utilizing efficient

Maintaining the ecological balance

Care and disposal of farm and animal waste

CROPS

In general, crop is plant/herb grown and / or harvested for obtaining yield. Agronomically, crop is a plant cultivated for economic purpose.

Classification of crops

Classification is done to generalize similar crop plants as a class for better understanding of them.

Classification types used in crops

Based on ontogeny (Life cycle) , Based on economic use (Agronomic)
Based on Botany (Scientific), Based on seasons , Based on climate

1. Based on Ontogeny (Life cycle)

a) Annual crops:

Crop plants that complete life cycle within a season or year. They produce seed and die within the season. Ex. Wheat, rice, maize, mustard etc.

b) Biennial crops:

Plants that have life span of two consecutive seasons or years. First years/ season, these plants have purely vegetative growth usually confined to rosette of leaves. The tap root is often fleshy and serves as a food storage organ. During the second year / season, they produce flower stocks from the crown and after producing seeds the plants die. Ex. Sugar beet, beet root, etc.

c) Perennial crops:

They live for three or more years. They may be seed bearing or non-seed bearing. Ex. Napier fodder grass, coconut, etc.

- **2. Based economic use (Agronomic)**
- ***a) Cereals:*** Cereal derived from word 'Ceres' which denotes as 'Goddess' who was believed as the giver of grains by Romans. Cereals are the cultivated grasses grown for their edible starchy grains. Larger grains used as staple food – Rice, wheat, maize, barley, oats etc.
- ***b) Millets:***
- Millets are small grained cereals, staple food in drier regions of the developing countries are called 'millets'. They are also annual grasses of the group cereals. But' they are grown in lesser area or less important area whose productivity and economics are also less important. These are also staple food for people of poor countries. In India, pearl millet is a staple food in Rajasthan. Millets are broadly classified in to two, 1) Major millets and 2) Minor millets.

- Sorghum /*Jowar*/*Cholam* - *Sorghum bicolor*
- Pearl millet /*Bajra*/*Cumbu* - *Pennisetum glaucum*
- Finger millet or *Ragi* - *Eleusine coracona*

- ***c) Pulses:***
- Seeds of leguminous plants used as food (*Dhal)* rich in protein. Pod containing grain is the economic portion. Pulses are preferred for protein rich value & also economic important in cropping system. The wastes or stalk is called the 'haulm' or 'stover'. Haulm is used as green manure and has high value cattle feed. Green pods used as vegetables, e.g. cowpea, lablab. Seed coat of pulses are nutritious cattle feed.
- 1. Red gram *Cajanus cajan* 2. Black gram *Vigna mungo*
- 3. Green gram *V. radiata* 4. Cowpea *V. unguiculata*

- ***d) Oil seeds:*** Those crops which are rich in fatty acid are cultivated for the production of vegetable oil. They are used either for edible or industrial or medicinal purposes.
- 1. Groundnut or peanut - *Arachis hypogeae* 2. Sesame or gingelly -*Sesamum indicum*

- ***Sugar crops***
- Crops cultivated for sugar. Juice is extracted from stem of sugarcane used for jaggery or sugar. Number of by products like molasses, bagasse, pressmud etc. is obtained from sugar industry.
- Sugar beet is another sugar crop where tubers are mainly used for extraction of sugar. Tubers and tops are used as a fodder for cattle feed.
- 1. Sugarcane - *Saccharum officinarum* 2. Sugar beet - *Beta vulgaris*
- ***Fibre crops:***
- Plants are grown for obtaining fibre. Different kinds of fibre are, i) seed fibre – cotton;
- ii) Stem/ bast fibre – Jute, mesta; iii) leaf fibre – *Agave*, pineapple.
- ***Fodder / Forage:*** It refers to vegetative matter, fresh or preserved, utilized as feed for animals. It includes hay, silage, pasturage and fodder.
- Ex. 1. Grasses - *Bajra napier* grass, guinea grass, fodder sorghum, fodder maize. 2. Legumes - Lucerne, *Desmanthus*, etc.
- ***Spices and condiments:*** Crop plants or their products used for flavour, taste and add colour to the fresh or preserved food. Ex.– Ginger, garlic, fenugreek, cumin, turmeric, chillies, onion, coriander, anise and asafetida.
- ***Medicinal plants:*** Crops used for preparation of medicines. Ex. Tobacco, mint. etc.
- ***Beverages:*** Products of crops used for preparation of mild, agreeable and simulating drinking. Ex. Tea, coffee, cocoa (Plantation crops).

- **Based on seasons**
- Crops are grouped under the seasons in which their major field duration falls.
- ***Kharif crops:*** Crops grown during June-July to September–October which require a warm wet weather during their major period of growth and shorter day length for flowering.
- Ex. Rice, maize, castor, groundnut.
- ***Rabi crops:*** Crops grown during October–November to January-February, which require cold dry weather for their major growth period and longer day length for flowering.
- Ex. Wheat, mustard, barley, oats, potato, bengal gram, berseem, cabbage and cauliflower.
- ***Summer crops:*** Crops grown during February–March to May–June which require warm dry weather for growth and longer day length for flowering. Ex.Black gram, greengram, seasome, cowpea etc.
- This classification is not a universal one. It only indicates the period when a particular crop is raised. Ex. *Kharif* rice, *kharif* maize, *rabi* maize, summer pulse etc.

- **5. Based on climatic condition**
- Tropical crop : Coconut, sugarcane
- Sub-tropical crop : Rice, cotton
- Temperate crop : Wheat, barley
- Polar crop : All pines, pasture grasses

- **Genetic factors**
- The increase in crop yields and other desirable characters are related to Genetic make up of plants.
- High yielding ability , Early maturity, Resistance to lodging , Drought flood and salinity tolerance

Tolerance to insect pests and diseases , Chemical composition of grains (oil content, protein content

Quality of grains (fineness, coarseness), Quality of straw (sweetness, juiciness)

The above characters are less influenced by environmental factors since they are governed by genetic make-up of crop.

2. External factors

- Climatic , Edaphic , Biotic , Phsiographic, Socio-economic

A. CLIMATIC FACTORS

- Nearly 50 % of yield is attributed to the influence of climatic factors.T he following are the atmospheric weather variables which influences the crop production.
- Precipitation, Temperature, Atmospheric humidity , Solar radiation , Wind velocity, Atmospheric gases

Rainfall-Low and uneven distribution of rainfall is common in dryland farming where drought resistance crops like pearl millet, sorghum and minor millets are grown.

- In desert areas grasses and shrubs are common where hot desert climate exists
- Though the rainfall has major influence on yield of crops, yields are not always directly proportional to the amount of Precipitation as excess above optimum reduces the yields
- Distribution of rainfall is more important than total rainfall to have longer growing period especially in drylands

Temperature

- Temperature is a measure of intensity of heat energy. The range of temperature for maximum growth of most of the agricultural plants is between 15 and 40ºC.
- The temperature of a place is largely determined by its distance from the equator (latitude) and altitude.
- It influences distribution of crop plants and vegetation.
- Germination, growth and development of crops are highly influenced by temperature.
- Affects leaf production, expansion and flowering.
- Solubility of different substances in plant is dependent on temperature.
- The minimum, maximum (above which crop growth ceases) and optimum temperature of individual's plant is called as cardinal temperature.

- **3. Atmospheric Humidity (Relative Humidity - RH)**
- Relative humidity is ratio between the amount of moisture present in the air to the saturation capacity of the air at a particular temperature.
- If relative humidity is 100% it means that the entire space is filled with water and there is no soil evaporation and plant transpiration.
- Relative humidity influences the water requirement of crops
- Relative humidity of 40-60% is suitable for most of the crop plants.
- Very few crops can perform well when relative humidity is 80% and above.
- When relative humidity is high there is chance for the outbreak of insect and pests

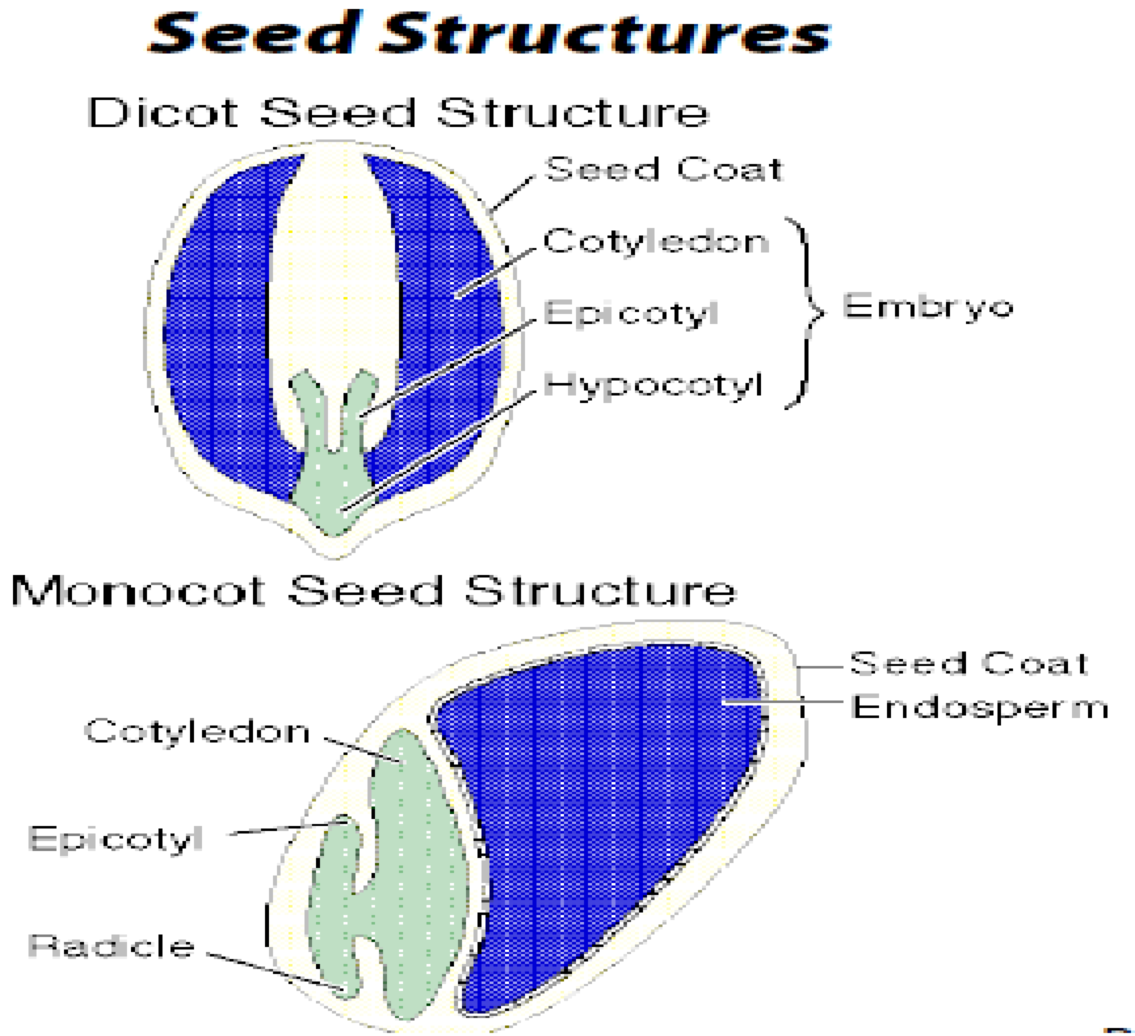
Solar radiation (without which life will not exist)

- From germination to harvest and even post harvest crops are affected by solar radiation.
- Biomass production by photosynthetic processes requires light.
- Photosynthetically Active Radiation (PAR - 0.4 – 0.7μ) is essential for production of carbohydrates and ultimately biomass.
  - to 0.5 μ - Blue – violet – Active
  - to 0.6 μ - Orange – red - Active
- Photoperiodism is a response of plant to day length
- Short day – Day length is <12 hours (Rice, Sunflower and cotton), long day – Day length is > 12 hours (Barley, oat, carrot and cabbage), day neutral – There is no or less influence on day length (Tomato and maize).
- Phototropism ––
- Photosensitive – Season bound varieties depends on quantity of light received

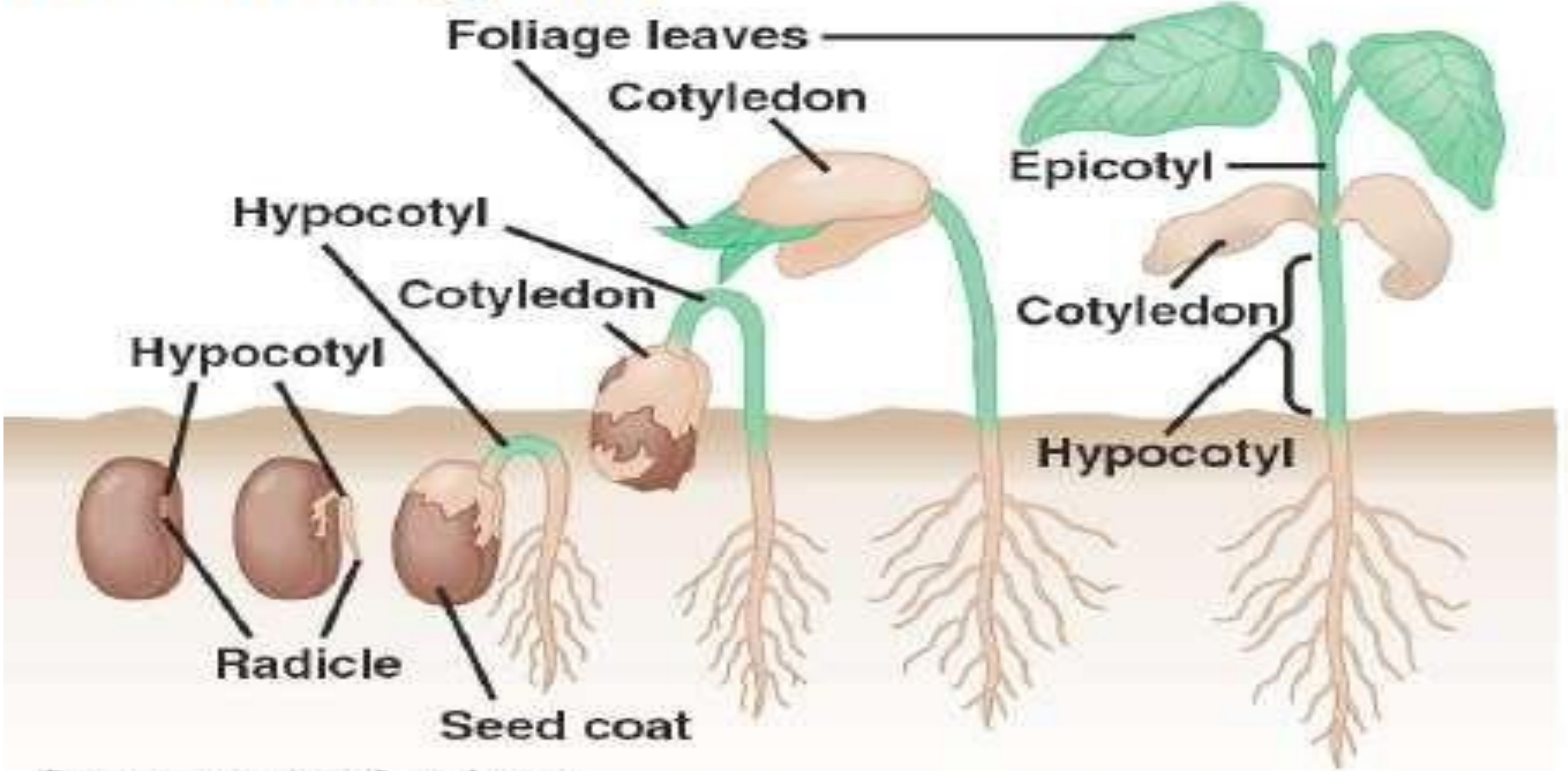
- **5. Wind velocity**
- The basic function of wind is to carry moisture (precipitation) and heat.
- The moving wind not only supplies moisture and heat, also supplies fresh CO_2 for the photosynthesis.
- Wind movement for 4 – 6 km/hour is suitable for more crops.
- Causes soil erosion.
- Helps in cleaning produce to farmers.
- Increases evaporation.
- Spread of pest and diseases.
- **6. Atmospheric gases on plant growth**
- CO_2 – 0.03%, O_2 - 20.95%, N_2 - 78.09%, Argon - 0.93%, Others - 0.02%.
- CO_2 is important for Photosynthesis, CO_2 taken by the plants by diffusion process from leaves through stomata
- CO_2 is returned to atmosphere during decomposition of organic materials, all farm wastes and by respiration
- Certain gases like SO_2, CO, CH_4, HF released to atmosphere are toxic to plants

- **EDAPHIC FACTORS (Soil factors)**
- Plants grown in land completely depend on soil on which they grow. The soil factors that affect crop growth are
- Soil moisture
- Soil air
- Soil temperature
- Soil mineral matter
- Soil organic matter
- Soil organisms
- Soil reactions

Growth and Development



Growth Diagram

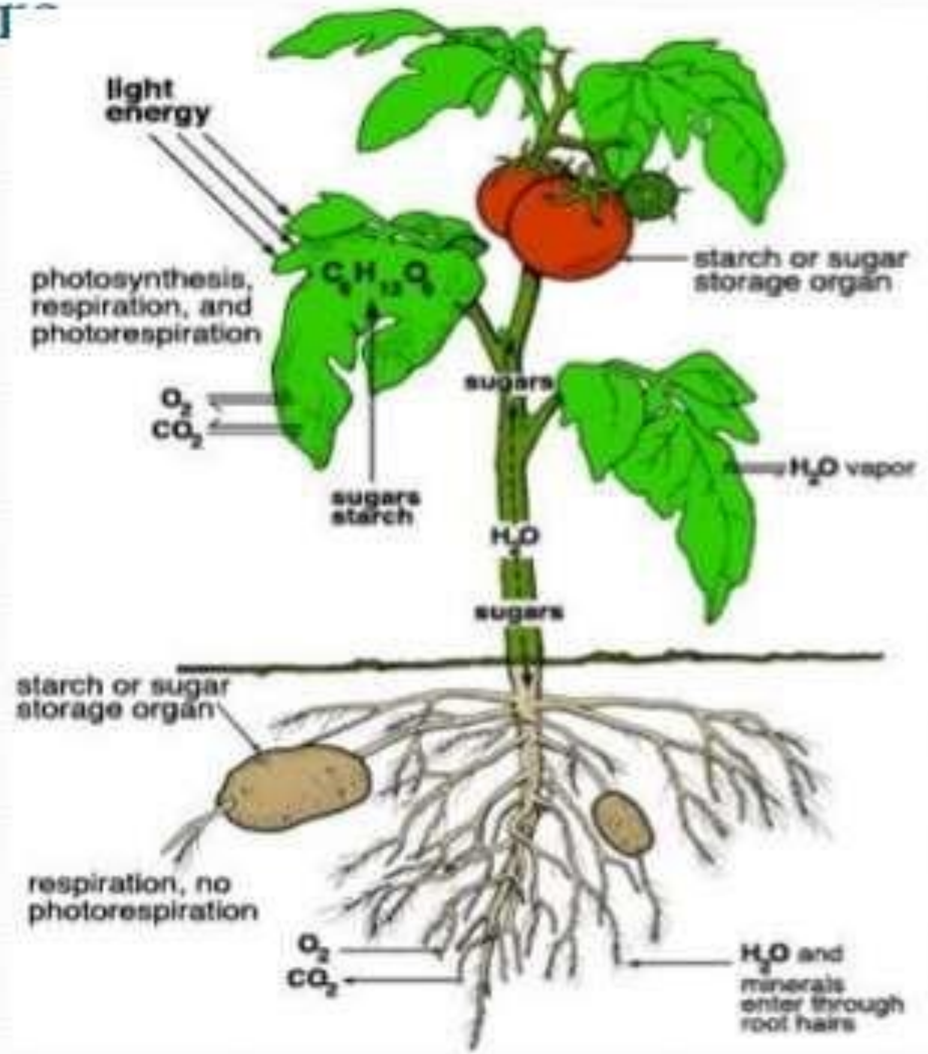


Common garden bean

Germination ?
Emergence ?

There are 6 plant processes that effect growth which ar

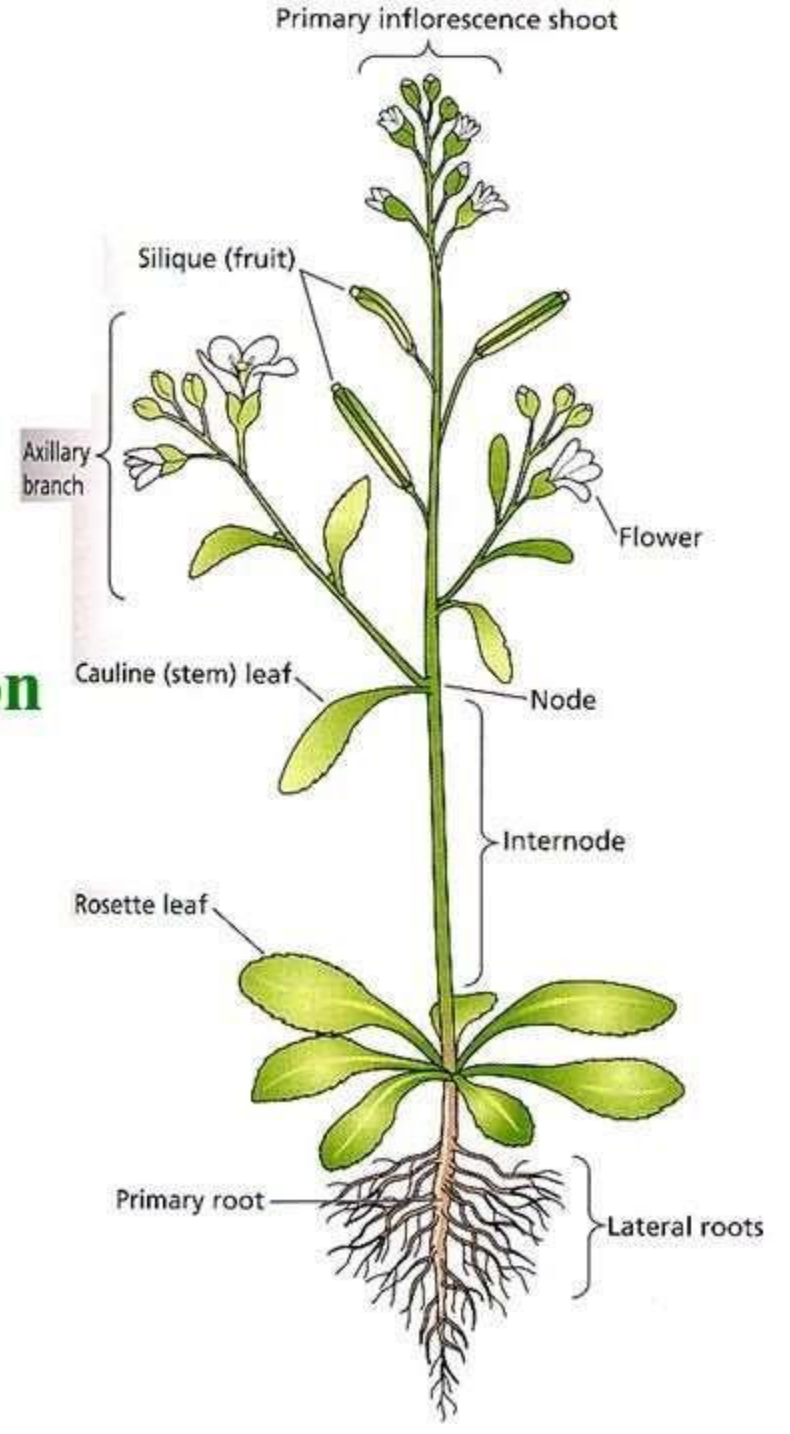
- Photosynthesis
- Respiration
- Absorption
- Transpiration
- Translocation
- Reproduction



Plant Growth & Development

3 stages

1. Embryogenesis
   Fertilization to seed
2. Vegetative growth
   Juvenile stage
   Germination to adult
   "phase change" marks transition
3. Reproductive development
   Make flowers, can
   reproduce sexually



What is the difference between growth and development?

GROWTH

Growth

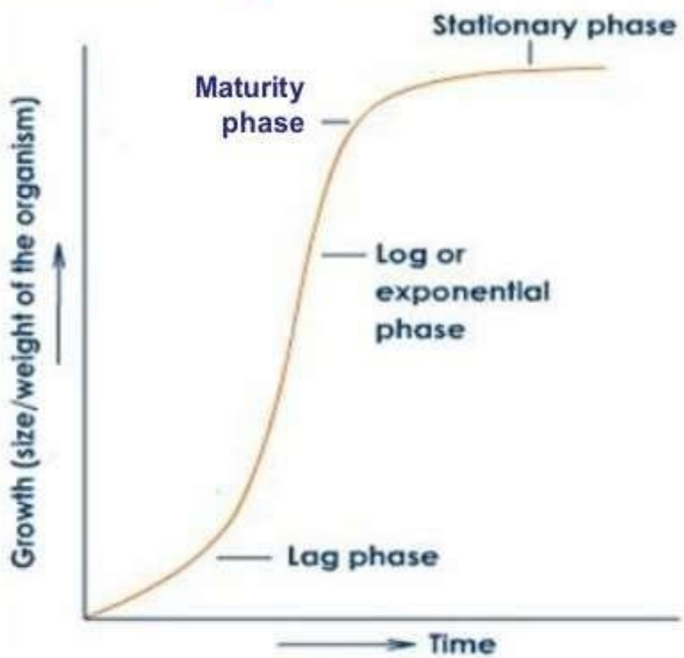
- Irreversible change in Mass, i.e. increase in size, volume and weight of any part of plant's body.
- It means quantitative increase in plant body.
- e.g. Cell division ⟶ Cell enlargement.

Development

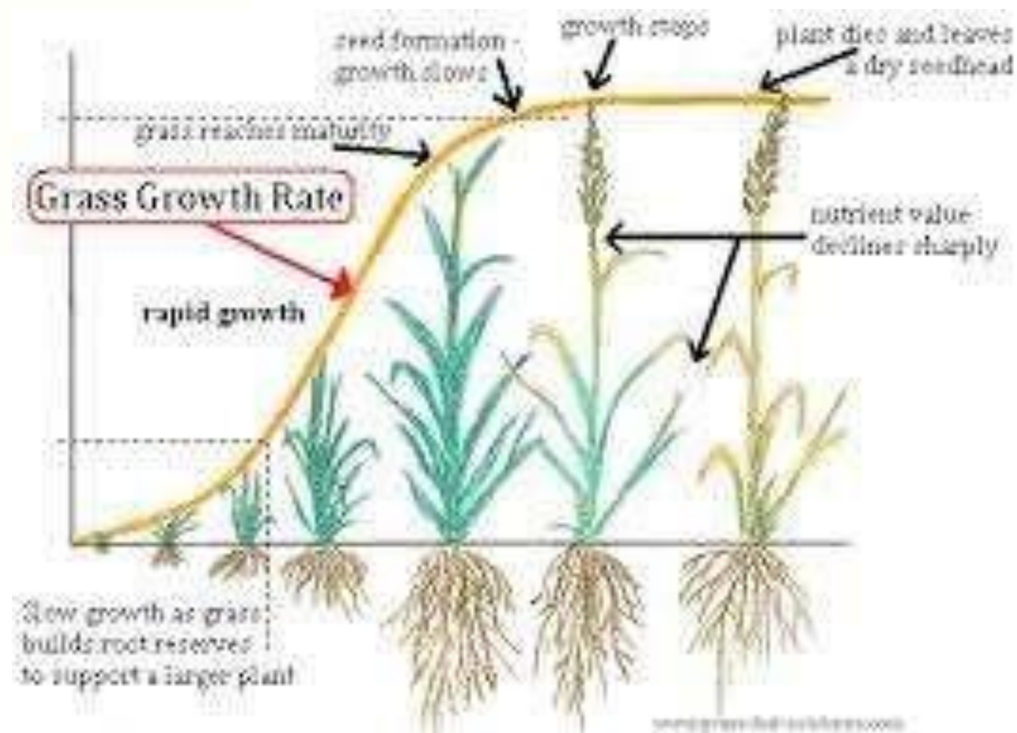
- Irreversible change in state.
- It means the qualitative change in plant body.
- e.g. Seed ⟶ Seedling ⟶ Vegetative maturation ⟶ Flowering.

Growth is a continuous process
Development is phase to phase process.

Sigmoid Curve

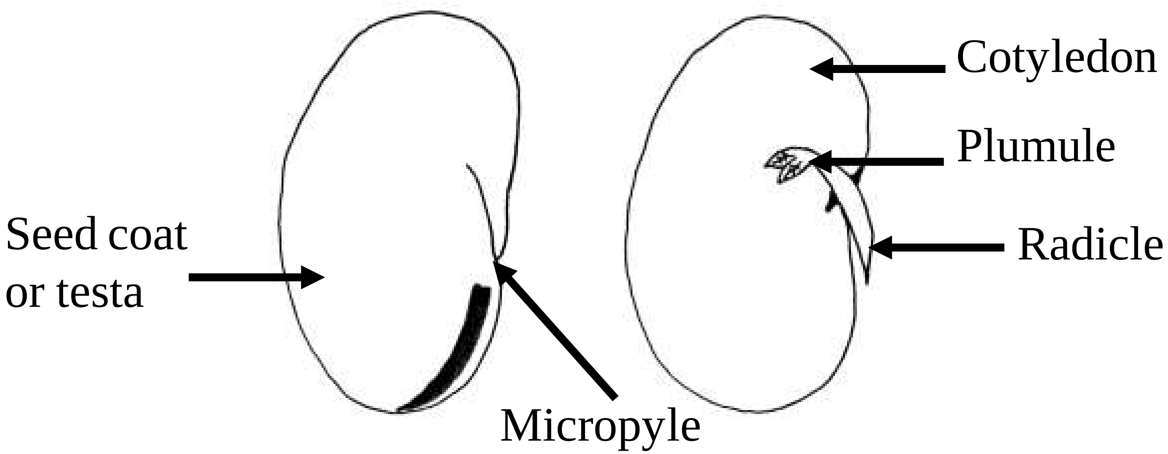


Senescence & death



Seed and sowing

Seed structure



Seed viability

- **Viability:** When a seed is capable of germinating after all the necessary environmental conditions are met
- Conditions are very important for longevity
  Cold, dry, anaerobic conditions
- These are the conditions which are maintained in **seed banks**.

Factors affecting germination

- **Water**
  Rehydration of tissues
  Dilution of inhibitors
- **Oxygen** (c.f. Respiration)

- **Temperature**
  Enzyme controlled processes
- Some seeds may require exposure to light or high temperatures.

- **There are three basic parts of a seed in the angiosperms:**

(a)an embryo, (b) Endosperm, and (c) seed coat/ covering.

Embryo

- A mature seed has a diploid (2N) embryo which develops from a fertilized egg or zygote. It consists of the *epicotyl* (The epicotyl is a tiny shoot from which the entire plant shoot system develops) The growing tip of the epicotyl is the plumule, *hypocotyl* (transition zone between the rudimentary root and shoot), *radicle* (embryonic root), and one or two *cotyledons* (specialized seed leaves which develop from the plumule and occur singly in most monocot seeds but two in dicot seeds)

Endosperm- The stored food is used to support the embryo during seed germination.

Seed Covering- is of maternal origin. It covers and provides mechanical protection to the other parts of a seed.

- The seed coat is usually hard, thickened, brownish or otherwise colored, and partly impermeable to water.
- It prevents excessive loss of water from within the seed and serves as a barrier against the entry of parasites. Hard seed coats cause dormancy, a condition which prevents germination when environmental conditions are not favorable for sustained growth of seedlings.
- There are usually two layers of the seed coat. The outer layer, known as the testa, is thicker. The inner one is more delicate, known as tegmen.

Types of Seeds- primarily of two types.

1. Monocotyledonous Seed, 2. Dicotyledonous Seed

Structure of a Monocotyledonous Seed- has only one cotyledon. There is only one outer layering of the seed coat. A seed has the following parts:

Seed Coat: In the seed of cereals such as maize, the seed coat is membranous and generally fused with the fruit wall, called Hull.

Endosperm: The endosperm is bulky and stores food.

Aleuron layer: The outer covering of endosperm separates the embryo by a proteinous layer called aleurone layer.

Embryo: The embryo is small and situated in a groove at one end of the endosperm.

Scutellum: This is one large and shield-shaped cotyledon.

Embryonal axis: Plumule and radicle are the two ends.

Coleoptile and coleorhiza: The plumule and radicle are enclosed in sheaths. They are coleoptile and coleorhiza.

Structure of a Dicotyledonous Seed

- Unlike monocotyledonous seed, a dicotyledonous seed, as the name suggests, has two cotyledons. It has the following parts:

Seed coat: This is the outermost covering of a seed. The seed coat has two layers, the outer testa and the inner tegmen.

Hilum: The hilum is a scar on the seed coat through which the developing seed was attached to the fruit.

Micropyle: It is a small pore present above the hilum.

Embryo: It consists of an embryonal axis and two cotyledons.

Cotyledons: These are often fleshy and full of reserve food materials.

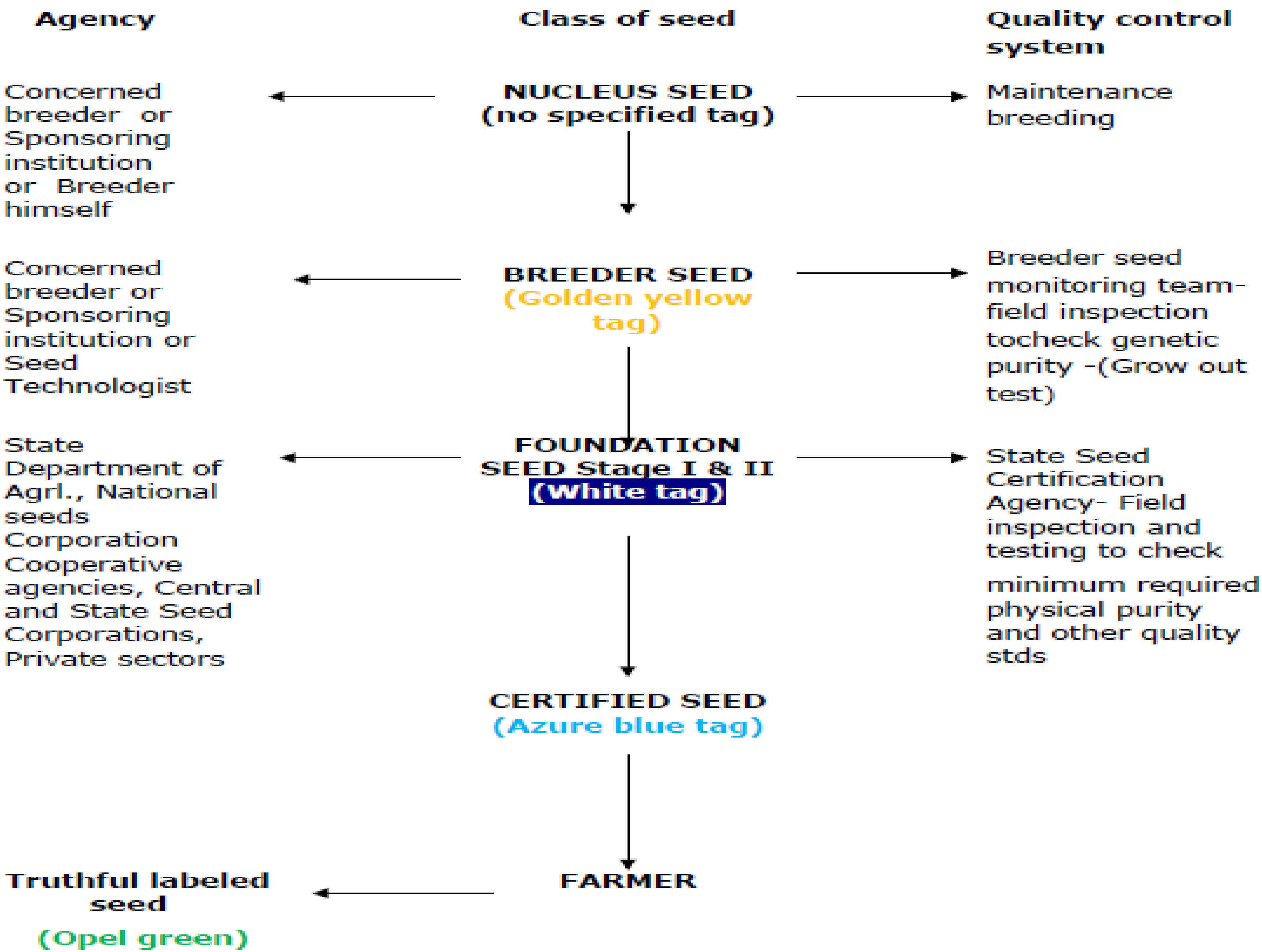
Radicle and plumule: They are present at the two ends of the embryonal axis.

Endosperm: is a food storing tissue

- **CLASSES OF SEED -**Breeder's seed, Foundation seed, Registered seed and Certified seed.
- Breeder seed- The seed or vegetatively propagated material directly controlled by the originating or the sponsoring breeder or institution which is the basic seed for recurring increase of foundation seed.
- Foundation seed- It is the progeny of breeder seed. The seed stock handled to maintain specific identity and genetic purity, which may be designated or distributed and produced under careful supervision of an agricultural experiment station. This seed is the source of all other certified seed classes either directly or through registered seed.

- Registered seed- The progeny of the foundation seed so handled as to maintain its genetic identity and purity and approved and certified by a certifying agency. It should be of quality suitable to produce certified seed.
- Certified seed- It is the progeny of the foundation seed. Its production is so handled to maintain genetical identity and physical purity according to standards specified for the crop being certified. It should have the minimum genetical purity of 99%. Certified seed may be the progeny of certified seed , provided this reproduction does not exceed two generations beyond foundation seed and provided that if certification agency determines the genetic and physical purity.

Certified seed	Truthful labelled seed
Certification is voluntary	Truthful labelling is compulsory for notified kind of varieties
Applicable to notified kinds only	Applicable to both notified and released varieties
It should satisfy both minimum field and seed standards	Tested for physical purity and germination
Seed certification officer ,seed inspectors can take samples for inspection	Seed inspectors alone can take samples for checking the seed quality.


Agency
Class of seed
Quality control system
Concerned breeder or Sponsoring institution or Breeder himself
NUCLEUS SEED (no specified tag)
Maintenance breeding
Concerned breeder or Sponsoring institution or Seed Technologist
BREEDER SEED (Golden yellow tag)
Breeder seed monitoring team- field inspection tocheck genetic purity -(Grow out test)
State Department of Agrl., National seeds Corporation Cooperative agencies, Central and State Seed Corporations, Private sectors
FOUNDATION SEED Stage I & II (White tag)
State Seed Certification Agency- Field inspection and testing to check minimum required physical purity and other quality stds
CERTIFIED SEED (Azure blue tag)
FARMER
Truthful labeled seed
(Opel green)

Tillage

- The word tillage is derived from **'Anglo-Saxon' words *Tilian* and *Teolian***, meaning 'to plough
- **Jethrotull,** who is considered **as father of tillage** suggested that thorough ploughing is necessary so as to make the soil into fine particles.
- **Tillage** is the mechanical manipulation of soil with tools and implements for obtaining conditions ideal for seed germination, seedling establishment and growth of crops.
- **Tilth** is the physical condition of soil obtained out of tillage (or) it is the result of tillage. The tilth may be a **coarse tilth, fine tilth or moderate tilth**.

SOWING AND PLANTING EQUIPMENT The basic objective of sowing operation is to put the seed and fertilizer in rows at desired depth and seed to seed spacing, cover the seeds with soil and provide proper compaction over the seed. The recommended row to row spacing, seed rate, seed to seed spacing and depth of seed placement vary from crop to crop and for different agro-climati'c conditions to achieve optimum yields

Objectives of tillage

- To prepare a good seed bed which helps the germination of seeds.
- To create conditions in the soil suited for better growth of crops.
- To control the weeds effectively.
- To make the soil capable for absorbing more rain water.
- To mix up the manure and fertilizers uniformly in the soil.
- To aerate the soil.
- To provide adequate seed-soil contact to permit water flow to seed and seedling roots.
- To remove the hard pan and to increase the soil depth.

To achieve these objectives, the soil is disturbed / opened up and turned over.

- **Types of tillage:** Tillage operations may be grouped into

1. On season tillage 2. Off-season tillage

On-season tillage -Tillage operations that are done for raising crops in the same season or at the onset of the crop season are known as on-season tillage. **They may be preparatory cultivation and after cultivation.**

A. Preparatory tillage: This refers to prepare the field for raising crops. It consists of deep opening and loosening of the soil to bring about a desirable tilth as well as to incorporate or uproot weeds and crop stubble when the soil is in a workable condition.

Types of preparatory tillage -Primary tillage and Secondary tillage

- ***Primary tillage:*** The tillage operation that is done after the harvesting. Ploughing is the opening of compact soil with the help of different ploughs. Country plough, mould board plough, bose plough, tractor and power tiller drawn implements are used for primary tillage.
- ***Secondary tillage:*** The tillage operations that are performed on the soil after primary tillage to bring a good soil tilth are known as secondary tillage. Secondary tillage consists of lighter or finer operation which is done to clean the soil, break the clods and incorporate the manure and fertilizers. Harrowing and planking is done to serve those purposes.
- *Planking* is done to crush the hard clods, level the soil surface and to compact the soil lightly. Harrows, cultivators, *Guntakas* and spade are used for secondary tillage.
- ***Layout of seed bed:*** This is also one of the components of preparatory tillage. Leveling board, buck scrapers etc. are used for leveling and markers are used for layout of seedbed.

- ***B. After cultivation (Inter tillage):*** The tillage operations that are carried out in the standing crop after the sowing or planting and prior to the harvesting of the crop plants are called after tillage. **This is also called as inter cultivation or post seeding/ planting cultivation.** It includes harrowing, hoeing, weeding, earthing up, drilling or side dressing of fertilizers etc. Spade, hoe, weeders etc. are used for inter cultivation.

2. Off-season tillage: Tillage operations done for conditioning the soil suitably for the forthcoming main season crop are called off-season tillage. Off season tillage may be, post harvest tillage, summer tillage, winter tillage and fallow tillage.

Special purpose tillage: Tillage operations intended to serve special purposes are as

- **Sub-soiling:** To break the hard pan beneath the plough layer, special tillage operation (chiseling) is performed to reduce compaction. Advantages of sub-soiling are, greater volume of soil may be obtained for cultivation, excess water may percolate downward to recharge the water table, reduce runoff and soil erosion and roots of crop plants can penetrate deeper to extract moisture from the water table.
- **Clean tillage:** It refers to working of the soil of the entire field in such a way no living plant is left undisturbed. It is practiced to control weeds, soil borne pathogen and pests.
- **Blind tillage:** It refers to tillage done after seeding or planting the crop (in a sterile soil) either at the pre-emergence stage of the crop plants or while they are in the early stages of growth so that crop plants (sugarcane, potato etc.) do not get damaged, but, extra plants and broad leaved weeds are uprooted.
- **Dry tillage:** Dry tillage is practiced for crops that are sown or planted in dry land condition having sufficient moisture for germination of seeds. This is suitable for crops like broadcasted rice, jute, wheat, oilseed crops, pulses, potato and vegetable crops. Dry tillage is done in a soil having sufficient moisture (21-23%). The soil becomes more porous and soft due to dry tillage. Besides, the water holding capacity of the soil and aeration are increased. These conditions are more favourable for soil micro-organisms.
- **Wet tillage or puddling:** Puddling operation consists of ploughing repeatedly in standing water until the soil becomes soft and muddy. Puddling creates an impervious layer below the surface to reduce deep percolation losses of water and to provide soft seed bed for planting rice. Wet tillage destroys the soil structure and the soil particles that are separated during puddling settle later. Wet tillage is the only means of land preparation for transplanting semi-aquatic crop plant such as rice. Planking after wet tillage makes the soil level and compact. Puddling hastens transplanting operation as well as establishment of seedlings. Wet land ploughs or worn out dry land ploughs are normally used for wet tillage.

Methods of sowing

- **Methods of Sowing:** The sowing method is determined by the crop to be sown. There are 6 sowing methods which differ in their merits, demerits and adoption. Those are:
  1. Broad casting 2. Broad or Line sowing 3. Dibbling
  4. Transplanting 5. Planting 6. Putting seeds behind the plough.

- **1. Broad casting:** It is the scattering of seeds by hand all over the prepared field followed by covering with wooden plank or harrow for contact of seed with soil. Crops like wheat, paddy, Sesamum, methi, coriander, etc. are sown by this method.
  Advantages:
  1) Quickest & cheapest method
  2) Skilled labour is not uniform.
  3) Implement is not required,
  4) Followed in moist condition.
  Disadvantages:
  1) Seed requirement is more,
  2) Crop stand is not uniform.
  3)Result in gappy germination & defective wherever the adequate moisture is not present in the soil.
  4)Spacing is not maintained within rows & lines, hence intercultivation is difficult.

2. **Drilling or Line sowing:** It is the dropping of seeds into the soil with the help of implement such as mogha, seed drill, seed-cum-ferti driller or mechanical seed drill and then the seeds are covered by wooden plank or harrow to have contact between seed & soil. Crops like Jowar, wheat Bajra, etc. are sown by this method.

Advantages:

1) Seeds are placed at proper & uniform depths,
2) Along the rows, intercultivation can be done,
3) Uniform row to row spacing is maintained,
4) Seed requirement is less than 'broad casting'
5) Sowing is done at proper moisture level.

Disadvantages:

1) Require implement for sowing,
2) Plant to plant (Intra row) spacing is not maintained,
3) Skilled person is required for sowing.

- **3. Dibbling:** It is the placing or dibbling of seeds at cross marks (+) made in the field with the help of maker as per the requirement of the crop in both the directions. It is done manually by dibbler. This method is followed in crops like Groundnut, Castor, and Hy. Cotton, etc. which are having bold size and high value.

- **Advantages:**
  1) Spacing between rows & plants is maintained,
  2) Seeds can be dibbled at desired depth in the moisture zone,
  3) Optimum plant population can be maintained,
  4) Seed requirement is less than other method,
  5) Implement is not required for sowing,
  6) An intercrop can be taken in wider spaced crops,
  7) Cross wise Intercultivation is possible.

- **Disadvantages:**
  1) Laborious & time consuming method,
  2) Require more labour, hence increase the cost of cultivation,
  3) Only high value & bold seeds are sown,
  4) Require strict supervision.

- **4. Transplanting:** It is the raising of seedlings on nursery beds and transplanting of seedlings in the laid out field. For this, seedlings are allowed to grow on nursery beds for about 3-5 weeks. Beds are watered one day before the transplanting of nursery to prevent jerk to the roots. The field is irrigated before actual transplanting to get the seedlings established early & quickly which reduce the mortality. Besides the advantages & disadvantages of dibbling method, initial cost of cultivation of crop can be saved but requires due care in the nursery. This method is followed in crops like paddy, fruit, vegetable, crops, tobacco, etc.

- **5. Planting:** It is the placing of vegetative part of crops which are vegetatively propagated in the laid out field. E.g.: Tubers of Potato, mother sets of ginger & turmeric, cuttings of sweet potato & grapes, sets of sugarcane.
- **6. Putting seeds behind the plough:** It is dropping of seeds behind the plough in the furrow with the help of manual labour by hand. This method is followed for crops like wal or gram in some areas for better utilization of soil moisture. The seeds are covered by successive furrow opened by the plough. This method is not commonly followed for sowing of the crops.

- **SOILS**

as the thin layer of earth's crust

serves as the natural medium of growth of plants

- It provides nutrients, moisture, anchorage (support) and provides air to root system.
- There are different soil groups found in varied regions of India. Each group differs from other in physical and chemical properties. The variation in behaviour is mainly due to the nature of the parent material from which the soils are formed.
- Physical properties like structure, texture, colour, water holding capacity, depth etc. are to be noted. Chemical properties like the presence of various plant elements, pH, EC, CEC, acidic or alkaline, etc. are considered.

- **Major soils of India**
- Alluvial soil (*Entisols, Inceptisols and Alfisol)*
- Black soil (*Vertisol*)
- Red soil (*Alfisol*)
- Laterite soil (*Ultisol*)
- Desert soil (*Aridisol*)
- Forest soil and hill soil, peat and marshy soils
- Problem soils (saline, alkali, acid)

Alluvial soil or Indo-Gangetic Alluvium

- **This is the most extensive soil found in India. Out of total area of India, 48.0 mha comes under river alluvium.**
- **These soils include deltaic, calcareous and coastal alluvium.**
- **Newly formed alluvium may not have distinct soil horizons while older alluvium may have soil horizons. They occur in the basins of Indus, Ganges, Brahmaputra, Godavari, Krishna, Cauvery deltas spread in U.P., Bihar, W Bengal, Guj, Pun, Raj, A Predesh, T Nadu.**
- **Newer alluvium is called as *Khadar*, is sandy, light colour and less *Kankar* nodules. Older alluvium is called as *Bhangar*, full of clay, dark colour and more *Kankar* nodules.**
- **Alluvial soils of high altitude are acidic in nature and plains are neutral to alkaline. Alluvial soils of plains are medium in phosphorous content and high in potassium content. Generally, alluvial soils are rich in nutrients and are fertile and they support good crop growth with plenty of water.**

- **2. Black soil**
- Dark-grey in colour due to clay-humus complex. Area around 32.0 m.ha is under this soil. This soil is also called black cotton soil, mixing of soil along the entire column with *Montmorillonite* clay. Found in Mah, M Pradesh, Orissa, Coastal A Pradesh, North Karnataka and parts of T Nadu.
- **Black soil contains high proportion of clay (30-40%), so, the water holding capacity is high. Typical characteristics of this black soil are swelling (during wet period) and shrinkage (dry period). While dry, it forms very deep cracks of more than 30-45 cm. In Kovilpatti (Tamil Nadu) areas the cracks may extend to 2 to 3 m with a width of 1 to 6 cm. Field preparation takes longer time compared to other soil. Only after secondary tillage, the soil is suited for crop production.**
- The soils are fine grained contain high proportion of Calcium and Magnesium carbonates. They are poor in N, medium in P and medium to high in K (Characteristic feature of typical Indian soil).
- **In Tamil Nadu Black soils have high pH (8.5 to 9) and are rich in lime (5-7%), have low permeability. The soils are with more cation exchange capacity (40-60 m.e./100 g). Crops grown in this soil are cotton, bengal gram, mustard, millets, pulses, oil seeds (sunflower, safflower) are commonly grown in this soil. Most of the soils come under rainfed areas.**

- **3. Red soil**
- Based on the colour (due to presence of ferric oxides) it is called as red soil. Around 30 m.ha are found in India. They are formed from granites and other metamorphic rocks. Mostly found in semi-arid areas and the colour varies from red to yellow.
- **The soil is light textured, with *Kaolinite* type of clay. Well drained with moderate permeability. Low cation exchange capacity and low water holding capacity. Red soil is present in Gujarat, Tamil Nadu, Karnataka, Andhra Pradesh, North and East of Arunachal Pradesh, Madhya Pradesh, Parts of Bihar and Uttar Pradesh.**
- They are shallow in depth because they are degraded or drained soil. Lesser clay and more sandy than *Vertisol*. Red soil is always in acidic nature. Highly suitable for groundnut crop cultivation. Crops like millets, pulses, oil seeds (ground nut, gingelly, castor) and tuber crops like cassava are commonly cultivated.

- **4. Laterites and Lateritic soil**
- Laterite soils are formed due to the process of laterisation. i.e., leaching of all cations leaving Fe and Al oxides. Mostly found in hills and foothill areas. This soil is formed under high intensive down pour of rainfall. It is modified form of red soil, clay content is minimum.
- Rich in organic matter content and rich in fertility and medium water holding capacity. They become very hard when there is no water. The cohesive nature is high. Acid loving crops (Plantation crops) and fruits (pineapple, avacado) are more cultivated. Tea, rubber, pepper, spices are cultivated. At lower elevation places, rice is grown.

- **5. Desert soil**

Found in desert regions of Rajasthan (Thar desert), parts of Haryana and Punjab of India. More sand is found and sand dunes are common. Clay content is < 8% only. Poor fertility, poor water holding capacity and susceptible to soil erosion. Presence of sodic salts (high Na content) leads to alkalinity. Crops like date palm, cucumber, millets are cultivated (countries like Saudi Arabia, UAE, Jordan, Sudan etc).

- **6. Peaty and Organic soil**

These soils are very rich in organic matter. Found in Kerala, coastal regions of West Bengal, Orissa, South and East coast of Tamil Nadu. Deposition of organic matter by the elevated soil. Peaty and organic soil is not suitable for majority of crops. Rice is mostly cultivated in coastal area in rainy season.

7. Problem soil = *Saline soils:* Contain excess amounts of neutral soluble salts dominated by **chlorides and sulphates** of Na, Ca and Mg affects plant growth. White encrustation of salts and hence called white alkali. This soil needs leaching and drainage before cropping for amelioration.

- Salt tolerant: *Sesbania*, Rice, sugarcane, oats, berseem, lucerne cotton, sorghum, pearl millet, maize
- ***Sodic / Alkali soils:*** High content of **carbonates and bicarbonates of Na.** Hence, they are with high exchangeable sodium percentage (ESP) with dark encrustation, hence called as black alkali. Use gypsum ($CaSO_4$, $2H_2O$) as amendment. crops: rhodes / para/ bermuda grass, rice and sugar beetWheat, barley, oats, berseem and sugarcane.
- ***Acid soils:*** These are low pH with high amounts of **exchangeable H^+ and Al_3.** Occur in regions with high rainfall. Significant amount of partly decomposed organic matter exist. Liming and judicious use of fertilizers are the management measures suggested. Suitable crops: Acedophytes (like potato).

- **Mineral Nutrition**
- The process of absorption, translocation and assimilation of nutrients by the plants is known as mineral nutrition.
- **Essential Elements: Plants need 17 elements for their growth and** completion of life cycle.
- They are: Carbon,hydrogen,oxygen,nitrogen,phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, zinc, copper, boron, molybdenum and chlorine, nickel.
- In addition, four more elements sodium, cobalt, vanadium and silicon are absorbed by some plants for special purposes
- .
- The elements C, H, O are not minerals. The rest of the elements are absorbed from the soil and these are called mineral elements since they are derived from minerals. These mineral elements are mainly absorbed in ionic form and to some extent in non-ionic form.

Mineral element	Ionic form	Non-ionic form
Nitrogen (N)	NH_4^+ , NO_3^-	$CO(NH_2)^2$
Phosphorus (P)	$H_2PO_4^-$, HPO_4^{2-}	Nucleic acid, phytin
Potassium (Kalium-K)	K^+	
Calcium (Ca)	Ca^{2+}	
Magnesium (Mg)	Mg^{2+}	
Sulphur (S)	SO_4^{2-}	SO_2
Iron (Fe)	Fe^{2+} , Fe^{3+}	$FeSO_4$ with EDTA
Manganese (Mn)	Mn^{2+}	$MnSO_4$ with EDTA

EDTA = Ethylene di-amine tetra acetic acid

Mineral element	Ionic form	Non-ionic form
Zinc (Zn)	Zn^{2+}	$ZnSO_4$ with EDTA
Copper (Cu)	Cu^{2+}	$CuSO_4$ with EDTA
Boron (B)	H_3BO_3, H_2BO_3, HBO_3	
Molybdenum (Mo)	MoO_4^{2-}	
Chlorine (Cl) Cl^-	Cl^-	

Essential plant nutrients (17)

- Frame work elements (Taken from air and water: 3)
  - Carbon
  - Hydrogen
  - Oxygen
- Mineral elements (Taken mainly from soil in ionic forms: 14)
  - Macronutrients (6)
    - Primary nutrients (3)
      - Nitrogen
      - Phosphorus
      - Potassium
    - Secondary nutrients (3)
      - Calcium
      - Magnesium
      - Sulphur
  - Micronutrients (8)
    - Zinc
    - Copper
    - Manganese
    - Iron
    - Boron
    - Molybdenum
    - Chlorine
    - Nickel

Classification of essential elements

The essential elements can be classified based on the amount required, their mobility in the plant and soil, their chemical nature and their function inside the plant.

1. **Amount of Nutrients:** Depending on the quantity of nutrients present in plants, they can be grouped into three: basic nutrients, macronutrients and micronutrients.

a) **Basic Nutrients:** carbon, hydrogen, oxygen, which constitute 96 % of total dry matter of plants are basic nutrients. Among them, carbon and Oxygen constitute 45 % each.

Eg. The total dry matter produced by rice crop in one season is about 12 t/ha. In this 5.4 t is carbon, 5.4 t is oxygen and 0.7 t is hydrogen.

b). **Macronutrients:** the nutrients required in large quantities are known as macronutrients. They are N, P, K, Ca, Mg, and S. Among these, N, P and K are called primary nutrients and Ca, Mg and S are known as secondary nutrients. The latter are known as secondary nutrients as they are inadvertently applied to the soils through N,P and K fertilisers which contain these nutrients.

c). **Micronutrients :** the nutrients which are required in small quantities are known as micronutrients or **trace elements**. They are Fe, Zn, Cu, B, Mo and Cl, Mo, Ni. These elements are very efficient and minute quantities produce optimum effects. On the other hand, even a slight deficiency or excess is harmful to the plants.

2. **Functions in the plant:** based on the functions, nutrients are grouped into four: basic structure, energy use, charge balance and enzyme activity.

I. Elements that provide basic structure to the plant- C, H and O.

II. Elements useful in energy storage, transfer and bonding- N, S and P. These are accessory structural elements which are more active and vital for living tissues.

III. Elements necessary for charge balance- K, Ca and Mg. These elements act as regulators and carriers.

IV. Elements involved in enzyme activation and electron transport- Fe, Mn, Zn, Cu, B, Mo and Cl. These elements are catalysers and activators.

3. Mobility in the soil: based on the mobility in the soil, the nutrient ions can be grouped as mobile, less mobile and immobile. The mobile nutrients are highly soluble and are not adsorbed on clay complex e.g. NO_3, SO, BO_3, Cl, Mn. Less mobile nutrients are also soluble, but they are adsorbed on clay complex and so their mobility is reduced e.g. NH4, K, Ca, Mg, Cu. Immobile nutrients ions are highly reactive and get fixed in the soil. E.g. H_2PO_4, HPO_4, Zn.

3. Mobility in plants:

a. N, P and K are highly mobile.

b. Zn is moderately mobile.

c. S, Fe, Mn, Cu, Mo and Cl are less mobile.

d. Ca and B are immobile.

4. Chemical Nature: the nutrients can be classified into cations and anions and metals and non-metals based on their chemical nature.

a. Cations: K, Ca, Mg, Fe, Mn, Zn, Cu.

b. Anions: NO_3, SO, H_2, PO_4.

c. Metals : K, Ca, Mg, Fe, Mn, Zn, Cu.

d. Non-metals: N, P, S, B, Mo, Cl.

factors affecting nutrient availability to plants

1. **External Factors:**

a. **Oxidation Reduction State of Elements:** Many elements in their most oxidized state, in which they occur naturally, are favored in adsorption. However, Fe and Mn are more available in their reduced form.

b. **Concentration of the elements:** the relative concentration of an element influences the livelihood of absorption. Higher the concentration of a nutrient greater is its availability.

c. **Moisture content of the soil:** the nutrients are readily taken by the plant when they are present in soil solution. Therefore, soil moisture is an important factor influencing the absorption of nutrients. Water helps in transport of nutrients to the root surface.

d. **Aeration:** For active absorption, energy is necessary which is released during respiration. Better aeration of the soil provides sufficient oxygen for the respiration of roots.

e. **Temperature:** temperature has to be favorable both for root and shoot growth and also for microorganisms to increase nutrient availability.

f. **pH:** Soil reaction is an important external factor influencing absorption through its role in nutrient availability. The pH range where nutrient availability is more are: N-6 to 8, P-6 to 7.5 and beyond 8.5, K-7.5 to 8.5.

Mechanism of absorption

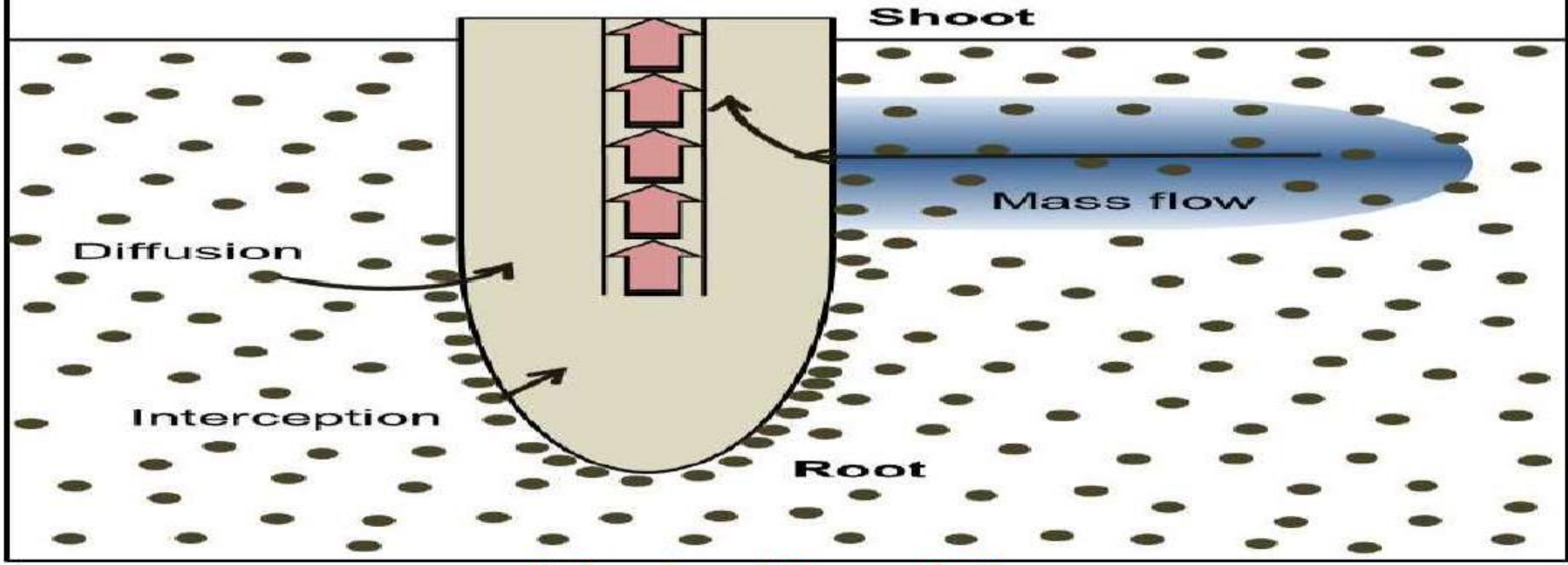
Nutrients are absorbed by the plants in two ways:

1. **Active Absorption:** Absorption of nutrients from soil solution containing low concentration of nutrients compared to plant sap, by expending energy, is called active absorption.
2. **Passive absorption:** Nutrients enter the plants along with transpiration stream without the use of energy.

Transport of Nutrients to Root Surface

Two important theories, namely soil solution theory and contact exchange theory explain nutrient availability to plants.

1. **Soil solution theory:** soil nutrients are dissolved in water and are transported to root surfaces by both mass flow and diffusion. Mass flow is movement of nutrient ions and salts along with moving water. The movement of nutrients reaching the root is thus dependent on the rate of water flow. Diffusion occurs when there is concentration gradient of nutrients between the root surface and surrounding soil solution. The ions move from the region of high concentration to the region of low
2. **Contact Exchange Theory**: A close contact between root surface and soil colloids allows a direct exchange of H, released from the plant roots with cations from soil colloids. The importance of contact exchange in nutrient transport is less than with soil solution movement.



Criteria of Essentially

Arnon and Stout (1939) proposed criteria of essentially which was refined by **Arnon (1954).**

1. An element is considered as essential, when plants cannot complete vegetative or reproductive stage of life cycle due to its deficiency.
2. When this deficiency can be corrected or prevented only by supplying this element.
3. When the element is directly involved in the metabolism of the plant.

Nutrients deficiencies symptoms and function

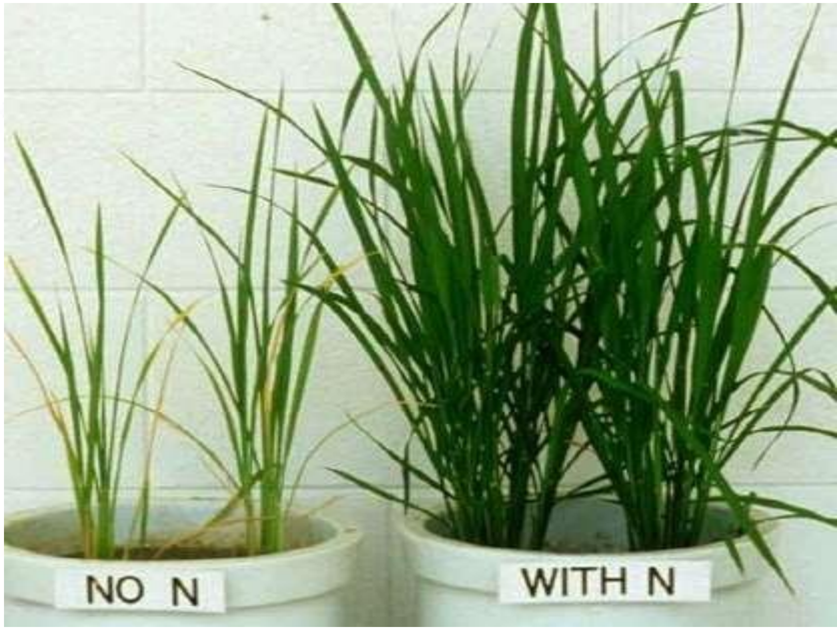
Nitrogen : symbol: N; available to plants as nitrate (NO_3^-) , and ammonium (NH_4^+) ions.

functions:

- N is biologically combined with C, H, O, and S to create amino acids, which are the building blocks of proteins. Amino acids are used in forming protoplasm, the site for cell division and thus for plant growth and development.
- Since all plant enzymes are made of proteins, N is needed for all of the enzymatic reactions in a plant.
- N is a major part of the chlorophyll molecule and is therefore necessary for photosynthesis.
- N is a necessary component of several vitamins.
- N improves the quality and quantity of dry matter in leafy vegetables and protein in grain crops.

Deficiency symptoms

- Stunted growth may occur because of reduction in cell division.
- Pale green to light yellow color (chlorosis) appearing first on older leaves, usually starting at the tips. This is caused by the translocation of N from the older to the younger tissues.
- Reduced N lowers the protein content of seeds and vegetative parts. In severe cases, flowering is greatly reduced.
- N deficiency causes early maturity in some crops, which results in a significant reduction in yield and quality.



Phosphorus : Symbol: P; available to plants as orthophosphate ions $H_2PO_4^-$, HPO_4^{2-}.

functions

- In photosynthesis and respiration, P plays a major role in energy storage and transfer as ADP and ATP.
- P is part of the RNA and DNA structures, which are the major components of genetic information.
- Seeds have the highest concentration of P in a mature plant, and P is required in large quantities in young cells, such as shoots and root tips, where metabolism is high and cell division is rapid.
- P play major role in root development, flower initiation, and seed and fruit development.

Deficiency symptoms

- Because P is needed in large quantities during the early stages of cell division, the initial overall symptom is slow, weak, and stunted growth.
- P is relatively mobile in plants and can be transferred to sites of new growth, causing symptoms of dark to blue-green coloration to appear on older leaves of some plants. Under severe deficiency, purpling of leaves and stems may appear.
- Lack of P can cause delayed maturity and poor seed and fruit development.

Potassium :

functions

- K assists in regulating the plant's use of water by controlling the opening and closing of leaf stomates, where water is released to cool the plant.
- In photosynthesis, K has the role of maintaining the balance of electrical charges at the site of ATP production.
- K promotes the translocation of photosythates (sugars) for plant growth or storage in fruits or roots.
- Through its role assisting ATP production, K is involved in protein synthesis.
- K has been shown to improve disease resistance in plants, improve the size of grains and seeds, and improve the quality of fruits and vegetables.

Deficiency symptoms

- The most common symptom is chlorosis along the edges of leaves (leaf margin scorching). This occurs first in older leaves, because K is very mobile in the plant.
- Because K is needed in photosynthesis and the synthesis of proteins, plants lacking K will have slow and stunted growth.
- In some crops, stems are weak and lodging is common if K is deficient.
- The size of seeds and fruits and the quantity of their production is reduced.

Nutrient Use Efficiency : Nutrient Use Efficiency is defined as the amount of dry matter produced per unit of nutrient applied or absorbed.

Nutrient Use Efficiency : Physiological efficiency X Apparent recovery efficiency

Classification of NUE:

1. **Agronomic efficiency**: it is defined as the economic production obtained per unit of nutrient applied. It is calculated by the following equation:

$$\text{Agronomic efficiency} = \frac{\text{(Grain yield of fertilized crop in kg)} - \text{(Grain yield of unfertilized crop in kg)}}{\text{(Quantity of fertilizer applied in kg)}}$$

2. **Physiological efficiency**: it is defined as the biological production obtained per unit of nutrient applied. It is calculated by the following equation:

$$\text{Physiological efficiency} = \frac{\text{(Total drymatter yield of fertilized crop in kg)} - \text{(Total drymatter yield of unfertilized crop in kg)}}{\text{(Nutrient uptake by fertilizer crop in kg)} - \text{(Nutrient uptake by unfertilized crop in kg)}}$$

3. **Apparent recovery efficiency**: it is defined as the quantity of nutrient absorbed per unit of nutrient applied. It is calculated by the following equation:

$$\text{Apparent recovery efficiency} = \frac{\text{(Nutrient uptake by fertilized crop)} - \text{(Nutrient uptake by unfertilized crop)}}{\text{(Quantity of fertilizer applied)}}$$

Time of fertilizer application

1. **Prior to sowing:** Some of water insoluble fertilizers such as rock phosphate and basic slag are applied 2 to 4 weeks before sowing to enable conversion of water insoluble form to soluble form for efficient crop utilization . In acid soils, when lime requirement is 2 ton or less, the entire amount should be applied at one month before sowing of the crop.
2. **At sowing:** Application of fertilizer at the time of sowing or just before sowing is called basal application. A part of recommended nitrogen and entire quantity of phosphatic and potassium fertilizers are applied as basal.
3. **After sowing the crop:** Application of fertilizers after the crop establishment is called top dressing. Depending on the stage of crop, generally a portion of nitrogen is applied as top dressing.
4. **Split application :** When fertilizer is applied at two or more deferent time, the system is called a split application. For long duration crops, N must be applied in two or three split doses.

Method of fertilizer application

A. Soil Application

- **Broadcasting:** Application of fertilizer uniformly on the soil surface is known as broadcasting of fertilizer. This is done either before sowing of the crop or in the standing crop (top dressing). Broadcasting is the most widely practiced method in India due to ease in application.

Band Placement: Application of fertilizers in narrow bands beneath and by the side of the crop rows is known as band placement of fertilizers. Band placement is done under the following situations: (I) when the crop needs initial good start, (2) when soil fertility is low, (3) when fertilizer materials react with soil constituents leading to fixation, and (4) where volatilization losses are high. Depending on the root system, fertilizer band is placed directly beneath the seed or by the side of the row. For crops like castor, redgram, cotton etc., with tap root system, fertilizer band can be 5 cm below the seed. In cereals and millets, which produce fibrous root system, it is advantageous to place fertilizers 5 cm away from the seed row and 5 cm deeper than the seed placement.

3. **Point Placement :** Placement of fertilizers near the plant either in a hole or in a depression followed by closing or covering with soil is known as point placement of fertilizers.

4. **Fertigation :** Application of fertilizers with irrigation water is known as fertigation. This saves the application cost and allows the utilization of relatively inexpensive water soluble fertilizers. Usually nitrogenous fertilizers are most commonly applied through irrigation water. It is generally followed with drip irrigation.

- **Application to plant**

1. **Root Dipping:** The roots of the seedlings are dipped in nutrient solution before transplanting. In soils deficient in phosphorus, roots of rice seedlings are dipped in phosphorus slurry before planting.

2. **Foliar application:** Application of fertilizers to foliage of the crop as spray solution is known as foliar spray of fertilizers. It is also called non-root feeding. These solutions may be prepared in a low concentration to apply any one of plant nutrient or a combination of nutrients. This method is suitable for application of small quantities of fertilizers, especially micronutrients.

FUE(Fertilizer Use Efficiency):

It may be defined as yield per unit fertilizer input or it may be fresh weight or product yield per unit content of nutrient.

Nutrient use efficiency of different nutrients

Nutrient	Efficiency	Cause of low efficiency
Nitrogen	30-50 %	Immobilization, volatilization, de-nitrification, Leaching
Phosphorus	15-20%	Fixation in soils Al – P, Fe – P, Ca – P
Potassium	70-80%	Fixation in clay - lattices
Sulphur	8-10%	Immobilization, Leaching with water
Micro-nutrients (Zn, Fe, Cu, Mn, B)	1-2%	Fixation in soils

Factors affecting FUE/NUE

1. Leaching (NO3).
2. Gaseous Losses (NH3,N2O,N2).
3. Immobilization by chemical precipitation, adsorption on exchange complex and microbial cells.
4. Chemical reactions between various components in fertilizers during mixing, before application to soil.
5. Physical properties of soil.
6. Chemical properties of soil.
7. Fertilizer characteristics.

Methods of Increasing Fertilizer Use Efficiency

- **Following methods which can be adopted to increase FUE:**
- **Agronomic methods**
- **Chemical methods**

1. Agronomic methods :

i. Application of fertilizers at right time with required quantity

The phosphates in general are more efficient when the entire dose applied as basal dressing, potash entire quantity as basal dressing or part as basal and rest in split doses depending on the soil texture and the nitrogen in 2-3 (or 4) split doses.

Example:

- **In Sugarcane,**

Potassium application normally done along with N application because of better utilization of N, in the presence of K. therefore K is applied at **45, 90 DAS.**

2.Chemical methods :

Synthetic or chemical fertilizers should be good quality and right source for crops.

Examples:

- Oilseed- Generally Sulphate fertilizers like elemental sulphur @ 25Kg/ha, $ZnSO_4$ @ 25 Kg/ha, Borax @ 1-2% application must be done.
- In tobacco plant avoid using of fertilizers containing chlorine for preventing from scorching effect.
- In tea plantation use of $(NH)_2SO_4$ is best.
- In Paddy, Ammonium and urea fertilizer are more efficient for paddy under different Indian conditions than nitrate fertilizers.

Water: Water is indispensable for human, animal and plant life. It is a part of all organisms some of which contain more than 90%.Water is an essential part of protoplasm. It is an important ingredient in photosynthesis. About 400 to 500 liter of water is necessary for the production of a kilo of plant dry matter. Water is also required for translocation of nutrients and dissipation of heat.

Role of water in plant

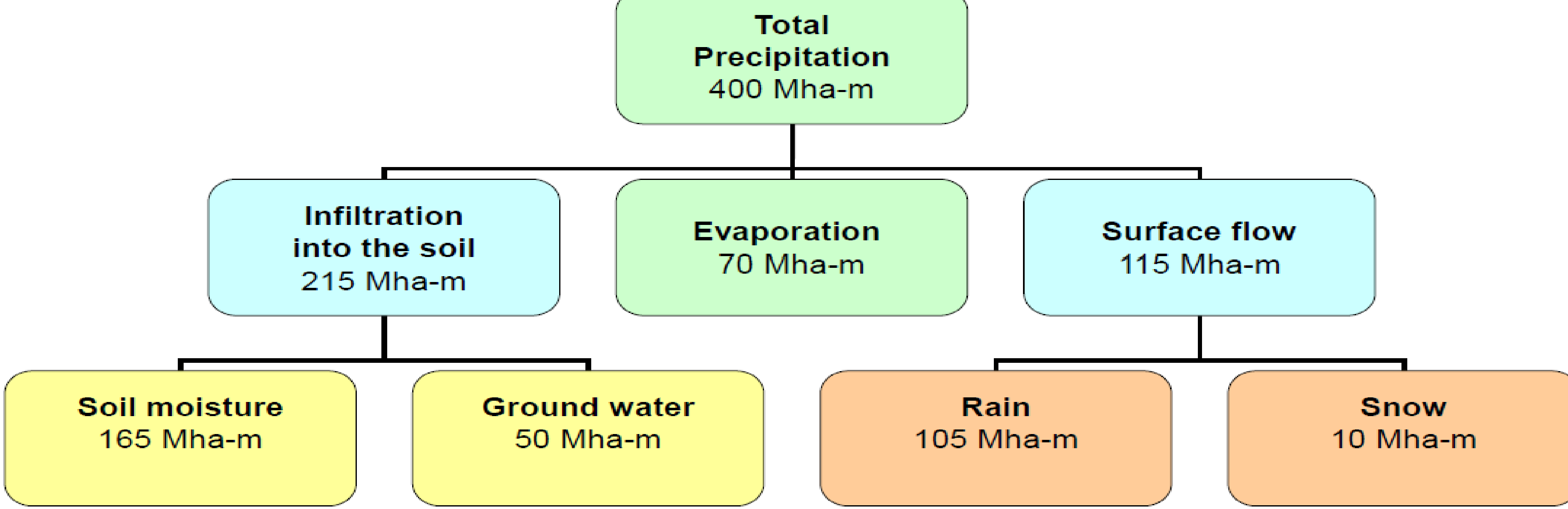
Water is essential for the germination of seeds and growth of plants.

During the process of photosynthesis, plants synthesize carbohydrates from carbon dioxide and water

Water act as a solvent for fertilizers and other minerals, which are taken up by the plant roots in the from of solution.

Water serves as medium for transport of chemicals to and from cell.

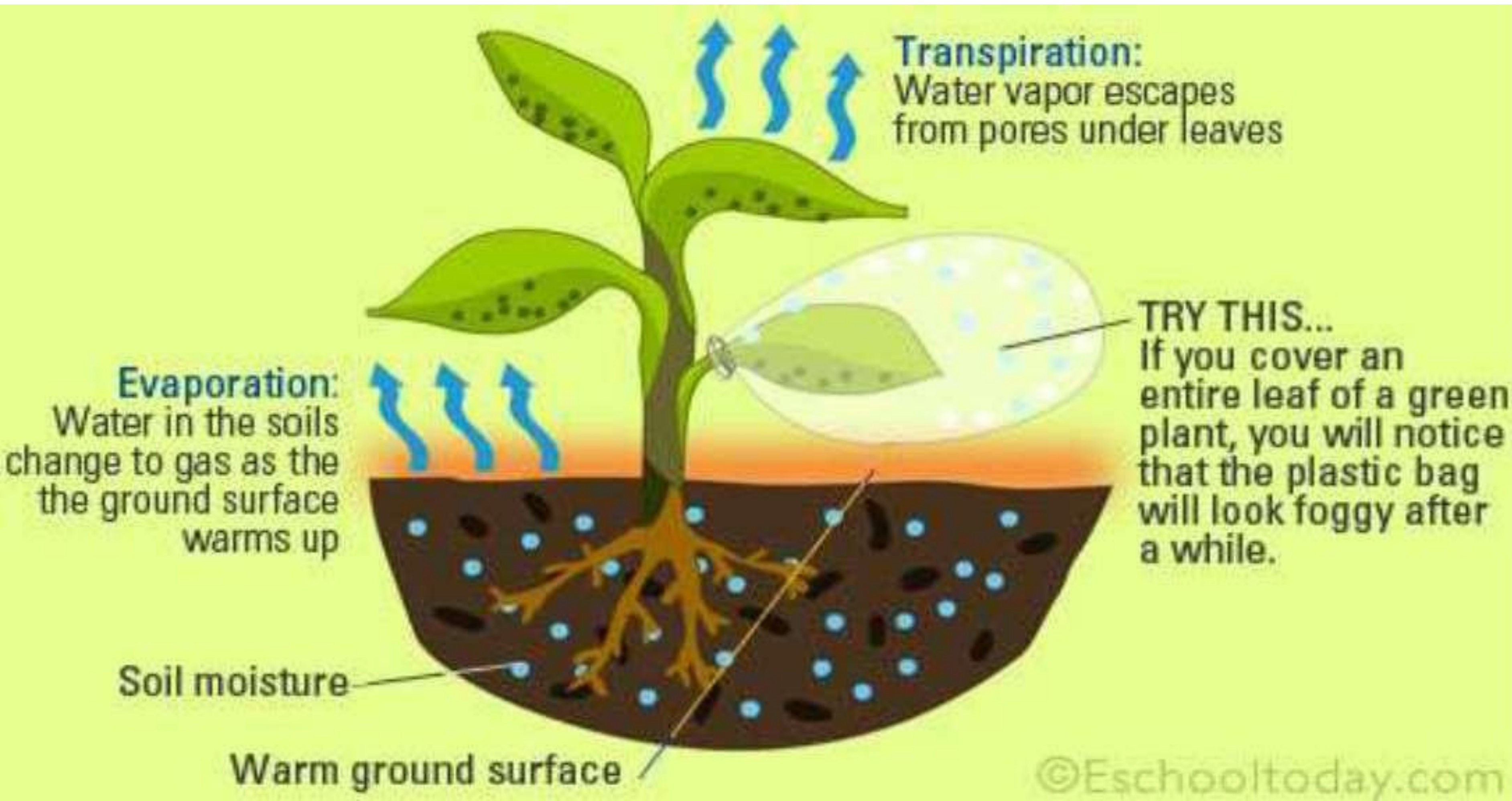
Aquatic life is possible in water only.



Transpiration: Transpiration is the process of water movement through a plant and its evaporation from aerial parts, such as leaves, stems and flowers. Water is necessary for plants but only a small amount of water taken up by the roots is used for growth and metabolism.

Factors affecting transpiration: Temperature, Water, Wind. The environmental factors affecting transpiration in plants include light, relative humidity, temperature, availability of water, and wind. Specifically, these are climatic elements which also affect photosynthesis and other plant growth and development processes.

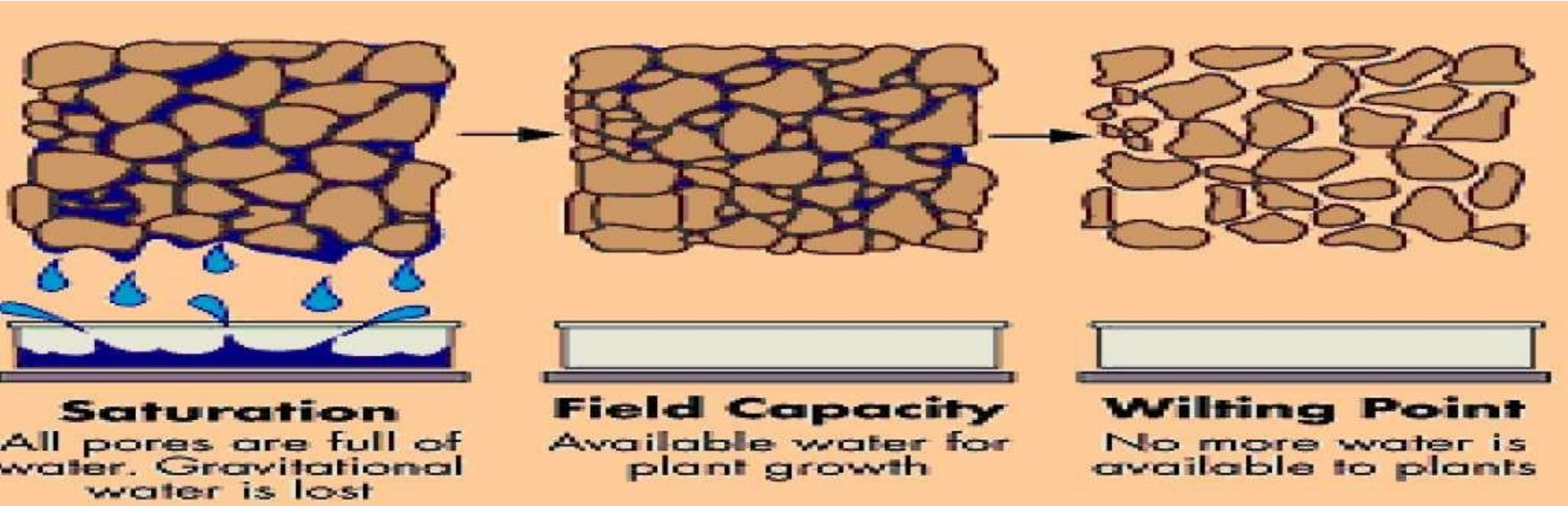
Purpose of transpiration in plants: Transpiration serves three essential roles: Movement of water and nutrients – Moves minerals up from the root (in the xylem) and sugars (products of photosynthesis) throughout the plant (in the phloem). Cooling – 80% of the cooling effect of a shade tree is from the evaporative cooling effects of transpiration.



Soil Moisture Constants

- Water contents under certain standard conditions are referred to as soil moisture constants.

1. **Saturation capacity:** Saturation capacity refers to the condition of soil at which all the macro and micro pores are filled with water and the soil is at maximum water retention capacity.
2. **Field capacity:** At field capacity, the soil moisture tension depending on the soil texture ranges from 0.10 to 0.33 bars (or −10 to −33 kPa). field capacity is considered as the upper limit of available soil moisture.



Physical Classification of Water

1. **Gravitational water:** Water held between 0.0 to 0.33 bars (0 to −33 kPa) soil moisture tension, free and in excess of field capacity, which moves rapidly down towards the water table under the influence of gravity is termed as gravitational water.
2. **Capillary water:** As the name suggests capillary water is held in the pores of capillary size i.e., micro pores around the soil particles by adhesion (attraction of water molecules for soil particles), cohesion (attraction between water molecules) and surface tension phenomena. It includes available form of liquid water extracted by growing plants and is held between field capacity (0.33 bars or −33 kPa) and hygroscopic coefficient (31 bars or −3100 kPa).
3. **Hygroscopic water:** The water held tightly in thin films of 4 – 5 milli microns thickness on the surface of soil colloidal particles at 31 bars tension (−3100 kPa) and above is termed as hygroscopic water.

Soil – Plant and Plant – Water Relations

To design a successful irrigation system, it is essential to know the plant rooting characteristics, effective root zone depth, moisture extraction pattern and moisture sensitive periods of crops.

Rooting characteristic of plants: The purpose of irrigation is to provide adequate soil moisture in the immediate vicinity of the plant roots. All plants do not have the similar rooting pattern i.e., root penetration and proliferation. Some plants have relatively shallow root system (for example annual crops), while others develop several meters under favorable conditions (for example tree crops).

Soil properties influencing root development

1. **Hard pan:** Root penetration is seriously affected by presence of a hard pan or compacted layer in the soil profile. Thus roots cannot penetrate a hard layer except through cracks.
2. **Soil moisture:** Since roots cannot grow in soil that is depleted in moisture down to and below the permanent wilting point, a layer of dry soil below the surface in the profile can restrict root penetration.
3. **Water table:** A high water table limits root growth, and a rising water table may kill roots that have previously grown below the new water level.
4. **Toxic substances:** Presence of toxic substances in the sub-soil also limits root growth and development. Saline layers or patches in the soil profile therefore inhibit or prevent root penetration and proliferation.

Types of water movement

- Generally three types of water movement within the soil are recognized –saturated flow, unsaturated flow and water vapour flow.

1. **Saturated water movement:** The condition of the soil when all the macro and micro pores are filled with water the soil is said to be at saturation, and any water flow under this soil condition is referred to as saturated flow.

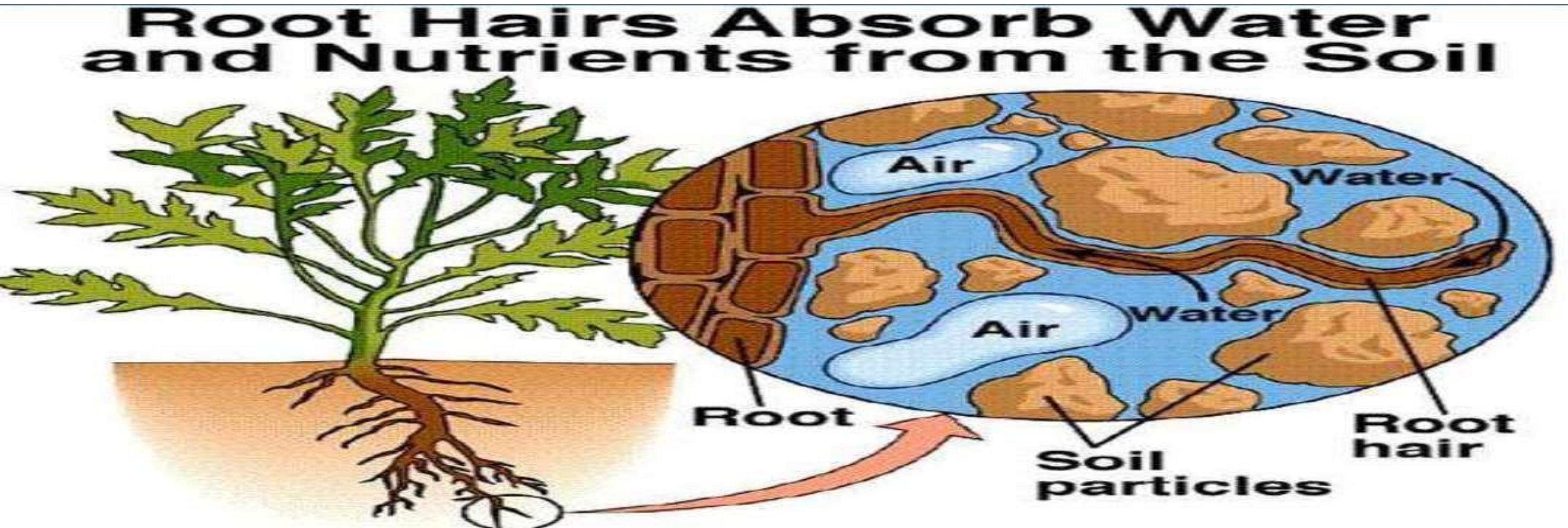
2. **Unsaturated water movement:** The soil is said to be under unsaturated condition when the soil macro pores are mostly filled with air and the micro pores (capillary pores) with water and some air, and any water movement or flow taking place under this soil condition is referred to as unsaturated flow.

Water absorption by plants

Mechanism of Absorption of Water: In higher plants water is absorbed through root hairs which are in contact with soil water and form a root hair zone a little behind the root tips.

Mechanism of water absorption is of two types:

1. **Active Absorption of Water:** In this process the root cells play active role in the absorption of water and metabolic energy released through respiration is consumed.
2. **Passive Absorption of Water:** It is mainly due to transpiration, the root cells do not play active role and remain passive.



Water stress: Water stress occurs when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use. Water stress causes deterioration of fresh water resources in terms of quantity (aquifer over-exploitation, dry rivers, etc.).

Moisture stress: Moisture stress occurs when the water in a plant's cells is reduced to less than normal levels.

Crop plant adaptation to moisture stress condition

Effect on cereals:

1. On floral initiation, anthesis (wheat and rice)
2. At ripening stage (reduction in test wt.)
3. Plant height, leaf area.
4. leaf rolling, drying, premature death of leaf.
5. Reduction in photosynthesis and dry matter production.

The Effect of Water Stress on Plants

- **Wilting:** As wilting increases, plant cells fully deflate, causing their deaths. Partially wilted plants that are still green may recover if watering is quickly initiated -- the addition of mulch helps to keep soil moisture even.
- **Reduced Photosynthesis:** Photosynthesis is the process through which plants create their own food. The amount of water, sunlight and carbon dioxide available to the plant directly influences the amount of food a plant can produce. When water levels are low due to water stress, photosynthesis can slow or even stop, causing internal food supplies vital to other processes to diminish or disappear -- yellowing may also occur if photosynthesis stops completely.
- **Reduced Respiration:** Respiration is the process through which plants break down their food supply for energy to power system processes. When plants are actively growing, they respirator heavily, using up food stores quickly. With low water levels reducing the plant's ability to photosynthesize, the plant's system processes slow down, causing reduced or delayed growth and discoloration of leaves, as well as flower or fruit drop.
- **Reduced Transpiration:** Water taken up by a plant's roots is slowly drawn up to openings in its leaves called stomas. The stomas release waste products such as oxygen into the environment and bring in carbon dioxide. This release also helps cool plant tissues. In addition, transpiration maintains turgor in plants, keeping cells evenly filled with water. When transpiration is stopped or slowed, the plant begins to die from lack of nutrients, usually from the top down.

WHAT IS WUE

- It is defined as in different context by
- 1. Hydrologist: It is the ratio of the volume of water used for productivity to the volume of water potentially available for irrigation & amount of water available from soil.
- 2. Agronomists: Amt of economic yield produced by unit of water applied where both evaporation and transpiration are considered.
- 3. Physiologist: It is the amount of water used in transpiration to produce unit amount of dry matter during a particular growth period.
- WUE=Dry matter produced (g) / Water lost in transpiration(Kg)

Factors effecting water use efficiency

1. Vapour pressure deficit (VPD) : It depends on atmospheric humidity. Under high RH, VPD will be low and vice versa. VPD is the driving force for transpiration, hence an increase in leaf to air vapor pressure difference substantially increases the transpiration, there by decrease in WUE. This situation occur under water limited situation or high leaf temp. hence the prevailing RH & leaf temp.

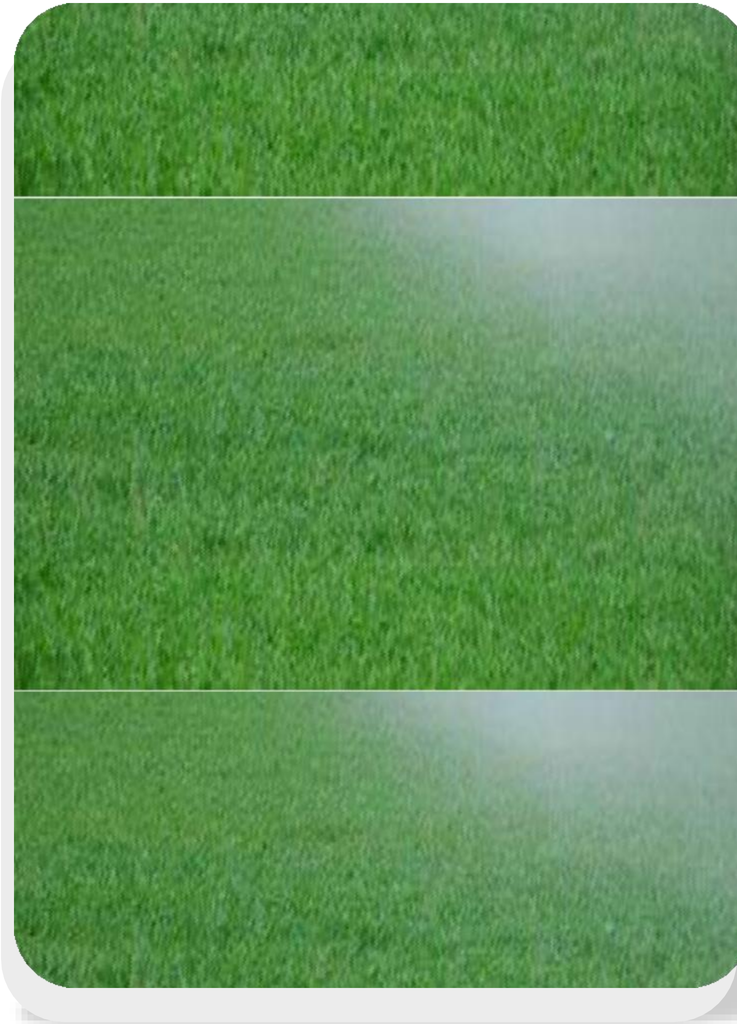
2. Light: The solar radiation has a vital role to play in determining WUE. Optimum irradiance will cause maximum efficiency of water use. High irradiance will increasing the leaf temp. and reducing the stomatal resistance there by decrease WUE.

3.Temperature: Leaf temp. have profound effect on WUE. Leaf temp. depend on atmospheric temperature & leaf water content. High atmospheric temp. coupled with lower water uptake (moisture limited conditions) increases high VPD , there by increases transpiration and finally WUE is affected. The genotypes maintain low leaf temp. are always good at efficient utilization of water.

4. **CO2 concentration:** Enhanced Co2 concentration in atmosphere will increase WUE , by higher photosynthesis, & higher dry matter accumulation. Such increased Co2 concentration is one of the component in global warming & increase in productivity of crops was estimated initially due to global warming or green house effect.

5. **Moisture stress:** Drought stress is a complex combination of stress because of both water deficit and high temp. moderate drought increases WUE up to 100% while extreme drought could substantially decrease WUE. A common response to water stress is simultaneous decrease in photosynthesis & transpiration & increase in leaf temp..

SIGNIFICANCE OF IRRIGATION SHEDULING AND TECHNIQUES



INTRODUCTION

- **Scheduling of irrigation to crops is essential for efficient utilization of available water, saving of input and enhancing yield.**

- **Scheduling of irrigation is a process to decide 'when to irrigate' and 'how much to irrigate' to the crops. Proper scheduling is essential for efficient use of irrigation water, inputs such as seeds, fertilizers, labour etc.**
- **Appropriate scheduling of irrigation not only saves water, but also, saves energy besides, higher crop yield.**
- **Farmers are generally irrigating their crops on either time interval basis (say weekly interval, ten days interval) or based on the appearance of the crops (based on wilting symptoms).**
- **There are several soil, plant and atmospheric (meteorological) indicators in addition to combination approach, critical stage approach etc. to decide when to irrigate? the crop.**
- **Similarly, based on the moisture content in the effective root zone quantity of irrigation water (how much to irrigate?) to crops is decided.**

1. Soil Indicators

- These methods involve in determining moisture content of the soil and finding the deficit level in available moisture.
- Based on pre-determined minimum water content, irrigation is given to bring the soil to field capacity.
- The soil water content is determined either by direct measurement or inference from measurements of other soil parameters such as soil water potential or electrical conductivity.

Gravimetric method

- **It is the direct method of measuring the moisture content of soil.**
- **Samples taken from the field, weighted, dried at 105°C for about 24 hours till constant weight is obtained and again weighed after drying.**
- **The difference in weight between the wet (WS_1) and oven dry (WS_2) samples gives the moisture content (Pw) in percentage.**

$$Pw\ (\%) = \frac{WS_1 - WS_2}{WS_2}$$

The method is simple and reliable, but, time consuming and sampling is destructive.

Feel and appearance method

- **With experience, farmer can judge soil water content by the feel and also appearance of the soil.**

- **Soil samples are taken with a probe or soil auger from each quarter of the root zone depth, formed into a ball, tossed into air and caught in one hand.**

- **Considerable experience and judgment are necessary to estimate available soil moisture content in the sample within reasonable accuracy.**

Tensiometer method

- Irrigation can be scheduled based on soil moisture tension.
- Tensiometers (Irrometers) are installed at specified depth in the root zone.
- When the soil moisture tension reaches to a specified values (0.5, 0.75 or 1.0 bars etc.) irrigation is scheduled.
- Tensiometers are generally used to schedule of irrigation in orchards, especially in coarse textured soils.

- This method however, fails to provide the quantity of water to be irrigated.

Electrical resistance method

- The principle involved in electrical resistance method is that a change in moisture content of the soil gives change in electrical conductivity in a porus block placed in a soil.
- Gypsum, nylon and fibre, fibre glass blocks are generally used to measure a tension of different levels.
- Use of tensiometers and electrical resistance (gypsum blocks) methods are not popular, because, tensiometer have working range of 0 to 0.8 bars, whereas, gypsum blocks don't work at low level tensions.

- Also, both of these methods don't provide moisture status.

2. Plant indicators

- **The primary objective of irrigation is to supply of water to meet the plant needs.**
- **Monitoring plants is the most direct method of determining irrigation scheduling.**

- **Plant parameters have to be related to soil water content to determine the irrigation scheduling.**

IW/CPE approach

- In this approach, a known quantity of irrigation water (IW) is applied when cumulative pan evaporation (CPE) reaches a predetermined level.
- The amount of water given in each irrigation ranges from 4 to 6 cm, the most common being 5 cm of irrigation.
- Scheduling irrigation at an IW/CPE ratio of 1.0 with 5 cm of irrigation water is applied when the CPE reaches 5 cm.
- Generally, irrigation is scheduled at 0.75 to 0.8 ratio with 5 cm of irrigation water.

- In IW/CPE ratio approach, irrigation can also be scheduled at fixed level of CPE by varying amount of irrigation water.
- However, the equipment to measure CPE and IW are not easily available with the farmers.

5. Rough methods for farmers

- Simple methods are suggested to the farmers to find out when to start irrigation and how much water to apply.
- They use only the feel and appearance method described earlier as a rough guide to know when to irrigate and the probe is used to determine when to stop irrigation.

Can evoporimetry method

- **Small can of one litre capacity (14.3 cm height and 10 cm diameter) are used to indicate evaporation from the cropped field.**
- **The cans are white painted and covered with 6/20 size mesh.**
- **A pointed indicator is fixed at 1.5 cm below the brim of can.**
- **When irrigation is given (bringing the soil to field capacity), the can is filled up with water to pointer level and kept to the crop height. Evaporation from the can is directly related to the crop evaporation.**
- **Irrigation is scheduled when water level in the can falls to a predetermined level (equal to the amount of water to be applied at each irrigation) and can is filled again to pointer level.**

Soil cum mini-plot technique

- **In this method, 1x1x1 m size of pit is dug in the middle of the field.**
- **About 5% of sand (by volume) is added to the pit, mixed well with soil and the pit is filled up in natural order.**
- **Crops are grown normally in all areas including pit area.**
- **The plants in the pit show wilting symptoms earlier than the other areas.**
- **Irrigation is scheduled as soon as wilting symptoms appear on the plants in the pit.**

Sowing high seed rate

- **In an elevated area, one square metre plot is selected and crop is grown with four times thicker than the normal seed rate.**

- **Because of high plant density, plants show wilting symptoms earlier than in the rest of the crop area indicating the need of scheduling of irrigation.**

5. Critical stage approach

- **In each crop, there are certain growth stages at which moisture stress leads to irrevocable yield losses.**
- **These stages are called as critical period or moisture sensitive period.**
- **Hence, irrigation must be given to these stages to avoid yield losses.**

Moisture sensitive stages of important crops

Crop	Important moisture sensitive stages
Rice, pearl millet, finger millet	Panicle initiation, flowering
Wheat	Crown root initiation, jointing, milking
Sorghum	Seedling, flowering
Maize	Silking, tasselling
Groundnut	Rapid flowering, pegging, early pod formation
Redgram, greengram, blackgram, peas	Flowering, pod formation
Sugarcane	Formative stage
Sesame	Blooming to maturity stage
Sunflower	Two weeks before and after flowering
Safflower	Rosette to flowering
Soybean	Blooming, seed formation
Cotton	Flowering, boll development
Tobacco	Transplanting to full blooming
Chilli	Flowering
Potato	Tuber formation to tuber maturity
Onion	Bulb formation to maturity
Tomato	From commencement of fruit setting
Cabbage	Head formation to firming stage of head
Carrot	Root enlargement

II. HOW MUCH TO IRRIGATE

- **The quantity of irrigation water to be applied to the soil at each irrigation depends upon the amount of available moisture in the soil (specifically at effective root depth i.e. moisture extraction depth of the roots), at the time of starting irrigation (or the level of available moisture depletion from filed capacity) at which irrigation is proposed.**
- **The effective rainfall expected in the period between this irrigation and the next one and the additional quantity of irrigation water required if salts are to be leached beyond root zone and the application losses.**
- **The basic principle is mainly to give irrigation to bring the soil (at effective root zone depth of crops) to field capacity.**
- **More often, allowance is given for expected effective precipitation to be stored in the soil.**