

**A Theory Notes
on**

Course No. AGRO-111 (2+1=3)

Title: FUNDAMENTALS OF AGRONOMY

As per Sixth Dean committee by 2024



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Suggested Readings of Books:

Sr. No.	Author(s)	Name of Book	Publication
1	William L Donn	Meteorology	McGraw-Hill Book Co. New York
2	Yawalkar K S and Agarwal J P.	Manures and Fertilizers	Agricultural Horticultural Publishing House, Nagpur.
3	Rao V.S.	Principles of Weed Science	Oxford and IBH Publishing Co. Ltd., Bangalore.
4	Reddy Yellamanda T and Shankar Reddy G H.	Principles of Agronomy	Kalyani Publishers 6. Ludhiana.
5	Reddy , S. R.	Principle of Crop Production	Kalyani Publisher, Ludiana
6	S. R. Reddy	Principles of Agronomy	Kalyani publication. Ludhiana
7	Vaidya, V.G., Sahasrabuddhe, K.R. and Khuspe, V.S.	Crop production and field experimentation.	Continental Prakashan, Vijaynagar, Pune.
8	Chhidda Singh	Modern techniques of raising field corps	Oxford and IBH Publishing Co. Ltd., Bangalore.
9	Gopal Chandra De.	Fundamentals of Agronomy	Oxford and IBH Publishing Co. Ltd., Bangalore.
10	Palaniappan, S.P.,	Cropping Systems in the tropics – Principles and Practices	Willey Eastern Ltd., New Delhi.
11	Panda, S.C.,	Agronomy	Agribios Publication, New Delhi.
12	Reddy, S.R.	Principles of Agronomy	Kalyani Publishers, Ludhiana, India
13	Sankaran, S and Subbiah Mudliyar, V.T	Principles of Agronomy	Bangalore Printing and Publishing Co. Ltd., Bangalore.
14	Gupta, O.P.	Modern Weed Management	Agribios Publication, New Delhi.
15	S R Reddy	Fundamentals of Agronomy	Kalyani publication. Ludhiana

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4.	Tillage and tith: Definition, objectives, types, advantages and disadvantages of tillage including conservation tillage.	
5.	Crop density and geometry: plant geometry and planting geometry, its effect on growth, yield	
6.	Crop nutrition: Definition of essential nutrients, criteria of essentiality, functional elements, classification of essential nutrients, role of macro and micro nutrients. Nutrient absorption, active and passive absorption of nutrients, forms of plant nutrients absorbed by plants, Combined /un-combined forms	
7.	Manures and fertilizers, nutrient use efficiency: Sources of nutrients: Inorganic (fertilizers), organic (manures) and bio-fertilizers; their classification and characteristics, method of preparation and role of organic manures in crop production	
8.	Integrated Nutrient Management: Meaning, different approaches and advantages of INM	
9.	Green manure- role in crop production: Definition, objectives types of green manuring, desirable characteristics, advantages and limitations of green manuring	
10.	Water management: Water resources of the world, India and the state; Soil Moisture Constants –gravitational water, capillary water, hygroscopic water, Soil moisture constants, Concept of water availability to plants, soil plant- water relationship, crop water requirement, water use efficiency, Methods of irrigation : Scheduling of irrigation, different approaches of scheduling irrigation	
8.	Weeds: Definition, Importance and basics of classification of weeds and their control	
9.	Cropping systems: Factors affecting cropping systems, major cropping patterns and systems in the country.	
10.	Sustainable crop production: Definition, importance and practices, natural resources and conservation pollution and pollutants,	
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12.	Growth and development of crops: Definition, Meaning and factors affecting growth and development	

Chapter-1

Agronomy, its scope and relationship with other sciences

Agriculture: - The term agriculture is derived from two Latin words **ager** or **agri** meaning **soil** and **cultura** meaning **cultivation**. Agriculture is a broad term including all aspects of crop production, livestock farming, fisheries, forestry etc.

Agriculture is a branch of applied science. It is the art of farming including the work of cultivating the soil for producing crops and raising livestock. There are three main spheres of agriculture as under;

Geoponic:- meaning cultivation in earth,

Hydroponic:- meaning cultivation in water and

Aeroponic:- meaning cultivation in air.

AGRICULTURE is defined in the Agriculture ACT, 1947, as including ‘horticulture, fruit growing, seed growing, dairy farming and livestock breeding and keeping, the use of land as grazing land, meadow land, osier land, market gardens and nursery grounds, and the use of land for woodlands where that use ancillary to the farming of land for Agricultural purposes’.

Agriculture is defined as an art, science and business of producing crops and livestock for economic purposes

Agriculture is a productive unit where the gifts of nature like land, light, water and temperature are integrated into a single primary unit i.e **crop plant** which is indispensable for human beings. The secondary productive units of agriculture are **animals** including **livestock, birds and insects** which feed on the primary units and provide concentrated products such as **meat, milk, hide, wool, eggs, honey, silk and lac**.

Agriculture is considered as mother of all agro-based industries because the development and functioning of all such industries is governed by the raw material supplied from agriculture sector E.g. Textile, Oil, Sugar, Dairy and Canning industries are directly governed by cotton, oilseeds, sugarcane, milk and fruits production, respectively.

Agronomy- definition

Agronomy is a **Greek word** derived from **agros** meaning field and **nomos** meaning management. It is a field management. It is a specialized branch in agriculture dealing with crop production and soil management. **It is defined as an agricultural science deals with principles and practices of crop production and field management.**

Agronomist is a scientist who is dealing with the study of problems of crop production and adopting/recommending practices of better field crop production and soil management to get high yield and income.

In recent times, agronomy has assumed newer dimensions and can be defined as a branch of agricultural science that deals with methods which **provides favourable environment to the crop** for higher productivity.

Scope of Agronomy

Agronomy is a dynamic discipline. With the advancement of knowledge and better understanding of plant and environment, agricultural practices are modified or new practices developed for higher productivity. For example;-

- ❖ Availability of chemical fertilizers and herbicides for control of weeds has led to development of a vast knowledge about time, method and quantity of fertilizer and herbicide application.
- ❖ Big irrigation projects are constructed to provide irrigation facilities. However, these projects created side effects like water logging and salinity. To overcome these problems, appropriate water management practices are developed.
- ❖ Population pressure is increasing but the area under cultivation is static. Therefore, to feed the increasing population, more number of crops have to be grown on the same piece of land in an year. As a result, intensive cropping has come into vogue.
- ❖ Similarly, no tillage practices have come in place of clean cultivation as a result of increase in cost of energy.(Fuel prices of oil)
- ❖ Likewise, new technology has to be developed to overcome the effect of moisture stress under dry land conditions.
- ❖ As new varieties of crops with high yield potential become available, package of practices has to be developed to exploit their full yielding potential.

Role of Agronomy in Crop Production

The so called green revolution has been brought in sight through introduction of high yielding and hybrid varieties of different crops. Despite of high genetic yield potential of such varieties, it can not fully exploit unless adequate agronomic requirements are provided to them. Plant breeders are evolving new high yielding and hybrid varieties, where as, agronomist working out their proper agronomic requirements. Viz; preparation of seed beds, suitable sowing time, seed treatment, seed rate, spacing etc. Unless we provide sufficient agronomic requirements as cited above we can not harvest potential yield from any varieties. Of the agronomic factors required to augment crop production, restoration of soil fertility, proper conservation and management of soil moisture and proper control of weeds play important role in crop production. Evolving suitable cropping system, crop rotation, and multiple cropping are also fall under the purview of Agronomy.

Relation of agronomy to other sciences

Agronomy is a synthesis of several disciplines like soil science, Agricultural chemistry, crop physiology, plant ecology, biochemistry and economics.

The soil physical, chemical and biological properties have to be understood thoroughly to effect modification of the soil environment.

It is necessary to understand the physiology of crops to meet their requirements. Developments in these subject help in developing new practices which are simpler and economical to provide favourable environment to the crop. The herbicidal properties of 2,4-D made revolutionary changes in weed control.

Advances in economic analysis helped in production of crops economically. For efficient utilization of resources systems approach is better than individualistic approach. Instead of taking individual crop into consideration, for taking decisions, cropping system as a whole is considered. Eg. IFS against cropping alone. Similarly, fertilizer recommendation for an entire cropping system saves considerable quantity of fertilizer instead of recommending fertilizer to individual crops.

Role of Agronomist

Agronomist aims at obtaining maximum production at minimum cost.

1. He exploits the knowledge of the basic and applied sciences for higher crop production.
2. In a large scale, agronomist is concerned with production of food and fibre to meet the needs of growing population.
3. To develop efficient and economic field preparation method (i.e.) energy should be minimized (i.e.) what type of crop, in which season, etc.

4. He is also involved to select suitable crop and varieties to suit or to match varied seasons and soils Eg. Red soil – select groundnut, Black soil- cotton, Sandy soil – tuberous crops, Saline soil – Finger millet (Ragi), (In Kharif if water is sufficient go for rice, not sufficient maize, sorghum).
5. To develop efficient method of cultivation (whether broadcasting, nursery and transplantation or dibbling, etc.) The method may vary according to the germination period and depending upon the crop establishment and what should be the optimum plant population
6. He has to identify various types of nutrients required by crops, e.g. for long duration rice (150-60-60 kg NPK), short duration : 120:50:50 kg NPK/ha .The time and method of applying nutrients must also be taken into account. Method refers to broadcasting or band application (close to the root) or through leaves (i.e.) foliage. Apply half NPK dose under dryland conditions.
7. Agronomist must select a better weed management practice. Either through mechanical or physical (by human work) or chemical (herbicides or weedicides, e.g. 2-4-D) or cultural (by having wide space it may increase weed growth by using inter space crops). Weeds are controlled by integrated weed management method also.
8. Irrigation management: Selection of proper irrigation method, irrigation scheduling i.e irrigation timing and quantity based on the crops to be irrigated, whether to irrigate continuously or stop in between and how much water to be supplied are computed so as to achieve maximum water use efficiency.
9. Crop planning (i.e.) suitable crop sequence should be developed by agronomist (i.e.) what type of crop, cropping pattern, cropping sequence, etc.
10. Agronomists are also developing the method of harvesting, time for harvesting, etc. The harvest should be done in the appropriate time
11. Decision-making in the farm management. What type of crop to be produced, how much area, including marketing should be planned. Decision should be taken at appropriate time

Chapter-2

Field crops and classification, importance, ecology and ecosystem

Field crops are herbaceous plants grown in cultivated fields under more or less extensive system of culture. Agronomic classification of different field crop is given as under

ACCORDING TO BOTANICAL /TAXONOMICAL ASPECTS

(A) Monocotyledons : A plant having only one seed leaf or cotyledon in each of its seed. Such plants have a shallow roots, narrow leaves and tillering ability. e.g., Families:

- (1) Poaceae: e.g. Cereals i.e. paddy, wheat, sorghum, pearl millet, maize, sugarcane, etc.
- (2) Zingiberaceae: e.g. Ginger
- (3) Liliaceae : e.g. Onion

(B) Dicotyledons : A plant having two seed leaf or cotyledons in each of its seed. Such plants have a deep taproots, broad leaves and branching ability. e.g., Families

- (1) Malvaceae: e.g. cotton, okra
- (2) Cruciferae : e.g. cabbage, mustard
- (3) Solanaceae: e.g. tobacco, potato, brinjal
- (4) Leguminoceae: e.g. groundnut, pigeon pea, gram, pea, mung bean, urd bean
- (5) Tiliaceae: e.g. jute, sun hemp
- (6) Linaceae: eg. linseed
- (7) Euphorbiaceae : e.g. castor
- (8) Composite : e.g. sunflower
- (9) chenopodiaceae: e.g. sugar beet

ACCORDING TO SEASON OF GROWTH

(A) Kharif or Monsoon: Crops are grown in the month of June - July. e.g. Paddy, pigeon pea, groundnut, sorghum, etc.

(B) Rabi or Winter: Crops are grown in the month of October - November. e.g. wheat, gram, mustard, cumin, fenugreek, onion etc.

(C) Summer / Zaid or Hot weather: Crops are grown in the month of February - June. e.g., paddy, green gram, black gram, cowpea, etc.

ACCORDING TO LIFE PERIOD

(A) Annuals: A plant which grows from seed, complete its life cycle and dies during the season or same year. e.g. cereal crops.

(B) Biennials: A plant which completes its life cycle in two season or year. During first season/year, they completes it's vegetative growth and during second season/year they completes it's reproductive growth. eg. sugarcane, sugar beet, banana, onion.

(C) Perennial: A plant which completes its life cycle in more than two seasons/years. e.g., agave, elephant foot.

ACCORDING TO CULTURAL PRACTICES

(A) Irrigated crops: e.g. Sugarcane, paddy, banana etc.

(B) Dry farming crops; The crop which are grown under natural precipitation. e.g. sorghum, bajra, groundnut, nagli, etc.

(C) Sole crops: One crop variety grown alone in pure stands at normal density.

(D) Monocropping: The repetitive growing of the same crops on the same piece of land. e.g. groundnut in Saurashtra region.

(E) Intercropping: Growing two or more crops simultaneously on the same piece of land in different rows e.g., sorghum + black gram, pigeon pea + ground nut, sugarcane + onion, etc.

(F) Mixed cropping: Growing two or more crops simultaneously on the same land without/irrespective to definite row pattern. e.g. sorghum + green gram+ black gram.

ACCORDING TO AGRONOMICAL OR ECONOMICAL ASPECTS

(A) Food crops

(i) **Cereals** : e.g. paddy, wheat, maize, sorghum, bajra, nagli,etc.

(ii) **Pulses** : e.g. gram, green gram, black gram, pigeon pea, cowpea, indian bean, moth bean, etc.

(iii) **Legumes** : e.g. groundnut, soybean, cluster bean

(iv) **Edible oil seeds** : e.g. groundnut, seasamum, sunflower, mustard, safflower

(v) **Fruit crops** : mango, banana, sapota, guava, papaya, ber, grape citrus crop, etc.

(vi) **Vegetable crops :**

- (a) Leafy : cabbage, fenugreek, palak
- (b) Fruit : tomato, okra, brinjal
- (c) Root : radish, carrot
- (d) Tuber/Stem : potato, sweet potato, ginger, turmeric
- (e) Bulb : onion, garlic
- (f) Flower : cauliflower
- (g) Pod : French bean, pigeon pea, cowpea, Indian bean

(B) Non-food crops

- (i) **Forage/fodder** : lucerne, berseem, hybrid nappier grass
- (ii) **Fibre crop** : cotton, jute, sun hemp
- (iii) **Non edible oilseeds** : castor, linseed
- (iv) **Sugar crop** : sugarcane, sugar beet
- (v) **Dyes** : safflower, indigo
- (vi) **Narcotics** : tobacco, coffee, tea, opium, poppy, chicory
- (vii) **Drugs/ Medicinal** : isabgul, jethimadh, senna, kariyatu
- (viii) **Spices & condiments**: cardamom, cumin, black pepper, coriander, fennel, fenugreek

ACCORDING TO CLIMATIC CONDITION

- **Temperate Crops:** Temperate crops are commonly found in cold regions where the climate is mild and temperate.
- Temperate Crops such as apple, plum, cherry, and almond, withstand cold and go into dormancy by shedding all of their leaves during the winter.
- **Tropical Crops:** Tropical crops are those that cannot withstand extreme cold but can withstand temperatures of up to 1000 degrees Fahrenheit.
- Those plants require a lot of sunlight, warmth, humidity, and a very mild winter.

- Fruits like papaya, banana, and pineapple are examples of tropical crops and cannot withstand frost for long.
- **Subtropical Crops: Subtropical crops with intermediate characteristics include orange, litchi, fig, mango, and cashew nut.**
- They require heat and humidity and can withstand mild winters.

SPECIAL PURPOSE CROPS/ACCORDING TO IMPORTANT USES:

(i) **Row crops:** Crops which are grown in rows with uniform spacing throughout the field.

e. g. cotton, castor, sorghum, etc.

(ii) **Support crops:** certain fast growing crops work as supporter to vine crops. e.g. castor, shevri in betel vine, sorghum in cowpea/bean.

(iii) **Wind break crops:** Crops which are grown on boundaries to protect the field crops from wind.

(iv) **Cover crops:** Cover crops are grown primarily to cover the soil and to reduce the loss of moisture and erosion by wind and water. e.g. groundnut, kidney bean, cowpea, mung bean.

(v) **Silage crops:** Crop which are preserved in a succulent condition by partial fermentation in a tight silo pit. e.g. maize, sorghum, bajra.

(vi) **Cash crops:** crop grown for sale and brings money immediately. e.g. cotton, tobacco, potato, sugarcane.

(vii) **Green manure crops:** Any crop which are grown and buried into the soil for improving the soil condition by the addition of organic matter. e.g. sun hemp, dhaincha, glyricidia.

(viii) **Pasture crops:** Different types of vegetation found on pastures or grassland area which usually grow. e.g. dharo, zinzvo.

(ix) **Catch crops:** Crop which is grown as substitute for the main crop that has failed on account of unfavorable condition. e.g. cowpea, sesame, green gram.

(x) **Trap crops:** Crop which is grown on boundary of the field for protection against pest, insect, disease.

(xi) **Nurse crops:** Crop which is used to protect or nurse the other crops in their young stage. e.g. cluster bean in ginger, sun hemp in sugarcane.

(xii) **Companion crops:** Two crops are taken together with the aim that they are benefited to each other. e.g. maize and green gram.

(xiii) **Mixed crops** : Two or more than two crops are grown together on the same piece of land at the same time. e.g. bajra + cowpea + green gram.

Classification according to root depth

It is clear that the root system of field crops differs in structure, function and extent. Therefore, field crops can be classified according to the depth of their roots as follows:

- 1- **Hallow root crops**: the root system of these crops extends in the soil to a depth of one meter such as wheat, barley and rye.
- 2- **Intermediate crops**: the depth of the root system of these crops ranges from 1- 1.5 meter in the case of faba bean and sugar beat.
- 3- **Deep root crops**: the root system of these plants extends in the soil to a depth more than 1.5 meter as in alfalafa.

Importance of field crops:

Field crops are essential to human life and play a vital role in the global food system, economy, and environment. Here are some of the key importance of field crops:

Food Security:

1. Food source: Field crops provide staple foods like wheat, rice, maize, and other cereals, legumes, and tubers.
2. Nutrition: They are a primary source of carbohydrates, proteins, fibers, and essential nutrients.

Economic Benefits:

1. Employment: Field crop farming provides livelihoods for millions of people worldwide.
2. Income generation: Crop sales contribute significantly to national and local economies.
3. Export earnings: Field crops are a major export commodity for many countries.

Environmental Benefits:

1. Soil conservation: Crop roots hold soil in place, preventing erosion.
2. Water cycling: Crops help regulate water cycles, maintaining groundwater levels.
3. Biodiversity: Field crops support ecosystem services, pollinators, and beneficial insects.

Industrial Uses:

1. Biofuels: Crops like corn, sugarcane, and soybeans are used to produce biofuels.
2. Textiles: Cotton, flax, and hemp are used to produce clothing and fabrics.

3. Pharmaceuticals: Certain crops, like tobacco, are used in medicine production.

Social Benefits:

1. Rural development: Field crop farming supports rural communities and infrastructure.
2. Cultural significance: Crops are integral to traditional practices, festivals, and identities.
3. Food sovereignty: Local crop production ensures community food self-sufficiency.

Other Importance:

1. Animal feed: Field crops are used as livestock feed, supporting animal agriculture.
2. Research and development: Crop science advancements improve yields, disease resistance, and climate resilience.
3. Climate change mitigation: Sustainable crop practices can help sequester carbon and reduce greenhouse gas emissions.

Ecology and Ecosystem:

Definition of Ecology

Ecology is the branch of biology that studies the interactions among organisms and their environment. It encompasses various levels of biological organization, from individual organisms to populations, communities, ecosystems, and the biosphere. Ecologists investigate how living organisms interact with each other and with their physical surroundings, including factors such as climate, soil composition, water availability, and nutrient cycling.

Definition of Ecosystem

An ecosystem is a specific community of living organisms (biotic components) interacting with their non-living environment (abiotic components) in a particular area. This includes all plants, animals, microorganisms, soil, water, and atmospheric conditions that influence life within that area. Ecosystems can vary greatly in size—from small tide pools to vast forests or entire biomes like deserts or rainforests—and they are characterized by the flow of energy and the cycling of nutrients.

Components of an Ecosystem

Ecosystems consist of two main components:

1. **Biotic Components:** These include all living organisms within an ecosystem—plants (producers), animals (consumers), and decomposers (fungi and bacteria). Each organism plays a specific role in the ecosystem's food web.
2. **Abiotic Components:** These are the non-living elements that affect the ecosystem's functioning. Key abiotic factors include sunlight, temperature, water availability, soil

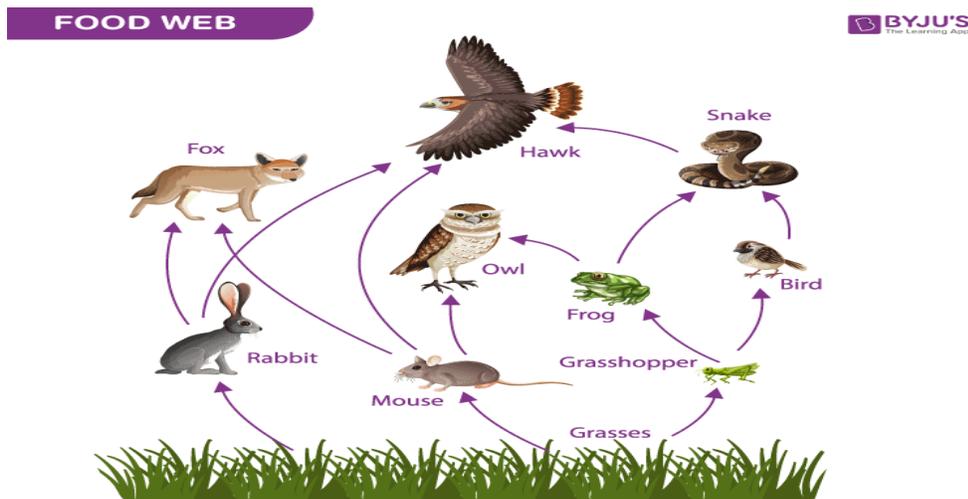
composition, and atmospheric gases. These factors influence which species can thrive in a given ecosystem.

Energy Flow in Ecosystems

Energy flow is a fundamental concept in ecology that describes how energy moves through an ecosystem. The primary source of energy for most ecosystems is sunlight. Through photosynthesis, plants convert solar energy into chemical energy stored in biomass. This energy then flows through various trophic levels:

- **Producers:** Plants capture sunlight and produce organic matter.
- **Consumers:** Herbivores eat plants; carnivores eat herbivores or other carnivores.
- **Decomposers:** Organisms like fungi and bacteria break down dead organic matter, returning nutrients to the soil.

This flow of energy is often represented as a food chain or food web.



Nutrient Cycling

Nutrient cycling refers to the movement and exchange of organic and inorganic matter back into the production of living matter within ecosystems. Essential nutrients such as carbon, nitrogen, phosphorus, and water cycle through different forms—such as gases in the atmosphere or minerals in soil—before being utilized by organisms. For example:

- Carbon dioxide from the atmosphere is absorbed by plants during photosynthesis.
- Animals consume these plants for carbon-based energy.
- Decomposers break down dead organisms to release nutrients back into the soil.

Importance of Ecosystems

Ecosystems provide essential services that sustain human life and contribute to overall environmental health. These services include:

1. **Provisioning Services:** Supply resources such as food, fresh water, timber, fiber, genetic resources.
2. **Regulating Services:** Control climate regulation, disease control, flood regulation.
3. **Cultural Services:** Provide recreational benefits and spiritual enrichment.
4. **Supporting Services:** Include nutrient cycling and primary production necessary for sustaining life on Earth.

Understanding ecology helps us appreciate how ecosystems function and highlights our responsibility to protect these vital systems against threats such as pollution, habitat destruction, climate change, and biodiversity loss.

The study of ecology provides insights into sustainable practices that can help maintain healthy ecosystems while meeting human needs.

Chapter- 3

Seeds and Sowing

Seed:

Seed is a **mature ovual** with its normal covering, consisting of **intact embryo, stored food and seed coat** which is viable and has got the capacity to germinate. Seed is one of the most important inputs for increasing crop production. It should germinate rapidly and uniformly when sown. **Emergence** should be **prompt** and **early vegetative growth** should be **vigorous**. Hence, good quality seed is of prime importance in crop production.

Criteria/ Characteristics of good seeds

Good quality seed must fulfill the following criteria

- ❖ It must be viable and should have high germination capacity.
- ❖ It should belong to the proper variety of crop and free from mixture of other variety seeds. i.e. genetically pure.
- ❖ It should free from inert matter. i.e. physically pure
- ❖ It should free from mixture of weed seeds.
- ❖ It should be mature, well developed and plump in size.
- ❖ It should free from pests and diseases causing organisms.
- ❖ It should be uniform in its texture and outlook.

Quality of seed: Viability and **vigour** are the two important characters of seed quality.

Viability: Viability refers the capacity of seed to germinate. It can be expressed by the germination percentage which indicates the number of seedlings produced by a given number of seeds.

Vigour: Vigour of seed and seedlings is difficult to measure. Seeds with low vigour may not be able to withstand unfavourable conditions in the seedbed. The seedlings may lack the strength to emerge if the seeds are planted too deep or if the soil surface is crusted. Vigour is indicated by the **higher germination percentage, high germination rate and quicker seedling growth.**

Crop emergence: It refers the **coming-out of germinating seed on the soil surface.** Germination is measured with two parameters

1. **Germination percentage:** It is the number of seeds germinated to number of seeds planted and it is expressed as percentage.
2. **Germination rate:** It is expressed in two ways as under
 - a. The number of days required to produced a given germination percentage.
 - b. The average number of days required for radicle or plumule to emerge.

Seed Classes/Multiplication stages of seed:

On the basis of genetic purity and stages of development, seeds are classified into four different categories as under

Nucleus seed:

It is the initial seed of an improved seed which is always limited in quantity.it is produced by originating plant breeder. It is genetically pure. It is used for breeder seed production.

Breeder seed:

It is very important class of seed. It is produced at breeder's institute with the responsibilities of the concern breeder who developed a particular variety. Breeder seed is the main source for the increase of foundation seed. It is 100 % genetically pure.

Foundation seed:(also known as Mother seed)

This seed is directly produced from the breeder seed. Production of foundation seed is done carefully under the strict supervision of the highly qualified seed experts because genetic purity and identity of the variety should be maintained as this seed is the source of all certified seed classes, either directly or through the registered seed. Foundation seed is produced at state Government farms, and Agricultural university farms.

Registered seed:

This class of seed is increased from foundation seed or other registered seed produced by the private seed growers or seed companies.

Certified seed:

Certified seed means the production of commercial seed sold to the farmers for raising the crop. This type of seed is produced from foundation seed or registered seed. This type of seed is produced by the National Seed Corporation, Agricultural Universities, State Government, Private seed companies, Private seed producers and some Co-operative society. The seed produced by various agencies is certified by State Seed Certification Agency.

SEED TREATMENT

Any treatment given to the seeds before sowing the crop against the control of insects / Pests and diseases, hastening the germination, fixation of atmospheric nitrogen and inducing the root growth is known as seed treatment.

OBJECTIVES/PURPOSE OF SEED TREATMENT

1. **Easy sowing:** When the seed contain fuzzes and can not be separated from each other at the time of sowing, the physical or chemical methods of seed treatment is used for easy, sowing, e.g. cotton.

2. **Uniform distribution of seeds during sowing :** When the seed are small in size and light in weight, it is difficult to maintain uniform plant population. Therefore, the seeds are mixed either with sand or powdered oilseed cake or farm yard manure.

3. **Hormonal treatment:** Treating the seed with gibberillic acid (GA) break the dormancy of seeds caused by physiological reasons. The concentration is 500 ppm and duration of soaking is 12 hours. Similarly, cytokines and ethylene are also used to break the dormancy.

4. **To improve the germination of seeds:** Some crops have hard seed coat or hard layer over seed and ultimately it takes more time for germination. For the improvement of germination the seeds are soaked in water. For example, seeds of castor, dhaincha, subabul *etc.*

5. **Nutrient economy of nitrogenous fertilizers:** The seeds of legumes are inoculated with efficient bacterial culture for better nodulation. Different types of crops have different strains.

6. **To prevent the effect of the pests:** Some of the seed material carries eggs of the pests in dormant condition or the pest itself is in the dormant condition in the soil. After sowing of the crop, the pests become active and start to damage the seed and seedling, hence the seed treatment is necessary against the pests eg. termites.

7. **To prevent the seed borne or soil borne diseases:** In case of seed borne diseases, the pathogens are carried either on surface of the seed or within it. When pathogens are externally present, may be destroyed by treating the seeds with chemicals *viz.*, captan, thirum and agrosan. Whereas, if pathogens are present internally in the seed, the hot water treatment is effective. Recently systemic organic compounds are also found effective for eradicating pathogens externally as well as internally, eg. plantvax and vitavax.

8. **To reduce the seed rate:**To reduce the seed rate, the coriander seeds are rubbed and splitted in two helves and they are sown.

Seed dormancy:

Seed dormancy is the state of rest period of seed in which it does not germinate.

Causes of seed dormancy:

1. Seed coats being impermeable to water eg. Cotton
2. Hard seed coat eg. Mustard, amaranthus
3. Seed coats being impermeable to oxygen eg. Xanthium seeds
4. Rudimentary embryo of seeds eg. Orchid seeds
5. Dormant embryo eg. Apple, peach, pinus

Methods to break the dormancy:

1. **Scarification:** hard seed coat is broken by chemical and mechanical means
2. **Stratification:** hard seed coat is broken by temperature treatment
3. Exposure of seeds to light
4. Application of pressure to seeds

Methods of sowing and sowing implements:

Sowing:

It is a practice of putting the seeds in soil by manually or by seed drill. Establishment of a good crop stand is the essential pre - requisite for attaining high yields. It depends on Time, depth, distance and method of sowing.

Optimum Time of Sowing:

Sowing the crop at optimum time increases yields due to suitable environment at all the growth stages of the crop. Flowering is induced after sufficient vegetative growth. Moisture stress or dry spells may be avoided during critical stages. The optimum time of sowing for most of **tropical crops is immediately after the onset of monsoon i.e. June or July**. The optimum time of sowing for **temperate crops like wheat and barley are from last week of October to first week of November**. The optimum time of sowing for most of the **summer crops is first fortnight of January**.

Types of Sowing:

Dry sowing:

Dry sowing is adopted in black soils where sowing operations are difficult to carry out once rains commence. Field is prepared with summer rains and seeds are sown in dry soil around seven to ten days before the anticipated receipts of sowing rains. The seeds germinate after the receipts of rains. By this method, rainfall is effectively utilized.

Wet Sowing:

Wet sowing is the most common method of sowing crops. The minimum amount of rainfall necessary for taking up sowing is 20 mm. Two or three days after soaking rains, sowing can be taken and continued for 2 or 3 days. Certain amount of moisture is wasted during the period between receipt of rainfall and sowing.

Distance of sowing:

Yield of a crop is the result of **final plant population** which depends on the **number of viable seeds, germination percent and survival rates**. Establishment of **optimum plant population** is essential to get maximum yield. Plant population is governed by inter and intra row spacing.

Inter row spacing is the distance between two rows, whereas the distance between two plant within row is termed as Intra row spacing.

Plant population increase with decrease in spacing and vice versa or in other words at **narrow spacing the plant population will be high (dense or thick population)** and at **wider spacing the plant population will be low (thin population)**. After emergence of crop, after care operations like Thinning and Gap filling are done to maintain the plant population in field.

Thinning:

It is the removal of excess plants from the densely populated field to maintain optimum plant population and avoid competition between plants.

Gap filling:

It is the process of putting the seeds / seedlings in a gapy field to maintain optimum plant population and best utilization of land resource.

Depth of sowing:

Depth of sowing is governed by size **of seed** and **soil moisture content**.

Uneven depth of sowing results in uneven crop stand. Plants will be of different sizes and ages and finally harvesting is a problem as there is no uniformity in maturity. **Shallow or deep sowing results in low plant population because all seeds do not germinate**. Therefore, it is essential to sow the crop at optimum depth for obtaining good stand of the crop.

Crops with bigger sized seeds like groundnut, castor, sunflower, etc. can be sown even up to the depth of 6 cm. Whereas, small sized seeds like tobacco, sesamum, bajra, mustard have to be sown as shallow as possible. If the seeds are sown too shallow, the surface soil dries up quickly and germination may not occur due to lack of moisture. Therefore, small sized seeds which are sown shallow should be watered frequently to ensure good emergence of the crop. If the small seeds are sown deep in the soil, the seed reserve food may be inadequate to put forth long coleoptiles for emergence. Even if the seedling emerges, it is too weak to survive as an autotrophic.

For better germination, the soil should have sufficient moisture in the surface layer. Crop grown in *rabi* are sown deeper than *kharif* crop, because in *rabi* surface soil have insufficient moisture for germination.

The thumb rule is to **sow seeds to a depth approximately 3 to 4 times their diameter**. The optimum depth of sowing for most of the field crops ranges between **3 cm to 5 cm**. **Shallow depth of planting of 2 cm to 3 cm is follow for small seeds like bajra, sesamum, mustard**. Very small seeds like tobacco are placed at a depth of 1 cm. This is generally done by broadcasting on the soil surface and mixing them by racking.

Methods of Sowing and Transplanting

1. Broadcasting

This is an oldest method. This method is suitable for close planted crop which do not require a specific geographic area. Crop plants which do not require special type of cultural practices e.g. earthing up or Interculturing etc. may be sown by broadcasting. This method is followed in the crop having short life period. Seeds are spread or scatter by hands over the field and covered with the help of wooden rake or light plank. Broadcasting is mostly followed for small sized to medium sized crops.

Advantages:

- This method is cheap.
- It is easy and quick.

Disadvantages:

- Require more seed rate.
- Uneven distribution of seed is possible. Only a skilled person should broadcast the seeds for uniform scattering.
- Uneven depth of sowing and 100 % germination is not possible.
- Interculturing is not possible.
- Weeding becomes difficult.
- Selections of seeds are not possible.
- Covering seeds with the help of rake is necessary.
- e.g. Cumin, Isabgul, Lucerne, Coriander, Rajgira, Berseem etc. and in mix cropping situation.

2. Drilling:

Drilling is practice of dropping the seeds in furrows by a mechanical device at a distance rows. Seed are drilled in parallel line. Distribution of seeds is regulated by releasing seeds in to the bowl by the hand. For covering the seeds light planking is done by plank.

Advantages:

- Uniform distance between two rows can be maintained.
- Less seed rate as compared to broadcasting.
- Interculturing is possible between two rows.
- Seeds are placed at uniform depth and covered and compacted uniform.

Disadvantages:

- Distance between two plants within the row is not maintained.
- Thinning and gap filling operations are necessary
- Selection of seed is not possible.
- e.g. Upland rice, Wheat, Bajra, Barley, Mustard, Greengram, Cowpea, etc. and in intercropping situation.

3. Dibbling:

Putting the seed or few seeds in a hole or pit or pocket, made at predetermine spacing and depth with a dibbler or very often by hand. This method is suitable for wide space crops requiring a specific geometric area for their canopy development or cultural practices. First all lines are marked vertically and horizontally with the help of marker at a particular distance. At each cross seeds are dibbled with the help of dibbler by manual labour. Then seeds are covered with soil.

Advantage:

- Spacing is maintained between two rows and between two plants within the row, hence interculturing is possible in both directions.
- Requirement of seed rate is less as compared to broadcasting and drilling.
- Depth of sowing is maintained.
- Selection of good seed is possible.
- Give rapid and uniform germination with good seedling vigour.

Disadvantages:

- More laborious and time consuming method.
- It is costly.
- e.g. Cotton, Castor, Indian bean, Pigeon pea etc.

4. Sowing behind the plough

Sowing behind the plough (line sowing) done by manual or mechanical means. Seeds are dropped in the furrows opened by the plough and the same is closed or covered when the next furrow is opened. The seeds are sown at uniform distance. Manual method is a laborious and time consuming process. Seeds like Chickpea, red gram, cowpea and groundnut are sown behind the country plough.

Advantages

- The seeds are placed at desired depth covered by iron planks,
- except very small, very large seeds most of the seeds can be sown, e.g. maize, sorghum, millets, sunflower, etc.

5. Nursery Transplanting

Transplanting is the removal of an actively growing plant from nursery and planting it in main field for further growth and production. In this method seeds are not directly sown in the field but seeds are sown first in nursery with proper care. After proper growth (**generally four weeks**), seedlings are uprooted and transplanted in well prepared main field. This method is useful for raising the crops which have **small size seeds and require more care in the initial stage**.

Age – 1/4th of the total duration is on the nursery beds. If the total duration is **16 weeks, four week period (1 month) is under nursery beds.** Nursery age is not very rigid,

e.g., thumb rule – 3 months crop – nursery duration 3 weeks minimum, **4 months crop – 4 weeks minimum period**; 5 months crop – 5 weeks. After the nursery period, seedlings are pulled out and transplanted. This is done on the main field after thorough field preparation or optimum tilth. The **seedlings are dibbled in lines or in random**. Closer spaced crops are mostly raised in random method even after nursery, e.g. rice, ragi. For vegetables, desired spacing is required during transplanting. **Transplanting shock is a period after transplanting, the seedlings show no growth**. This is mostly due to the change in the environment **between root and the soil**. The newly planted seedlings should adjust with new environment. **It is for a period of 5 – 7 days depending upon season, crop, variety, etc.** At higher temperature – dehydration – leaves dry out. Normally area of nursery should be **1/10th of the total planting area**.

Advantages:

- Economy of costly seeds.
- Available sufficient time for preparing seedbed.
- Management in the main field is reduced.
- Provide better chances for better care in small area during seedlings stage.
- Can ensure optimum plant population with healthy and pure seedlings.
- Crop intensification is possible under transplanting.

Disadvantages:

- Total duration of crop may be more.
- It increases the labour and power requirement in peak period.
- It increases the cost of land preparation, uprooting and transplanting of seedling.
- e.g. **Seedlings** – Rice, Tobacco, Tomato, Brinjal, Chilly, Onion, Cabbage, Cauliflower etc. **Saplings** – Subabool, Sag, Eucalypts.

Sowing Implements:

There are different methods of sowing viz., broadcasting, dibbling, line sowing by drill, planting and transplanting of seedlings etc. Out of these methods, sowing in lines by seed drill is the most common and popular method of sowing in Maharashtra. The crops are sown in lines parallel to one another, therefore weeding and interculture can easily done between two lines of the crop. Regulation of seed rate and adjustment of depth of sowing is also possible by this method.

1) Seed Drill

Seed drill is a machine for placing the seeds in a continuous flow in furrows at uniform rate and at controlled depth with or without the arrangement of covering them with soil.

Function of seed drill:

1. To carry the seeds

2. To open furrow to an uniform depth
3. To meter the seeds
4. To place the seed in furrows in an acceptable pattern
5. To cover the seeds and compact the soil around the seed.

2) Seed cum fertilizer drill:

Seed drills, fitted with fertilizer dropping attachment, distribute the fertilizer uniformly on the ground. It is called seed cum fertilizer drill. Such a drill has a large seed box which is divided length wise into two compartments, one for seeds and another for fertilizers. Seed drill may be classified as: (1) Bullock drawn (2) Tractor drawn.

Depending upon the method of metering the seeds, bullock drawn seed drill can be further divided into two groups viz., those in which seeds are dropped (a) by hand (b) or mechanically. There are a number of bullock drawn implements which are used for sowing seeds in which seeds are dropped by hand. In different parts of the country it is made in different sizes and shapes.

Advantages:

1. Seed and fertilizer can be sown at a time.
2. Seeds of different size can be sown.
3. The required quantity of seed and fertilizer can be sown.
4. The fertilizer can be sown below the seeds.
5. Inter row spacing can be adjusted according to our requirement.
6. It is made up of iron, hence its durability is more.

3) Cultivator with seeding attachment (Tifan)

A bullock drawn cultivator with seeding attachment is popular in the country. It may be three rows cultivator. Three tined cultivators with seeding attachment is used for sowing seeds in three rows at a time. The rate of seed dropping is controlled by hand. The main parts of the cultivator are the frame, three tynes fitted with reversible shovels, handle with seeding attachment and the beam. This implement is drawn by a pair of average bullocks.

- 4) **Planter:** Planter is normally used for those seeds which are larger in size and can not be sown by usual seed drills.

Functions of planter:

1. To open the furrow
2. To meter the seed
3. To deposit the seed in the furrow
4. To cover the seeds and compact the soil over it.

The different types of planters are:

1. Potato planters
2. Sugarcane planter (Semi automatic)
3. Manual rice transplanter
4. Japanese rice transplanter
5. Fertilizer distributor (Tractor mounted)

Chapter 4

Tillage and Tilth

TILLAGE

Cultivation involves management of physical environment to produce a favourable habitat for successful crop production. Tillage operations in various forms have been practiced from the very inception of growing plants. Primitive man used tools to disturb the soils for placing the seeds. The word tillage is derived from the Anglo- Saxon words *tilian* and *teolian*, meaning to plough and prepare soil for seed to sow, to cultivate and to raise crops. **Jethrotull**, who is considered as father of tillage suggested that thorough ploughing is necessary so as to make the soil into fine particles.

Definition of Tillage and Tilth

Tillage

It is the mechanical manipulation of soil with tools and implements for obtaining conditions ideal for seed germination, seedling establishment and growth of crops.

OR

Any operation carried out on the soil surface by agricultural implements for the purpose of softening the soil surface for better advantage to germination and plant growth.

Tilth:

It is the physical condition of soil obtained out by tillage (or) it is the resultant effect of tillage in which soil air, soil water and soil aggregates are in perfect harmony or in balance condition.

OR

It is physical condition of soil as related to its easy to tillage, fitness as seedbed, easy root penetration and better plant growth.

Based on the requirement of crops being grown on different soils, tilth may be a **coarse, fine or moderate tilth**. When a soil is brought to a condition suitable for germination of seeds and growth of crops it is called as seedbed and it is then said to be in good tilth. Obtaining and maintaining good tilth by tillage operation is also the essential requirement for successful crop production. Tilth indicates following two properties;-

1. Size distribution of aggregates

The relative proportion of different sized soil aggregates is known as size distribution of soil aggregates. For irrigated agriculture higher amount of larger aggregates (> 5mm in diameter) are necessary, while under dry land agriculture higher amount of smaller aggregates (1 to 2 mm in diameter) are necessary.

2. Mellowness or Friability

It is that property of soil by which the clods when dry become more crumbly. A soil with good tilth is quite porous and has free drainage up to water table. The capillary and non-

capillary pores should be in equal proportion, so that sufficient amount of water (moisture) and air is maintained.

Maintenance of proper tilth

Soil tilth can be maintained on normal soil by following measures;-

1. Use of mulch to protect the soil aggregates from direct action of raindrop and wind.
2. Proper and timely intercultivation in the field to different depth to prevent hard pan formation.
3. On problematic soils use of soil conditioner and amendments over long period of time.
4. Proper crop rotation should be followed.
5. On sloppy land, terracing and bunding are pre-requisites for maintenance of proper tilth.

Objectives of Tillage

There are several objectives of tillage of which the most important are discuss hereunder

1. Suitable seedbed preparation

Good seedbed is necessary for early seed germination and initial good stand of the crop. The seedbed should be fine for small seeded crops and moderate for bold seeded crops. Intimate contact between the soil particles and seed are necessary to facilitate movement of water for quicker germination.

2. Weed control

Weed control is an important and prime objective of tillage. Weed can be removed up to 90 percent by carrying out tillage at proper time. The problematic weeds like Nut sedge or Chidho can be controlled by two or three deep ploughing during summer season.

3. Soil and water conservation

Proper tillage results in soil and moisture conservation through higher infiltration reduced runoff and increased depth of soil for moisture storage. On sloppy land, tillage across the slope of field will create a furrow dikes, which slow down the velocity of runoff water and consequently soil erosion can be reduce. Before rainy season the fields are left cloddy to prevent erosion and increase the water storage in soil. This is a good practice under dry farming situation. When the compact soil is ploughed, it becomes fluff and can hold more amount of water. Removal of hard pans increases the soil depth for water absorption. Surface roughness and furrow dikes slow down the velocity of runoff and provide more opportune time for infiltration of water.

4. Improvement of soil structure

Good soil structure can be produced by tilling the soil at proper time when the soil moisture is optimum. Soil structure is damage and form hard pans when tillage is carried out at improper moisture content. Frequent harrowing also results in destructions of soil structure. Summer deep ploughing improves soil structure due to alternate drying and cooling of soil.

5. Improvement in soil permeability and soil aeration

Soil permeability is increased by breaking the compacted layers. Tillage improves soil aeration which helps in multiplication of microorganisms. Organic matter decomposition is hastened resulting in higher nutrient availability. The process of nitrification hastens because of proper air- moisture regime in soil, and better microbial activities in soil. Increased aeration also helps in degradation of herbicide and pesticide residues and harmful allelopathic chemicals exuded by roots of previous crop of weeds.

6. Easy root penetration and better root development

Roots occupy only a tenth of the soil mass. Tillage has, therefore, less limited impact on root growth. However, breaking of hard pans and compacted layers increase depth of root penetration. In addition, root growth is unhindered when the soil mechanical resistance or soil strength is less. Roots proliferate profusely in loose soil. Increases in 0.5 bar soil mechanical resistance decreased root growth of barley by 50 per cent. Root development of wheat, pea, rapeseed, linseed, safflower, sunflower etc. decreased when they are sown on unploughed lands. The seminal and lateral root growth of these crops is reduced due to high soil mechanical resistance of unploughed compact soil. Thus, loosening the soil is necessary for better root growth.

7. Destruction of pests and diseases

Many of the insect pests remain dormant as pupae in the top layers of the soil. They are exposed to sun's heat or to birds during tillage. It is a common sight during preparatory cultivation that the root grubs are exposed and eaten away by crows and other birds. The stubbles of previous crop which harbor insects are removed following tillage resulting in reduced pest attack on the succeeding crop.

8. Soil inversion

Crop residues and farmyard manure are incorporated into the soil by soil inversion action of tillage. Decomposition of these materials is quicker when incorporated into the soil. Herbicides and fertilizers are also mixed and incorporated into the soil to reduce volatilization losses.

Disadvantages/ Demerits of Excess Tillage

The following are disadvantages of excess tillage;

1. Formation of hard pan

Hard pans may be present in the soil which restricts root growth of plant. These may be silt pan, clay pan or man made pan. Man made pans are tillage pan that induced by tillage at same depth repeatedly as well as tillage at improper moisture content. Hard pans also reduce the infiltration rate and aeration in soil.

2. Oxidation of organic matter

Excess tillage results in more air circulation in soil, which increases the rate of oxidation of organic matter and consequently reduced the organic matter content in soil within short

time. If organic matter is reduced, the bulk density of soil is increased. Bulk density beyond 1.55 g/cc is not conducive for proper plant growth.

3. Increase soil erosion

Frequent tillage will disintegrate the soil aggregates and the primary soil particles are easily eroded or transported by rain water and wind.

4. Cost of crop production increase

Tillage operations are more laborious and expensive, so with increase in frequency of tillage operation the cost of crop production increase.

Effect of tillage on soil physical properties

Tillage has considerable influence on soil physical properties like pore space, structure, bulk density, water content and colour. This effect of tillage lost for about a month. Tillage practice has, therefore, greatest effect on seed germination, seedling emergence and stand establishment.

1. Pore space:

Soils are made up of particles of different sizes. Air filled spaces between these particles constitute pore space. When a field is ploughed, the soil particles are loosely stacked in a random manner and pore space is increased. When the soil is in good tilth, the capillary and non-capillary pores would be roughly equal. This facilitates free movement of air and moisture in the soil and increases infiltration.

2. Soil structure:

Soils with crumbly and granular clods are considered as soils with good structure. When the soil is subjected to tillage at optimum moisture level, crumb structure is developed so that loss of soil by erosion is greatly reduced. Rain water is held in the large pores, between the aggregates and also in the micro pores of the aggregates. It is considered that soil aggregates of 1 to 5 mm in size are favourable for growth of plants. Smaller aggregates may clog the soil pores and larger ones may have large pore space between them and affects the development of rootlets of the young seedlings. Soil structure is destroyed when tillage is carried out at inappropriate soil moisture content.

3. Bulk density:

When the soil is loosened, the soil volume increases without any effect on weight. Therefore, bulk density of tilled soil is less than the untilled soil. (Table-1)

4 Soil colour: Organic matter is mainly responsible for the dark brown to dark grey colour of the soil. Tillage increases oxidation and decomposition of organic matter, resulting in fading of colour.

5. Soil water:

Tillage improves soil water in different ways. The amount of available water depends on soil porosity, soil depth and random roughness. All these characters are increased by tillage. Roughness is a measure of micro-elevations and depressions caused by furrows and ridges, clods and depressions. It influences the volume of surface- depression storage or temporary storage of rainfall. Tillage also increases rate of infiltration, water holding capacity and hydraulic conductivity. (Table- 1)

6. Soil temperature:

Tillage creates soil temperature optimum for seed germination and seedling establishment. Tillage loosens the soil surface resulting in decrease of thermal conductivity and heat capacity.

Table: Soil characteristics before and after tillage

Soil properties	Sandy soils		Clay loam soils	
	Before	After	Before	After
Hydraulic conductivity (cm/ hr)	17.64	22.23	1.91	6.08
Soil water at saturation (%)	32.00	38.00	40.00	61.00
Bulk density (g/ cc)	1.42	1.11	1.24	0.80
Random roughness (cm)	1.15	1.75	1.72	2.77

Types of tillage: Tillage operations may be grouped into

1. On season tillage 2. Off-season tillage

1. 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 grouped into two types based on the time (**with reference to crop**) at which they are carried out.*

1. Preparatory cultivation: Which is carried before sowing the crop?

2. After cultivation: That is practiced after sowing the crop.

1. Preparatory cultivation

This refers to tillage operations that are done 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. Generally, the terms **preparatory cultivation and seedbed preparation** are used **synonymously**. Preparatory cultivation includes three distinct operations viz;

a. Primary tillage/Ploughing b. Secondary tillage C. Seed bed preparation.

a. Primary tillage or Ploughing

Ploughing is opening of the compacted soil with the help of different ploughs. Ploughing is done mainly to **open the hard soil**. In addition, ploughing should ensure **inversion (whenever necessary) of soil, uprooting of weeds** and stubbles and less cloddy soil surface. Country plough, mould board plough, borse plough, tractor and power tiller are used for primary tillage.

Right time of ploughing

The correct time for ploughing depends on soil moisture content. When the **soil is dry**, it is difficult to open the soil, more energy is used and **large sized clods are form**. When the soil is ploughed under **wet conditions**, the soil **sticks to the plough**, the soil below the plough sole becomes **compacted** and on drying becomes a **hard pan**, soil **structure is destroyed** and the clods on drying become very hard. The optimum range of soil moisture for effective ploughing is 60% of field capacity. **Light soils** can be ploughed in a **wide range of soil moisture** conditions while the range is **narrow** for **heavy soils**.

Depth of ploughing

Depth of ploughing mainly depends on the **effective root zone depth of the crops**. Generally, crops with tap root system require greater depth of ploughing, while fibrous, shallow rooted crops require shallow ploughing. The desirable depth of ploughing is 12.5 to 20 cm. The depth of ploughing is **10-20 cm for shallow rooted crops and 15-30 cm deep rooted crops**.

Deep ploughing

One centimeter of surface soil over one hectare of land weights about 150 tons. Therefore, to plough deeper, huge amount of energy is required. In western countries, deep ploughing is **50cm depth for rain fed conditions and 70cm for irrigated conditions**. **Central Research Institute for Dry land Agriculture (CRIDA)**, Hyderabad classified ploughing depth as under:-

<u>Categories</u>	<u>Depth of ploughing</u>
Shallow	5 to 6 cm
Medium deep	15 to 20 cm
Deep	25 to 30 cm

Deep ploughing turns out large sized clods, which are crushed by the hot sun when it is done in summer. These clods crumble due to **alternate heating and cooling** and due to **occasional summer showers**. This process of gradual disintegration of clods **improves soil structure**. The rhizomes and tubers of **perennial weeds** (Problematic weeds) die due to **exposure to hot sun**. Summer deep ploughing kills **pests due to exposure of pupae to hot sun and birds attack**. Deep tillage also **improves soil moisture content**. However, the advantage of deep tillage in dry farming conditions depends **on rainfall pattern and type of crop**. There is no yield advantage if

the **rainfall is below normal**. The residual effect of deep tillage is **marginal**. Therefore, it is advisable to go for deep ploughing **only for long duration, and for deep rooted crops**.

Number of ploughing

The number of ploughing necessary to obtain a good tilth depends on soil conditions, time available for cultivation between two crops, type of cropping systems, weed problem and crop residues on the soil surface. In **heavy soils**, more number of ploughing is necessary, the range being **3 to 5** ploughing. **Light soils** require **1 to 3** ploughing to obtain proper tilth of the soil. When **weed growth and plant residues** are higher, more number of ploughing is necessary. Minimum number of ploughing is taken up at **optimum moisture level** to bring favourable tilth depending on need of the crop.

Selection of plough

Depending on the purpose, soil condition and nature of weed problem, different ploughs are used as mention in Table:2.

Table: 2. Suitable ploughs for different situations

Type of plough	Situation or purpose
Mouldboard-Tractor drawn	Deep ploughing and inversion.
Mouldboard-Bullock drawn	Incorporation of manures, fertilizers and plant residues.
Disc plough & Country plough	Cutting of creeping or spreading grass and inversion.

b. Secondary tillage

After ploughing, the soil is left with **large clods** with some **weeds and stubbles** partially uprooted. Lighter or finer operations performed on the soil after primary tillage to bring a good soil tilth are known as secondary tillage. Secondary tillage operations are done to **clean the soil, break the clods** and **incorporate the manure and fertilizers**. **Harrowing** is done to a shallow depth to crush the clods and to uproot the remaining weeds and stubbles. **Planking** is done to crush the hard clods, level the soil surface and to compact the soil lightly. Thus, the field is made ready for sowing after ploughing by harrowing and planking. Generally, **sowing operations** are also included in **secondary tillage**. Harrows, cultivators, guntakas and spade are used for secondary tillage.

C. Seed bed preparation/Layout of seedbed / Tertiary tillage

After the seedbed preparation, the field is laid out properly for irrigation and sowing or planting seedlings. These operations are crop specific. For most of the crops like wheat, soybean, pearl millet, groundnut, castor etc. **flat levelled seedbed is prepared**. That is, after the secondary tillage, these crops are sown without any land treatments. However, growing crops during **rainy season in deep black soils is a problem** due to poor drained conditions and tillage is also not possible during the rainy season. **Broadbed and furrows (BBF)** are, therefore, formed before the onset of monsoon and dry sowing is resorted. For some crops like maize,

vegetables etc. the field has to be laid out **into ridges and furrows**. Sugarcane is planted in furrows or trenches.

After field preparation, sowing is done with seed drills. These seeds are covered by **running blade harrow** to a shallow depth followed by planking so as to **level soil surface and seed covering** for **quick and uniform germination**. Sowing is also done by dropping the seeds behind the country plough.

2. After cultivation (Inter tillage)

The tillage operations that are done in the **standing crop after the sowing** or planting and **prior to the harvesting of the crop** are called after tillage. This is also called as **inter cultivation** or **post seeding planting cultivation**. It includes drilling or side dressing of fertilizers, earthing up and intercultivation etc. Spade, hoe, weeders etc. are used for inter cultivation.

Interculturing is working with blade harrows, rotary hoes etc. in between the crop rows so as to **control weeds**. Interculturing may also serve as **moisture conservation** measure by **closing deep cracks in black soils**.

Earthing up is an operation carried out with **country plough or ridge plough** so as to **form ridges at the base of the crop**. It is done either to provide **extra support** against **lodging** as in **sugarcane** or to provide **more soil volume** for better **growth of tubers** as in **potato** or to **facilitate irrigation** as in vegetable crops.

2. Off-season tillage

Tillage operations intended to serve special purposes during off-season are called off-season tillage. Off season tillage may be

- Sub soiling
- Year -round tillage/ Clean tillage
- Levelling
- Dry tillage
- Wet tillage

Sub soiling

Hard pans may be present in the soil which restricts root growth of crops. These may be **silt pans, clay pans** or **man made pans**. Man made pans are tillage pans developed due to **repeated tillage at the same depth**. These are present in most of the Indian soils.

Root growth of crops is confined to top few centimeters of soil where deep penetration of roots is inhibited by hard pans. For example, cotton roots grow to a depth of **2 m in deep alluvial soil without any hard pans**. When hard pans are present, they grow only **up to hard pan, i.e. 15-20cm**. Similarly, vertical root growth of sugarcane is restricted due to hard pans and it is not compensated by horizontal spread.

Sub soiling is **breaking the hard pan without inversion and with less disturbance of top soil**. A narrow cut is made in the top soil while share of the subsoiler shatters hard pans. **Chisel ploughs** are also used to **break hard pans present even at 60-70cm depth**. The effect of sub soiling does not last long. To avoid closing of subsoil furrow, **vertical mulching** is adopted. Sub soiling is essential **once in four to five years where heavy machineries are used for field operations**, seeding, harvesting, transporting etc.

Advantages of sub- soiling

- ❖ Greater volume of soil may be obtained for cultivation of crops.
- ❖ Excess water may percolate downward to recharge the permanent water table.
- ❖ Reduce runoff and soil erosion.
- ❖ Roots of crop plants can penetrate deeper to extract moisture from the water table.

Year- round tillage

Tillage operations carried out **throughout the year** are known as year-round tillage. In dry farming regions, field preparation is initiated with the help of summer showers. Repeated tillage operations are carried out until sowing of the crop. Even after harvest of crop, the field is repeatedly ploughed or harrowed **to avoid weed growth in the off season**. It is practiced to control weeds, soil borne pathogen and pests.

Levelling

Levelling is considered essential operation under **irrigated farming** to ensure **uniform distribution of irrigation water** and to increase the **water use efficiency** by crop. It also **saves irrigation water** by increasing efficiency of irrigation method. Levelling board, buck scrapers etc. are used for levelling.

Dry tillage

Dry tillage is practised 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 paddy, 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 this the **water holding capacity (WHC)** of the soil and **aeration** are increased. These conditions are more favourable for soil micro-organisms.

Wet or puddling tillage

The tillage operation that is done in a land **with standing water** is called wet or puddling tillage. 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**. Puddling tillage is done in both the directions for the **incorporation of green manures and weeds**. Wet tillage (Puddling) **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 easily and smoothly as well as establishment of seedlings. **Wet land ploughs** or **worn out dry land ploughs** are normally used for wet tillage.

Modern concepts in tillage

Conventional tillage involves primary tillage to break open and turn the soil followed by secondary tillage to obtain seed bed for sowing or planting. With the introduction of herbicides in intensive farming systems, the concept of tillage has been changed. Continuous use of **heavy ploughs create hard pan in the subsoil**. This results in **poor infiltration**. It is more **susceptible to run off and erosion**. It is capital intensive and increase soil degradation.

1. Minimum tillage

In conventional tillage the soil is broken in to a loose system of clods of mixed size and subsequently, a fine seedbed is prepared by several other operations. In this **process energy is often wasted** and sometimes, soil structure is destroyed. Efforts were made to know whether the several operations carried out on the farm are necessary or not. Repeated use of heavy machinery, **destroys soil structure, causes hard pans and leads to erosion**. Now, considerable changes have taken place in tillage practice and several new concepts have been introduced.

The concept of minimum tillage was **started in U.S.A.** The immediate cause for introducing minimum tillage was high cost of tillage **due to steep rise in oil prices in 1974**. **Dr. G.B. Triplett is considered as father of modern tillage.**

Minimum tillage is a method aimed at reducing tillage to the minimum necessary for ensuring a good seedbed, rapid germination, satisfactory plant stand and favourable growing conditions.

OR

Reducing tillage only to those operations that are timely and essential for producing the crop and avoiding damage to the soil.

Approaches for reduced tillage

Tillage can be reduced in two ways

1. By omitting operations which do not give much benefit when compared to the cost. Means omit those operations whose cost exceeds than its contribution to increase crop production.
2. By combining agricultural operations like seeding and fertilizer application with seed-cum fertilizer drill.

Advantages/ Merits of minimum tillage

1. Improved soil physical conditions due to decomposition of plant residues in situ.
2. Higher rate of infiltration caused by channels formed due to decomposition of dead roots. Hence, water storage in the plough layer is increased.
3. Less soil compaction due to reduction in movement of heavy tillage implements.
4. Less resistance to root growth due to improved soil structure.

5. Less soil erosion compared to conventional system.
6. The cost and time for field preparation is reduced, hence, reduce energy and fuel consumption.

Types of minimum tillage

1. Row zone tillage

Primary tillage is done with mould board plough in the entire area of the field, secondary tillage operations like disking and harrowing are reduced and done only in row zone

2. Plough plant tillage

After the primary tillage a special planter is used for sowing. In one run over the field, the row zone is pulverized and seeds are sown by the planter

3. Wheel track tillage

Primary ploughing is done as usual. Tractor is used for sowing; the wheels of the tractor pulverize the row zone in which planting is done

In all these systems, primary tillage is as usual. However, secondary tillage is replaced by direct sowing in which sown seed is covered in the row zone with the equipment used for sowing.

2. Zero tillage or No tillage

Zero tillage is an extreme form of minimum tillage. In this system mechanical soil manipulation is reduced to only minimum number of traffic. In conventional method 5 to 8 tillage trips which are reduced to only one in zero tillage.

In this, new crop is planted in the residues of the previous crop without any prior soil tillage or seed bed preparation and it is possible when all the weeds are controlled by the use of herbicides. Zero tillage is applicable for soils with

1. a coarse textured surface horizon
2. good internal drainage
3. high biological activity of soil fauna
4. favourable initial soil structure
5. An adequate quantity of crop residue as mulch. These conditions are generally found in alfisols, oxisols and ultisols in the humid and sub humid tropics.

Zero tillage means growing a crop with least possible soil disturbance, which involves controlling of unwanted vegetation (Weeds) by other than mechanical means/ methods.

Types of zero tillage

1. Till planting

Till planting is one method of practicing zero tillage. A wide sweep and trash bar clears a strip over the previous crop row and planter opens a narrow strip into which seeds are planted and covered. Here herbicide functions are extended. Before sowing, the

vegetation present has to be destroyed for which broad spectrum non selective herbicides are used.

2. Sod planting or Sod culture

Sod refers to top few centimeters of soil permeated by and held together with grass roots. Planting of seeds in sods without any tillage operation is known as sod planting or sod culture.

Advantages/Merits of Zero tillage

1. Zero tilled soils are homogenous in structure.
2. More number of earth worms are present.
3. The organic matter content is increases due to less mineralization.
4. Surface run off is reduced due to presence of mulch.

Limitations/ Demerits/ Management problems associated with Zero tillage

1. Rate of decomposition of organic matter is slow hence, higher dose of nitrogen to be applied for mineralization of organic matter.
2. Some times herbicide costs are in excess of tillage cost.
3. Residual effect of herbicides creates pollution problems.
4. Herbicide resistant strain of weed may be developed.
5. Large population of perennial weeds appears in zero tilled plots.
6. Sowing operations are difficult with ordinary equipment.
7. Seed germination is low.
8. Nodulation in legumes affected adversely.
9. Efficient and selective herbicides are limited in number.
10. Efficient herbicide should be regularly and easily available at cheaper rate.
11. Easy availability of skill labour.

Scope of Zero tillage under Indian conditions

1. Direct seeding of crops is possible with liberal use of fertilizers and herbicides.
2. In dry farming regions no tillage will provide surface mulch.
3. In high rainfall areas and on sloppy lands no tillage reduce soil erosion to the extent of 65 to 95 per cent.
4. Multiple cropping feasibility is increased by no tillage.

3. Stubble mulch tillage or stubble mulch farming

It is a new approach to keep the soil protected at all times whether by growing crops or by crop residues left on the soil surface during fallow periods. It is known as stubble mulch tillage.

It is a year round system of managing plant residue with implements that undercut residues, loosen the soil and kill weeds. The main objective of this system is to reduce the soil erosion. When large amount of residues are present a disc type implement is used for the first operation to incorporate some of the residues into the soil. This hastens the decomposition but still keeps enough residue on top soil.

Limitations of stubble mulch tillage

Following practical problems are associated with stubble mulch tillage.

1. The residues left over the soil surface interfere with seedbed preparation and sowing operations.
2. The traditional tillage implements are not suitable under these conditions.

Two methods for sowing crops in stubble mulch tillage

1. Similar to zero tillage a wide sweep and trash bars are used to clear a strip and a narrow planter shoe opens a narrow furrow into which seeds are placed.
2. A narrow chisel of 5-10 cm width is worked through the soil at a depth of 15-30 cm leaving all plant residues on the surface. The chisel shatters the tillage pans and surface crusts. Planting is done with special planters.

4. Conservation tillage

The major objective is to **conserve soil and soil moisture**. It is a system of tillage in which organic residues are not inverted into the soil such that they remain on surface **as protective cover against erosion and evaporation losses of soil moisture**. If stubble form the protective cover on the surface it is usually referred to **as stubble mulch tillage**. Sweep or blades are generally used to cut the soil up to 12-15 cm depth in the first operation after harvest and the depth of cut reduced during the subsequent operation. This hastens the decomposition.

Advantages

1. Energy conservation through reduced tillage operations.
2. Improve the soil physical properties.
3. To reduce the water runoff from fields.

Characteristics of good seedbed

Seedbed requirement of different crops depends on **size of seed, root depth of crop, duration of crop and whether the crop is sown under irrigated or rain fed conditions**. Some crops requires loose seedbed and some requires a firm and fine seedbed. Some crops remain on the soil for long time and others for short time; hence **seedbed preparation varies with the crops**. A good seedbed should have the following qualities

1. It should have a loose, friable and fine granular structure on the surface.
2. It should resist the washing away of soil through erosion.
3. It should permit easy penetration of rain water, and does not form a hard surface crust after a rain.
4. It should facilitate quick germination of seeds.
5. It should provide good media for the growth of plant roots.

Chapter-5

Crop density and plant geometry

Plant Population or Plant Density

Number of plants per unit area in the cropped field is the plant population.

Plant density is the number of plants per unit area in a cropped field. It indicates the size of the area available for individual plant.

Crop geometry is the pattern of distribution of plant over the ground or the shape of the area available to the individual plant, in a crop field.

Optimum plant population

1. Optimum plant population – It is the number of plants required to produce maximum output or biomass per unit area.
2. Any increase beyond this stage results in either no increase or reduction in biomass.

IMPORTANCE

Yield of a crop depends on the final plant density. The density depends on the germination percentage and the survival rate in the field. Establishment of required plant density is essential to get maximum yield. For example when a crop is raised on stored soil moisture under rainfed conditions, high density will deplete moisture before crop maturity. Where as, low density will leave moisture unutilized. Hence, optimum density will lead to effective utilization of soil moisture, nutrients, sunlight etc. When soil moisture and nutrients are not limited, higher density is necessary to utilize other growth factors (solar radiation) efficiency. When maximum yield per plant. On the contrary when the density is more, individual plant gets narrow space leading to competition for growth factors between plants resulting in reduction of yield per plant. Yield per plant decreases gradually as plant density per unit area is increased as shown in the. However, the yield per unit area is increased up to a certain level of plant density due to utilization of growth factors. Maximum yield per unit area can, therefore, be obtained when the plant density is optimum.

(a) Plant Density and Yield

Biological yield increases with increases in plant density up to a point and reaches a plateau with further increase in density, thus no additional biological yield can be obtained. On the other hand, the economic yield increases with increase in plant density up to a point and subsequently decreases with increased in density.

(b) Plant Density and Growth

Plant height increase with increase in plant density due to competition for light. Dense plant stands leads to reduction in leaf thickness and alters leaf orientation. Dry matter production per unit area increase with increase in plant density up to a limit, as in biological yield.

Factors affecting plant population/Plant density

1. Genetic Factors

1. Size of the plant

1. The volume occupied by the plant at the time of flowering decides the spacing of the crop
2. Plants of red gram, cotton, sugarcane etc occupy larger volume of space in the field compared to rice, wheat, ragi
3. Even the varieties of the same crop differ in size of the plant

2. Elasticity of the plant

1. Variation in size of the plant between minimum size of the plant that can produce some economic yield to the maximum size of the plant that can reach under unlimited space and resources is the elasticity of the plant.
2. The optimum plant population range is high in indeterminate plants. e.g. Optimum population range for red gram is 55000-133, 000 plants/ha
3. The elasticity is due to tillering and branching habit of the plants
4. For determinate plants like bajra, sorghum elasticity range is less
5. For indeterminate plants like cotton and redgram more branches will be produced the crop

3. Foraging area or soil cover

1. Should cover the soil as early as possible so as to intercept maximum sunlight
2. Higher the intercepted radiation more will be the dry matter produced
3. Close spaced crops intercept more Solar radiation than wide spaced crops

4. Dry matter partitioning

1. Dry matter production is related to amount of solar radiation intercepted by the canopy which depends on plant density
2. As the plant density increases the canopy expands more rapidly, more radiation is intercepted and more dry matter is produced.

2. Environmental factors

1. Time of sowing

1. The crop is subjected to various weather conditions when sown at different periods.
2. Among weather factors, day length and temperature influence the plant population. As low temperature retards growth, high plant population is required to cover the soil

2. Rainfall / irrigation

1. Plant population has to be less under rainfed than irrigated condition
2. Under more plant densities, more water is lost through transpiration
3. Under adequate rainfall / irrigation, high plant population is recommended.

3. Fertilizer application

1. Higher plant population is necessary to fully utilize higher level of nutrients in the soil to realize higher yield.
2. Nutrient uptake increases with in plant population
3. High population under low fertility soil leads to nutrient deficiency symptoms leading low yield

4. Seed rate

1. Quantity of seed sown/unit area, viability and establishment rate decides the plant population Under broadcasting the seed rate is higher when compared with line sowing / transplanting, e.g. for rice
 - Direct sowing - 100 kg/ha
 - Line sowing -60 kg/ha
 - Transplanting - 40 kg/ha

Plant geometry

Plant geometry refers the shape of the plant / plant canopy. Like Vertical growth in sorghum, maize, paddy etc. Horizontal growth in cotton, tobacco, pulses etc.

Crop geometry

Crop geometry refers the shape of the land available to individual plant to grow. e.g. random, square, rectangular etc.

The arrangement of the plants in different rows and columns in an area to efficiently utilize the natural resources is called crop geometry. It is otherwise area occupied by a single plant e.g. rice – 20 cm x 15 cm. This is very essential to utilize the resources like light, water, nutrient and space. Different geometries are available for crop production

Different crop geometries are available for crop production

1. Random geometry

This type of geometry is observed under broadcasting method of sowing, where no equal space is maintained, resources are either under exploited or over exploited.

2. Square method or square geometry

The plants are sown at equal distances on either side. Mostly perennial crops, tree crops follow square method of cultivation.

Advantages

1. Light is uniformly available,
2. Movement of wind is not blocked and
3. Mechanization can be possible.

3. Rectangular method of sowing

There are rows and columns, the row spacing are wider than the spacing between plants.

The different types exist in rectangular method

a. Solid row

Each row will have no proper spacing between the plants. This is followed only for annual crops which have tillering pattern. There is definite row arrangement but no column arrangement, e.g., wheat.

b. Paired row arrangement

It is also a rectangular arrangement. If a crop requires 90 cm spacing and if paired row is to be adopted the spacing is altered to 75 -120 - 75 instead of 90 cm, i.e. distance between two pair is 120 cm, whereas the distance between two rows within pair is 75 cm. The intercrop can be grown in-between two pair. The base population is kept constant.

c. Skip row

A row of planting is skipped and hence there is a reduction in population. This reduction is compensated by planting an intercrop; practiced in rainfed or dryland agriculture.

d. Triangular method of planting

It is recommended for wide spaced crops like coconut, mango, etc. The number of plants per unit area is more in this system.

Chapter-6

Crop nutrition

Plant like animal and human being, require food for their growth and development. This food is composed of certain chemical elements. These chemical elements are referred as plant nutrients or plant food elements. According to the present state of our knowledge Sixteen (16) mineral elements are considered essential for plant growth.

Terminology

Plant nutrition: Plant nutrition is defined as the supply and absorption of chemical compounds required for plant growth and metabolism. It is the process of absorption and utilization of essential elements for plant growth and reproduction.

Nutrient: Nutrient may be defined as the chemical compound or ion required by an organism. The mechanism by which the nutrients are converted to cellular material or used for energetic purposes are known as metabolic processes.

Beneficial elements: The elements, the essentiality of which for growth and metabolism has not been unequivocally established, but which are shown to exert beneficial effects at very low concentrations are often referred to as beneficial elements, or potential micronutrients. Eg : Silicon, vanadium, cobalt and aluminium.

Essential Plant Nutrient:- A nutrient essential for proper growth and development of plant is termed as essential plant nutrient.

Essentiality Criteria of Plant Nutrients :-

Plant analysis using modern techniques reveals that plant body contains about 30 elements and in some cases as many as 60 elements. The presence of several elements in plant does not mean that all these are essential for plant. Arnon (1954) proposed three criteria of essentiality. Hence, the element should fulfil the following three criteria to prove their essentiality in plant.

- (1) Plants can not complete vegetative or reproductive stage of its life cycle due to deficiency of nutrient.
- (2) The deficiency is specific to the element and shows specific deficiency symptoms on plant. As such deficiency can be corrected only by supplying that particular nutrient to plant.
- (3) The element is directly involved in the metabolic activities of plant.

Plant absorbs a large number of elements from the soil and other sources during their growth and development. According to the present state of our knowledge, sixteen mineral elements are found to be essential in plant nutrition, the elements are known as essential plant nutrients. The growing plants have three sources from which they get nutrients are listed below:

Macro nutrients	Source	Micro (trace) nutrients	Source
Carbon	Air	Iron	Soil
Oxygen	Air	Manganese	Soil
Hydrogen	Water	Boron	Soil
Nitrogen (Major)	Soil	Zinc	Soil
Phosphorus (Major)	Soil	Copper	Soil
Potassium (Major)	Soil	Molybdenum	Soil
Calcium (Secondary)	Soil	Chlorine	Soil
Magnesium (Secondary)	Soil	-	-
Sulphur (Secondary)	Soil	-	-

From the above given list of plant nutrients it is seen that most of the nutrient are absorbed by plant from the soil. The absorption of macro nutrients is relatively high from the soil. If these nutrients are not added to the soil, the fertility status of soil goes down. Hence, these elements must be added to the soil through manures and fertilizers.

Role of plant nutrients:

Group	Essential plant nutrients	Biochemical functions
Ist	C,H,O,N,S	Major constituent of organic material, essential elements of atomic groups which are involved in enzymatic processes and assimilation by oxidation – reduction reactions.
II	P, B, Si	Esterification with native alcohol groups in plants. Involved in energy transfer reactions.
III	K, Na, Mg, Ca, Mn, Cl	Non specific functions establishing osmotic potentials; enzyme activation, balance of ions, controlling

		membrane permeability and electro potentials.
IV	Fe, Cu, Zn, Mo	Present predominantly in a chelated form incorporated in prosthetic groups.

Classification of essential nutrients: Nutrients are chemical compounds needed for growth and metabolic activities of an organism. The essential plant nutrients may be divided into macronutrients (primary and secondary nutrients) and micronutrients.

A. Macronutrients : Macronutrients or major nutrients are so called because they are required by plants in larger amounts. These are found and needed in plants in relatively higher amounts than micronutrients. They include Primary minerals like C, H, O, N, P, K, and secondary minerals like Ca, Mg and S.

B. Micronutrients: Micronutrient is an element that is required in relatively small quantities but is as essential as macronutrients. These elements have often been called trace elements. They are again classified into micronutrient cations (eg. Fe, Mn, Zn and Cu) and micronutrient anions (eg., B, Mo and Cl) depending upon the form in which they are available.

FERTILIZER

Any artificially manufactured material added to the soil in order to supply one or more plant nutrients is known as fertilizer. The term is generally applied to inorganic material.

The classification of various fertilizers is given below:

(1) Straight fertilizer

When fertilizer contain only one plant nutrient, they are known as straight fertilizer. They are also termed as incomplete or special fertilizers.

- e.g. (a) Nitrogenous fertilizer
 (b) Phosphatic fertilizer
 (c) Potassic fertilizer

(A) Nitrogenous fertilizer

Nitrogenous fertilizer may be classified into four groups on the basis of chemical form in which nitrogen is combined with other elements within fertilizer.

(i) Nitrate containing: Nitrogen is combined as NO_3 (nitrate) with other elements.

e.g. Sodium nitrate or Chilean nitrate (16% N), Calcium nitrate (15.5%N)

(ii) Ammonium containing: In these fertilizers nitrogen is combined in ammonium (NH_4) form with other elements.

e.g. Ammonium sulphate (20% N), Ammonium phosphate (20%N)

Ammonium chloride (24 to 26%N), Anhydrous ammonia (82% N)

Ammonium solution (20 to 25% N)

(iii) Nitrate and Ammonium containing: These fertilizers contain nitrogen in the form of nitrogen as well as ammonium

e.g. Ammonium nitrate (34%N), Calcium ammonium nitrate (26%N)

Ammonium sulphate nitrate (26%N)

(iv) Amide containing: these fertilizers contain nitrogen in amide form.

e.g. Urea (46%N), Calcium cyanamide (21%N)

(B) Phosphatic fertilizer

Phosphatic fertilizers can be classified into three groups depending on the form in which phosphoric acid is combined with calcium.

(i) Phosphatic fertilizers containing water soluble phosphoric acid or monocalcium phosphate $\text{Ca}(\text{H}_2\text{PO}_4)_2$:

They contain water soluble phosphoric acid which can be absorbed quickly by the plant roots. These fertilizers are suitable on neutral to alkaline soils. e.g. Single super phosphate (16% P_2O_5), Double super phosphate (32% P_2O_5), Triple super phosphate (48% P_2O_5), Ammonium phosphate (20% P_2O_5).

(ii) Phosphatic fertilizers containing citric acid soluble phosphoric acid or calcium phosphate $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$ or CaHPO_4 :

These fertilizers are suitable for acidic soils because with low pH, citrate soluble phosphoric acid gets converted into monocalcium phosphate and there are less chances of fixation e.g. basic slag (14 to 18% P_2O_5), Dicalcium phosphate (34 to 39% P_2O_5), raw and steamed bone meal (part of P_2O_5) soluble in citric acid).

(iii) Phosphatic fertilizers containing phosphoric acid which is neither soluble in water or citric acid or containing insoluble phosphoric acid or tricalcium phosphate $\text{Ca}_3(\text{PO}_4)_2$:

These fertilizers are well suited for strongly acidic soils. e.g. Rock phosphate (20 to 40% P_2O_5), Raw bone meal (20 to 25% P_2O_5), Steamed bone meal (22% P_2O_5).

(C) Potassic fertilizer

Potassic fertilizers can be classified into two groups depending upon the form of K in fertilizer.

(i) Fertilizers having K in Chloride form :

e.g. Muriate of potash (60% K_2O)

(ii) Fertilizers having K in non chloride form:

e.g. Sulphate of potash (48 to 52% K_2O)

(2) Complex fertilizer

The commercial fertilizers containing at least two or more of the primary essential nutrients, when such fertilizers contain only two of the primary nutrients, they are designated as incomplete complex fertilizers. While those containing all three primary nutrients are called as complete complex fertilizer.

Incomplete complex fertilizers –e.g.

Ammonium phosphate	(20-20-0)
Diammonium phosphate	(18-46-0)
Urea ammonium phosphate	(28-28-0)

Complete complex fertilizer – e.g.

Sulphala	(15-15-15)
Suphala	(18-18-9)
NPK	(12-32-16)

(3) Mixed fertilizer

A mechanical mixture of two or more straight fertilizer materials is referred as mixed fertilizer or fertilizer mixture. Sometimes complex fertilizers containing two plant nutrients are also used in formulating fertilizer mixture. Mixed fertilizer made by mixing the ingredients either mechanically or manually.

Nutrient Absorption-Active & Passive:

Plants obtain carbon and oxygen from the atmosphere. The remaining mineral nutrients are absorbed from the soil through the plant roots.

Mineral nutrients are the chemical elements required as essential nutrients by all plant species to perform all the necessary functions.

Altogether, plants require thirteen different types of minerals. Among calcium, magnesium, nitrogen, phosphorus, potassium and sulphur are six essential mineral nutrients which are required in large quantities and are often called macronutrients.

Uptake of Mineral Nutrition

Mineral uptake is the natural process in which all the essential minerals enter the plant's cellular material, typically following the same pathway as water. The uptake of mineral nutrients occurs at both the roots and the leaves.

The process of uptake or transport of mineral nutrients is carried out by the plant cells in two different ways:

Passive Absorption

It is the absorption of minerals without the direct expenditure of metabolic energy.

Active Absorption

It is the absorption of minerals with the direct expenditure of metabolic energy. During the active absorption of minerals, ions from the outer space of the cell move into the inner space and it generally occurs against the concentration gradient. Hence it requires metabolic energy and this energy is obtained from the cell's metabolism either directly or indirectly.

All the minerals cannot be transported passively in the roots as the concentration is low in the soil and moreover they are present as a charged particle, which cannot cross the cell membrane. These are actively transported in the roots using energy stored as ATP. Minerals are transported by specific proteins present in the membrane of the root hairs. Transport proteins are embedded

in the plasma membranes of endodermal cells and control the type and amount of solutes reaching the xylem.

Forms of absorption-combined and un-combined in crop production:

Absorbed as single nutrient ion		Absorbed in a combined form	
Nutrient elements	Forms absorbed by plants	Nutrient elements	Forms absorbed by plants
Potassium	K^+	Nitrogen	Ammonium (NH_4^+) and Nitrate (NO_3^+)
Calcium	Ca^{++}	Phosphorus	$H_2PO_4^-$, HPO_4^{--}
Magnesium	Mg^{++}	Molybdenum	MoO_4^{--} (Molybdate)
Iron	Fe^{++} (Ferrous), Fe^{+++} (Ferric)	Sulphur	SO_4^{--}
Manganese	Mn^{++} (Manganous), Mn^{++++} (Manganic)	Boron	H_3BO_3 (Boric acid), $H_2BO_3^-$ (Borate), HBO_3^- , BO_3^{--}
Copper	Cu^{++}	Hydrogen	H_2O , H^+
Zinc	Zn^{++}	Carbon	CO_2
Chlorine	Cl^{++}	Oxygen	CO_2 , O^- , OH^-
Silicon	Si^{++++} , $Si(OH)_4$		
Cobalt	CO^{++}		
Sodium	Na^+		

MANURE

Any organic materials of animal or plant origin, added to the soil in order to improve the physical condition of soil and supply one or more plant nutrients to the soil is known as manure. There are two types of manures.

(1) Bulky organic manure

These manures are bulky in nature and supply, but contain small quantities of plant nutrients. Such manures are Farm Yard Manure (FYM), farm compost, night soil, sewage and sludge, green manure etc. among these, FYM, farm compost and green manure are most important and widely used.

(2) Concentrated organic manure

These have required in small quantities and contain higher nutrients as compared to bulky organic manures. The most commonly used are oil cakes, fish meal, meat meal, blood meal, horn & hoof meal, bird guano, raw bone meal etc. which act a good source of organic manures for organic farming system.

B.1 OIL CAKES

Oil cakes are generally grouped into two groups, viz., *edible* oil cakes suitable for feeding the cattle and other domestic animals and *non-edible* oil cakes exclusively used as manure due to their higher content of plant nutrients. It has been estimated that India produced about 2.5 million tones of oil cakes annually

Non-edible oil cakes are used as manure especially for horticultural crops. Nutrient present in oil cakes, after mineralization, are made available to crops 7-10 days after application. Oil seed cakes need to be well powdered before application for even distribution and quicker decomposition. **Neem cake** acts as **Nitrification Inhibitor**.

B.2 FISH MEAL

Sea food canning industries are present in almost all coastal states of India, Fishes which is not preferred for table purposes due to their small size, bonny nature and poor taste can be converted into very good organic manure. The fish is dried, powdered and filled in bags. It contains average nutrients are 4-10, 3-9 & 0.3-1.5 NPK. These manures are highly suitable for fruit orchards and plantation crops.

B.3 MEAT MEAL

The meat of dead animals is dried and converted into meat manure. An adult animal can provide 35 to 45 kg of meat after slaughter or death. It contains 9-11% N and 3.5% P₂O₅.

B.4 BLOOD MEAL

Blood meal when dried and powdered can be used as a manure. Blood meal contain about 10-12%N.

B.5 HORN & HOOF MEAL

A healthy animal can give about 3 to 4 kg of horn and hoof. These materials are dried, powdered, bagged and marketed as manure. It contains 13% N.

B.6 GUANO (Bird / Fish)

The excreta and dead remains of the bird is called *bird guano* (11-14% N & 2-3% P₂O₅) and the refuse left over after the extraction of oil from the fish in factories, dried in cemented yards and used as manure is called as *fish guano* (7% N & 8% P₂O₅).

B.7 RAW BONE MEAL

An excellent source of organic phosphorus. It contains 3 to 4% N and 20 to 25% P₂O₅.

Average percentage of N,P, K in the different manures and farm materials

Sr. No.	Materials/Manures	Per cent		
		N	P ₂ O ₅	K ₂ O
(A)	Excreta of farm animal			
1	Cow and Buffalo Dung	0.40	0.20	0.10
	Urine	1.00	Trace	1.35
2	Sheep and Goat Dung	0.75	0.50	0.45
	Urine	1.35	0.05	2.10
3	Horse Dung	0.55	0.30	0.40
	Urine	1.35	Trace	1.25
4	Pig Dung	0.55	0.50	0.40
	Urine	0.40	0.10	0.45
(B)	Straw of crops			
1	Paddy	0.36	0.08	0.71
2	Wheat	0.53	0.10	1.10
3	Sorghum	0.40	0.23	2.17
4	Maize	0.42	1.57	1.65
5	Pearl millet	0.65	0.75	2.50
(C)	Bulky organic manures			
1	Farm Yard Manure	0.50	0.20	0.50
2	Farm compost	0.50	0.15	0.50
3	Town compost	1.40	1.00	1.40
4	Night soil	5.50	4.00	2.00
5	Sludge	1.5-3.5	0.78-4.0	0.3-0.6
6	Green manures	0.3-1.1	-	-
7	Poultry manure	3.03	2.63	1.40
8	Vermi compost	3.00	1.00	1.50
(D)	Concentrated organic manures			
1	Castor cake	4.30	1.80	1.30
2	Cotton seed cake (Undecorticated)	3.90	1.80	1.60
3	Cotton seed cake (Decorticated)	6.40	2.90	2.20

4	Karanj cake	3.90	0.90	1.20
5	Mahuda cake	2.50	0.80	1.20
6	Neem cake	5.20	1.00	1.40
7	Safflower cake (Undecorticated)	4.90	1.40	1.20
8	Safflower cake (Decorticated)	7.90	2.20	1.90
9	Groundnut cake	7.30	1.50	1.30
10	Coconut cake	3.00	1.90	1.80
11	Linseed cake	4.90	1.40	1.30
12	Niger cake	4.70	1.80	1.30
13	Rape seed cake	5.20	1.80	1.20
14	Sesamum cake	6.20	2.00	1.20
15	Blood meal	10-12	1-2	1.00
16	Meat meal	10.50	2.50	0.50
17	Fish manure	4-10	3-9	0.3-1.5

Functions of manures :-

1. Physical functions :-The organic matter promotes soil crumbs (structure) , make the soil loose, friable, soft and mellow to facilitate the proper movement of air and water in the soil. It also helps in the absorption of rain water.
2. Chemical functions :- It adds plant food to the soil and produces organic acids during decomposition. It helps in conversion of unavailable nutrients (insoluble food) into available plant nutrients, thus, nutrients are converted into available form for plants.
3. Biological functions :- It provides food for soil micro organisms which fix-up atmospheric nitrogen and produce into nitrate form (NO₃) for supply to plant.

Organic manure maintain the physical condition of soil and produce favourable environment for soil micro organism and thereby maintain soil productivity.

Nutrient use efficiency

Introduction:

The utilization efficiency of fertilizer under farmer's field conditions is universally low. In case of low land paddy the percentage utilization of nitrogen varies from 30-40. For upland irrigated crops the utilization of nitrogen varies from 50-60 percent. Most of the nitrogen is lost by leaching and by conversion of gases which escapes to the air. Even a small percentage gain in nitrogen use efficiency has the potential of big saving of energy, raw materials and labour. In the case of phosphorus, 15-20 % of applied P is utilized by the first crop with some residual P is being available for the succeeding crops. 60-70% of potassium is not used by the crops in the year of application.

Definition of NUE: Nutrient use efficiency (NUE) is the fraction of fertilizer nutrients removed from the field with the crop harvest.

$$\text{NUE} = (\text{Crop nutrient removal} / \text{Nutrient input}) * 100$$

NUE is a workable indicator to assess and monitor sound fertilizer use.

For plant nutrients, BMPs are the in-field manifestation of the Four Rights (4Rs), application of the right nutrient source, at the right rate, in the right place, and at the right time

Factors Affecting Nutrient Use Efficiency:

The object of manuring is to improve the nutritional status of the soil by increasing the store of nutrients present and thus to raise the yield from a lower to a higher level. Consequently, the response of a particular crop to a given fertilizer application cannot be foretold because a material so readily subjected to change is placed in contact with the soil and the crop, which react with it both chemically and biologically, and thus affect its efficiency.

Again there is the soil moisture which has a tremendous effect upon the crop, and upon the fertilizers. If there is an excess or deficiency of moisture, the full efficiency of fertilizer cannot be expected. In the event of such a complex situation and attempt has been made to highlight the various factors affecting the response of crop to fertilizer and to suggest the soil and crop management to increase the efficiency of fertilizer.

A. Crop Characteristics:

1. Kind of plant and root system
2. Varieties
3. Plant populations
4. Rotation and crop residues

B. Soil Characteristics:

1. Nutrient status of the soil
2. Soil moisture
3. Soil reaction
4. Soil temperature
5. Physical condition of the soil
6. Chemical nature of the soil
7. Effect of soil amendment

C. Fertilizer Characteristics and Fertilizer Manipulations:

1. Types of fertilizers.
2. Time of application
3. Method of application
4. Use of nitrate inhibitors.
5. Use of chelating substances.

A. Crop Characteristics:

- 1. Kind of plant and its root-system:** The response to the application of fertilizers may differ widely from crop to crop because of a number of factors among which the yield level and root characteristics are the most important. The yield level has a direct effect on the amount of nutrient removed from the soil. Although the nutrient uptake by different crop is a fairly good guide for the response of crops to fertilizers, the root characteristics of different plant species might often modify the response to different fertilizers. The root system of different plant species vary greatly in rapidity and extent of development. The extensive root system of corn exploited the soil more thoroughly than the limited root system of potatoes and consequently, the former used more nutrients from the soil and less from the fertilizers, whereas the reverse was true in case of potatoes. Thus the response to fertilizer will be more in case of potatoes than in case of corn.

The cation exchange capacity of the roots of dicotyledonous plants is much higher than that of monocotyledonous plant and absorbs more divalent cations such as calcium and less of monovalent cations such as potassium. In contrast, plants with a low root cation exchange capacity absorb less than of the divalent and more of the monovalent cations. Thus the response to K may be higher in the case of monocotyledonous plants than that in the case of dicotyledonous plants.

- 2. Varieties:** Marked differences in response to fertilizers have been obtained within varieties of the same crop. In many cases, these differences may be due to differences in plant types. Some of the highly responsive varieties of cereal crops have got dark-green upright leaves which do not shade the lower leaves, intercept the maximum amount of sunshine and thus, make the most efficient use of added fertilizers.
- 3. Plant population:** Sufficient plant population is one of the most important factors affecting response to the fertilizer application. In an experiment at Dharwad, with the lowest plant populations of sorghum (91,000), the highest response to the application of nitrogen was obtained at 150 kg N/ha, but with medium (136,000) and high (272,000) plant population, the maximum response was obtained with 200 kg N/ha.
- 4. Rotation and Crop Residues:** The crop rotation has a profound effect on the fertilizer use efficiency and fertilizer requirements of the crops in the rotation. The legumes affect the nutrient status of the soil for the succeeding crop differently from exhaustive crops like jowar and maize. The crop requiring high levels of fertilizers, such as potato or hybrid maize, may not use the fertilizer applied to them fully and thus some quantities of nutrient element may be left in the soil and they may be available for the succeeding crop. On the other hand, if sub-optimal doses of fertilizers are applied to a crop, they may leave the soil in a much exhausted condition and the fertilizer requirement of the succeeding crop may be increase. The legumes leave N-rich root residues in the soil for the succeeding crops and thus, reduce its N-requirement.

B. Soil Characteristics:

- 1. Nutrient Status of the soil:** The response of crop to fertilizer application directly depends on chemical composition of the soil in respect to the available plant nutrient. On the basis of soil testing, the soils are related as 'low', 'medium' or 'high' in plant nutrients and suitable fertilizer doses are recommended. A 'low' rating in phosphorus

means that crop in such soils should respond very readily to phosphate application. If the rating is 'medium' the response is probable: and if the rating is 'high' there may be little or no response to the applications of the phosphorus fertilizer.

2. **Soil moisture:** In most cases under irrigated conditions, fertilizers have greatly helped to increase crop yields by having favorable effects on the mass and distribution of roots. Nutrient absorption is affected directly by the level of soil moisture as well as indirectly by the effect of water on the metabolic activities of the plant, soil aeration and the concentration of the soil solution.
3. **Soil reaction:** Soils differ markedly in their reaction of pH. The soil microorganisms respond very markedly to soil reaction which has direct and indirect effect on crop growth. Since the soil reaction has a profound influence on the availability of plant nutrients, there is definitely likely to be a different response to the application of fertilizers on soil differing in their reaction. The fertilizer practices have, therefore to be greatly modified for soil reactions. Another possibility may be to modify the soil reaction so as to make it most favorable to crop growth and fertilizer efficiency.
4. **Soil temperature:** Low soil temperatures, become a limiting factor in seed germination. The power of root cells to cumulate various nutrient ions within a certain temperature range is related directly to temperature. The nitrate production in soil increases with temperature up to about 30⁰ C and then decreases with a further increase in temperature.
5. **Physical condition of the soil:** The physical condition of the soil largely determines the way in which it can be utilized by the plants. It is a resultant of the size, shape, arrangement and mineral composition of the soil particles as well as of the volume and form of its pores.
6. **Chemical properties of the soil:** Some fertilizer materials leaves acid residues in the soil, other a basic residue and still others might have no influence on the soil reaction. Fertilizer carriers of P and K have generally little influence on soil acidity, whereas the carriers of nitrogen have a considerable effect on soil pH.
7. **Effect of soil amendments:** Lime is the commonest material used for correcting the acidity of the soil. Lime affects plant growth mainly by correcting the soil pH and, thus, making available a large number of plant nutrients. Thus on acid soils, even responses to fertilizers are very much reduced without the use of lime. Likewise, gypsum and pressmud, like soil amendments, produce a beneficial effect in alkali soils in improving the efficiency of fertilizers.

C. Fertilizer Characteristics and Fertilizer Manipulation:

1. **Types of fertilizers:** Fertilizers may be differing from one another in different ways. They may differ in their nutrient contents or in the form of nutrients. Thus in the case of N-fertilizers, the nutrients may be supplied in the ammonium, nitrate or in amide forms. Likewise, in the case of P fertilizers it may be water soluble, citrate-soluble or water and citrate-insoluble form. It is seen that N and K salts have much higher salt indices and hence, are more detrimental to germination than phosphatic salts when placed closer to or into contact with seed.

2. **Time of application:** The time of applying fertilizers has been found important only in the case of N-fertilizers which have a tendency to leach with irrigation or rains. In the case of P and K fertilizers, all the quantity applied at sowing has given the best results with most of the crops. In general, the crops which are grown in the rainy season should receive N-fertilizers in split doses so that the leaching of the nutrients in heavy rains may be avoided and an adequate supply of the nutrients at the critical stages may be assured.
3. **Method of application:** The placement of P-fertilizers has been found to be beneficial almost universally. The response to P fertilizers found much higher when the fertilizers placed in a band 5 cm wide to the side and 5 cm below the seed than that from broadcast application of the fertilizers. The introduction of high analysis fertilizers like urea, and the low volume sprayers and the use of aircraft have helped in experimentation involving the foliar application of fertilizers. For the effectiveness of the foliar application of nitrogen, it is essential that the crop should form a canopy, so that the nitrogen may be retained on the leaves.
4. **Use of nitrate inhibitors:** The development of nitrate inhibitors that could be added to the existing cheap nitrogen sources in minute quantities to control the nitrate release by decreasing the activity of nitrifying bacteria has been, therefore, one of the most significant developments in the field of increasing the efficiency of nitrogenous fertilizers. The commonest NO_3 inhibitors are:
 1. Oxamide ($\text{NH}_2\text{-COCO-NH}_2\text{O}$ -31 % N).
 2. Dicyndiamide- $\text{NH}_2\text{C(=NH)NHCN}$ -42 % N
 3. Thiourea – 36% N
 4. Urea-pyrolyzate-48 % N

These inhibitors seem to be promising as slowly available nitrogen releasing compounds. Two nitrification inhibitors, AM (2 amino-4 Chloro 6 Methyl Pyrimidin) and N-Serve (2 Chloro 6 trichloro methyl pyridine), blended with urea have been very effectively utilized in increasing the efficiency of N from urea.

5. **Use of chelating substance:** In the case of micronutrients, low solubility has been found to be the greatest limiting factor. The development of chelates of some of the important micro-organic complex which, although soluble themselves, do not ionize to any degree. They retain the metals in soluble form, permitting their absorption by the plants, yet preventing their conversion into insoluble form in the soil. The metallic ions commercially chelated are Fe, Cu, Zn and Mn. Numerous substances have the ability to chelate them. Four of the most important compounds found useful in agriculture are: 1 EDTA, 2. DTPA, 3. CDTA, 4. EDDHA

The exact mechanism of metal-chelate absorption and utilization by plants is not yet completely understood.

BIO-FERTILIZERS (*Microbial inoculants*)

The atmosphere over an hectare of land consists of 80,000 tones of N. Though atmospheric N is present in sufficient quantity (80%), it is not available to plants since it exists in inert form. Biological nitrogen fixation is the conversion of atmospheric N by living organisms into forms that plants can use. This process is carried out by a group of bacteria and algae which fix atmospheric Nitrogen (N₂) in to assimilable forms of nitrogen (NH₃)

It can be defined as bio-fertilizers or microbial inoculants are preparations containing live or latent cell of efficient strain of N-fixing or P-solubilizing micro organisms used for seed or soil application with the objectives of increasing the numbers of such micro organisms in the soil or rhizosphere and consequently improve the extent of microbiologically fixed N for plant growth.

Classification/Types of Bio-fertilizers

S. No.	Groups	Examples
A) N₂ fixing Biofertilizers		
1.	Free-living	<i>Azotobacter, Beijerinckia, Clostridium, Klebsiella, Anabaena, Nostoc,</i>
2.	Symbiotic	<i>Rhizobium, Frankia, Anabaena azollae</i>
3.	Associative Symbiotic	<i>Azospirillum</i>
B) P Solubilizing Biofertilizers		
1.	Bacteria	<i>Bacillus megaterium var. phosphaticum, Bacillus subtilis Bacillus circulans, Pseudomonas striata</i>
2.	Fungi	<i>Penicillium sp, Aspergillus awamori</i>
C) P Mobilizing Biofertilizers		
1.	Arbuscular mycorrhiza	<i>Glomus sp., Gigaspora sp., Acaulospora sp., Scutellospora sp. & Sclerocystis sp.</i>
2.	Ectomycorrhiza	<i>Laccaria sp., Pisolithus sp., Boletus sp., Amanita sp.</i>
3.	Ericoid mycorrhizae	<i>Pezizella ericae</i>
4.	Orchid mycorrhiza	<i>Rhizoctonia solani</i>
D) Biofertilizers for Micro nutrients		
1.	Silicate and Zinc solubilizers	<i>Bacillus sp.</i>
E) Plant Growth Promoting Rhizobacteria (PGPR)		
1.	Pseudomonas	<i>Pseudomonas fluorescens</i>

Characters/ Benefits of bio- fertilizers in organic farming:

- Bio-fertilizers are eco-friendly and do not have any ill effect on soil health and environment.
- They reduce the pressure on non-renewable nutrient sources/fertilizer.
- Their formulations are cheap and have easy application methods.
- They also stimulate plant growth due to excretion of various growth hormones.
- They reduce the incidence of certain disease, pathogen and increase disease resistance.
- The economic benefits to cost ratio of bio-fertilizers is always higher.
- They improve the productivity of waste land and low land by enriching the soil.

Integrated nutrient management:

Integrated nutrient management is the combined application of chemical fertilizers and organic manures for crop production.

Its main aim is the maintenance of soil fertility and the supply of plant nutrients in adequate amounts. It is ecologically, socially and economically viable.

Concepts of Integrated Nutrient Management

- The nutrients stored in the soil.
- The nutrients purchased from outside the farm.
- Plant nutrients present in crop residues, manures, and domestic wastes.
- Nutrient uptake by crops at harvest time.
- Plant nutrients lost from the field during crop harvest or through volatilization.

Importance of Nutrient Management

Nutrient management is important for the following facts:

1. Nutrient management helps to reduce contamination to waterways by plant nutrients.
2. Improve soil fertility.
3. Enhance plant productivity.
4. Reduce the cost of chemical fertilizers.
5. Providing balanced nutrition to crops.
6. Promotes carbon sequestration and prevents the deterioration of soil, water, ecology, and also leaching of nutrients from the soil.

Chapter-9

GREEN MANURING

Definition : Crops grown for the purpose of restoring or increasing the organic matter content in the soil are called *green manure crops* while their green undecomposed plant material used as manure is called *green manure*. Their use in cropping system is generally referred as *green manuring*. It is obtained in two ways-either by grown *in situ* or brought from out site. In both ways, the organic material should be worked into the soil while they are fairly young for easy and rapid decomposition.

- i) ***In situ green manuring:*** Growing of green manure crops in the field and incorporating it in its green stage in the same field (i.e. *in situ*) is termed as *green manuring*. The most important green manure crops are sunhemp, dhaincha, Piliplera, clusterbeans and Sesbania rostrata.
- ii) ***Green leaf manuring:*** Application to the field, green leaves and twigs of trees, shrubs and herbs collected from elsewhere is known as green leaf manuring. Forest tree leaves are the main source of green leaf manuring. Plants growing in wastelands, field bunds etc. are another source of green leaf manure. The important plant species for green leaf manure are neem, mahua, wild indigo, glyricidia, karanj, subabul and other shrubs.

ADVANTAGES OF GREEN MANURING

1. It adds organic matter to the soil. This stimulates the activity of soil micro organisms
2. Green manuring concentrates plant nutrient in the surface layer of the soil
3. It improve the structure of soil by deep rooting system
4. It facilitates the penetration of rain water, thus decreasing run off & soil erosion.
5. It holds plant nutrients that would otherwise be lost by leaching (eg. Nitrogen)
6. It increases the availability of certain plant nutrients like P, Ca, K, Mg & Fe.
7. It checks weed growth by quick initial growth
8. It aid in reclamation of sodic soils by release of organic acids.

DISADVANTAGES OF GREEN MANURING

Some disadvantages are also associated with green manuring. When the proper techniques of green manuring is not followed or when weather conditions become unfavourable, the following disadvantages are likely to become evident :

- Under rained conditions, it is feared that proper decomposition of the green manure crop and satisfactory germination of the succeeding crop may not take place if sufficient rainfall is not received after burring the green manure crop.
- In case the main advantage of green manuring is to be derived from addition of nitrogen, the cost of growing green manure crops may be more than the cost of commercial nitrogenous fertilizers.
- Since green manuring for wheat means loss of *kharif* crop, the practice of green manuring may not be always economical.
- An increase of diseases,, insects and nematodes is possible.

- A risk is involved in obtaining a satisfactory stand and growth of the green manure crops, if sufficient rainfall is not available.

DESIRABLE CHARACTERISTICS FOR GREEN MANURE CROPS

The criteria for which green manure crops are selected should have following characters,

- It should be high biomass production
- It should be deep rooting system
- It should be leguminous family
- It should be fast initial growth
- It should be more leafy than woody
- It should be low C/N ratio
- It should be non-host for crop related pathogens
- It should be easy and abundant seed producer
- It should be useful for 'by-products'

Chapter-10 Water management

IRRIGATION:

Water is an important element for plant. To meet out the demand of water to the plant irrigation is essential. Irrigation can be defined as,

“Artificial application of water to the soil to escape stress of plant is called as irrigation”.

“The application of water to soil to assist in the production of crops, especially during stress period”.

Water Resources

Rain fall

South-west monsoon

- SW monsoon reach south India (in Kerala) around 1st June of every year and in the middle of July it covers whole india under grip of rainfall.
- It's also called as Grand period of rainfall in India
- It contributes around >75 % of total rainfall in India
- It withdrawal from western Rajasthan in 1st September to complete withdrawal from whole country by 15 October.

North- East monsoon

- North east monsoon is onset at about 15 October and limited mostly to southern states (AP & TN) and withdrawal almost by mid December.
- Tamil Nadu gets highest rainfall followed by Andhra Pradesh.
- It contributes about 15% of total rainfall in India.

India's water budget/water resources:

The basic source of water is rainfall or snowfall. The water resources of India are limited. The average annual rainfall is about 1194 mm. The rain spread over an area of the country (328 m. ha), amounts to 392 m. ha-m of water and it may about 400 m ha-m including snowfall.

Total geographical area = 328 M.ha.

Average annual rainfall = 1194 mm

In million hectare meter = 1194 x 328 = 392 M ha m

Contribution from snowfall = 8 M ha m

Total = 400 m ha m.

Considering all these factors it is estimated that out of 400 m.ha. meter of annual rainfall 70 m.ha. meter is lost to atmosphere through evaporation and transpiration, about 115 m.ha. meter flows as surface run-off and remaining 215 m.ha. meter soaks or infiltrates into the soil profile.

Sr. No.	Geographical Information	India (Millian ha)	Maharashtra (Lakh ha)
1	Geographical area	328.7	308
2	Cultivated area	186	208 (67.53 %)
3	Net Sown Area	142 (43.1 %)	175 (72.53 %)
4	Gross cropped area	187	223 (72.35 %)
5	Gross irrigated area	75 (39.98 %)	36.68 (16.4 %)
6	Net irrigated area	48.9	29.71 (16.90 %)
7	Cropping Intensity	140 %	127.35 %

Soil Moisture Constants: it is the study of water and its availability

Water available in the soil at standard crop growth stage is called soil moisture constants.

1. Maximum water holding capacity (MWHC) or Saturation capacity (SC)

- When all the pores of the soil are filled with water, the soil is said to be under saturation capacity of *maximum water holding capacity*.
- The tension of water at saturation capacity is almost zero and it is equal to free water surface.

2. Moisture equivalent (ME)

- Moisture equivalent is defined as the amount of water retained by initially saturated soil after being subjected to a centrifugal force of 1000 times that of gravity for about half an hour.
- The moisture content when expressed as moisture percentage on oven dry basis, gives the value of the moisture equivalent.
- In medium textured soils, the values of field capacity and moisture equivalent are nearly equal. In sandy soils, the field capacity exceeds the moisture equivalent.
- In very clayey soils, the field capacity is generally lower than the moisture equivalent.
- It represents moisture content in the inner capillary or micro capillary pores,.

3. Field capacity (FC)

- The moisture held by soil against gravitational force is called field capacity
- At field capacity, the large soil pores are filled with air, the micro pores are filled with water and any further drainage is slow.
- The field capacity is the upper limit of water availability to plants.
- The soil moisture tension between -0.1 to -0.33 atmospheres.

- It is determined with the help of presser plate apparatus.
- The moisture content at the FC is taken as 100%.
- It comes after 48 to 72 hrs (2-3 days) after irrigation.

4. Permanent wilting point (PWP) or wilting co-efficient

- Permanent wilting point proposed by Briggs & Shantz (1912)
- The soil moisture content at which plants can no longer obtain enough moisture to meet transpiration requirements; and remain wilted unless water is added to the soil.
- Its is the lower limit of available soil moisture to plant.
- Soil moisture tension at PWP is about 15 atmosphere or -15 bars.
- Wilting point in most soil is in the region of 50% FC.
- PWP is determined by growing dwarf sunflower plant.

5. Ultimate wilting point (UWP):

The moisture content at which wilting is complete and the plant die is called **ultimate wilting point (UWP)**. At UWP the soil moisture tension is as high as -60 bars.

6. Available soil moisture (ASM): Moisture available for plant growth is the capillary water between FC & PWP. It can be determined by, $ASM=FC-PWP$

7. Hygroscopic co-efficient

- Air dried soil at atmosphere contains tightly bound water with soil particles and water if macro and micro pores are completely replaced by air. The metric section of this stage is called hygroscopic coefficient.
- The clay soil contains more colloidal materials contain more hygroscopic water than sandy soil.
- At this moisture constant, the metric potential of soil water is about 31 atmosphere.
- At this point water in the soil is adsorbed on the soil colloids so tightly that it can move only in vapour form.

Soil-Plant-Water relationships:

Soil-plant-water relationships relate properties of soil and plants that affect the movement, retention and use of water. Soil is the medium for the presence of water and roots. Water as such is a carrier of nutrients. Hence it is essential to understand the physical properties of soil which ultimately decide the water and plant to be housed over it.

Water movement in the soil:

Normally water will move from higher potential to lower potential area in soil profile. Generally the water movement within the soil profile takes place under three conditions.

(1) Water movement in saturated conditions - Saturated flow occurs when water is in zero or smaller tension or at free water conditions. In this situation, all or most of the pore spaces are completely filled with water and the water moves downwards due to gravitational force. This saturated flow decreases as the soil pore space size decreases *i.e.*, the saturated flow is high in coarse textured soil than fine textured soil. Generally the rate of flow of various texture soils is in the following sequence.

Sand > loam > clay

The theory of water movement in the soil is based on Darcy's law or generalized form of Darcy's law.

Darcy's law - It states that the quantity (volume) of water passing through an unit cross-section of soil is proportional to the gradient of hydraulic head or hydraulic gradient.

(2) Water Movement in Unsaturated Condition: The unsaturated soil water movement is also called as capillary movement. In this condition the macro pores are filled with air and only micro pores are filled with water which is held relatively more tightly and water is able to move very slowly. When soil moisture decreases, a part of pore spaces is occupied by soil air and the cross-sectional area for water movement is reduced and three by hydraulic conductivity becomes low. In unsaturated conditions, the conductivity is more in fine soil than coarse textured soil. Hence, the unsaturated hydraulic conductivity is the function of soil moisture content, number, size and continuity of soil pores etc. The rate of unsaturated flow in various soil texture is in the following order.

Sand < loam < clay

(3) Water vapour movement: It takes place within the soil as well as between soil and atmosphere under dry range. The vaporization under wet range is not taken into account in irrigation practices as it is in negligible range. The finer the soil pores higher is the moisture tension under which maximum water vapour occurs. In the coarse textured soil, at low tension the soil pores become free of liquid water when soil dries out. There is little moisture left for vapour transfer.

Force acting on water movement in soil:

The retentions and movement of water in soils, the uptake and translocation in plants and its loss to the atmosphere are all energy related phenomenon.

The water moves readily from high free energy to low free energy. The more strongly water is held in the soil when greater is the heat required. This is called soil water energy concept.

Different kinds of energy are involved in this, including potential and kinetic.

1. **Matric force:** it is the force due to the attraction of the soil colloids for water which markedly reduces the free energy of the adsorbed water molecules.
2. **Osmatic force:** it is the force due to the attraction of ions and other solutes for which to reduces the free energy of soil solution. Matric and osmotic potentials are negative and reduces the free energy level of the soil water.
3. **Force of gravity:** it is the force due to the attraction towards the earths centre, which leads to pull the water downward. This force is always positive.

Movement of water into the soil

The main process through which water enters into the soil is as follows, Infiltration, Permeability, Percolation, Capillary movement and Seepage.

Infiltration

The downward movement of water from the surface into the soil is called infiltration and it is expressed in cm/hour. **It occurs in unsaturated soil.**

Infiltration rate is the rate at which water is passing through the soil surface and flowing into the soil profile.

Forces of water retention by soil

Water that enters into the soil is retained by means of three forces, viz., 1) Adhesion 2) Cohesion and 3) due to soil colloids like clay and humus. Water molecules do not exist individually. Hydrogen in the water serves as connecting link from one molecule to other is known as hydrogen bonding.

1) Adhesion (also called adsorption)

The water molecules get attached to the surface of the soil particles and that make a thin film of water which is tightly held around the soil particles is known as force of adhesion. Adhesion is operative only at the solid-liquid interface and hence film of water is established by it is very thin. By adhesion, water film is held more tightly at the soil-water interface.

2) Cohesion

Water sticks itself with great energy and this property is known as cohesion. Water molecules hold other water molecules by cohesive forces. This force makes thick water film due to attraction of water molecule to each other and it is operative at only liquid interface.

3) Soil colloids (Clay or humus particles)

The water is also retained in the soil colloids like clay or humus particles. These soil colloids absorb water and as result of it get swollen. The water thus retained in the soil as called imbibitional moisture.

Crop water requirement (WR) implies the total amount of water required at the field head regardless of its source, to mature a crop. It includes the amount of water needed to meet the losses through evapo-transpiration, application losses and the special needs like leaching of excess salts, puddling, pre-planting irrigation etc. The water requirement (WR) thus can be expressed as: $WR = CU + \text{Application losses} + \text{Water needed for special operation}$

$WR = \text{Irrigation} + \text{Effective rainfall} + \text{Ground water contribution} + \text{Change in soil moisture}$

Factors influence the crop water requirements are:

1) Crop factors

- a) Crops and varieties: tall crops and varieties intercept more solar radiation and have more ET than short crops and varieties.
- b) Growth stages
- c) Duration: Longer duration, higher the water requirement.
- d) Plant population
- e) Crop growing season
- f) Rooting habits: Deep rooted crops extract more water from deep soil layers.

2) Soil factors

- a) Soil Structure
- b) Soil Texture
- c) Soil Depth
- d) Soil Topography
- e) Soil chemical composition
- f) Hydraulic conductivity: Coarse textured soils have higher hydraulic conductivity than

fine textured soil at high soil moisture regime.

- g) Reflectivity:
- h) Thermal properties

3) Climatic factors

- a) Temperature
- b) Sunshine hours/solar radiation
- c) Relative humidity
- d) Wind velocity
- e) Rainfall

Higher solar radiation, temperature and wind velocity increase crop water needs. Higher humidity reduces ET. Hot and dry winds around irrigated crop increases the ET.

4) Agronomic management factors

- a) Irrigation methods used
- b) Frequency of irrigation and its efficiency
- c) Tillage and other cultural operations like weeding, mulching etc / intercropping etc

Based on all these factors, average crop water requirement for various crops have been worked out and given below for tropical conditions.

Irrigation requirement (IR):

Irrigation requirement (IR) refers to the quantity of water, exclusive of effective rainfall (ER) and contribution from soil profile (S) required for crop production. This amounts to net irrigation requirement plus other economically unavoidable losses.

$$IR = WR - (ER + S)$$

Net irrigation requirement (NIR):

It is the amount of irrigation water just required to bring the soil moisture content in the effective crop root zone depth to field capacity. Thus, the net irrigation requirement is the difference between field capacity and the soil moisture content in the root zone before starting of irrigation. This may be obtained by the relationship given below

$$d = \sum_{i=1}^n \frac{M_{fci} - M_{bi}}{100} \times A_i \times D_i$$

- d = Net irrigation water to be applied (cm)
- M_{fci} = FC in ith layer (%)
- M_{bi} = Moisture content before irrigation in ith layer (%)
- A_i = Bulk density (g/cc)
- D_i = depth (cm)
- n = number of soil layer

Gross irrigation requirement (GIR):

The total quantity of water used for irrigation is termed gross irrigation requirement. It includes net irrigation requirement plus losses in water application and other losses. The gross irrigation requirement can be determined for a field, for a farm, for an outlet command area, and for an irrigation project, depending on the need, by considering the appropriate losses at various stages of water conveyance and distribution.

Net irrigation requirement

$$\text{GIR (in field)} = \frac{\text{-----}}{\text{Field efficiency of the system}} \times 100$$

Irrigation interval (Irrigation frequency):

It is the number of days between two successive irrigations during the period without precipitation for a given crop and field. It depends on the crop ET rate and on the available water holding capacity of the soil in the crop root zone depth. Sandy soils require in general more frequent irrigations as compared to fine textured soils.

Irrigation period

It refers to the number of days that can be allowed for applying one irrigation to that of the next in a given design area during the period of highest consumptive use of the season.

Water Use Efficiency (WUE)

It is the yield of marketable crop produced per unit water used in evapo-transpiration (ET). It is expressed in kg/ha-mm.

Water use efficiency of are two types as (i) **crop water use efficiency** and (ii) **field water efficiency**.

(a) Crop Water Use Efficiency: It is the ratio of yield of crop (Y) to the amount of water depleted by crop in the process of evapotranspiration (ET).

$$\text{CWUE} = \frac{Y}{\text{ET}}$$

where, CWUE= Crop water use efficiency
 Y= Crop yield ET = Evapotranspiration

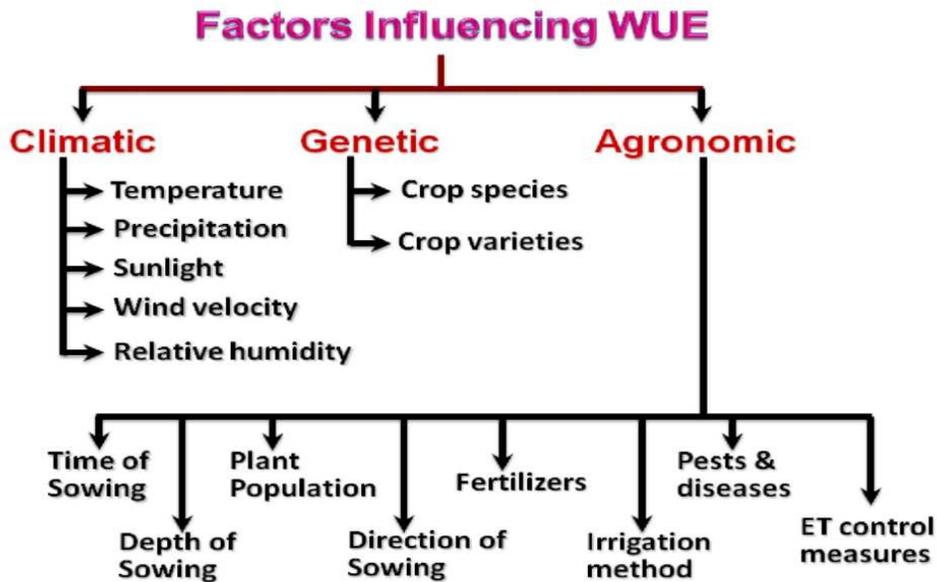
It is expressed in kg/ha/mm or kg/ha/cm.

(b) Field Water Use Efficiency:

It is the ratio of yield of crop (Y) to the total amount of water used in the field (WR).

$$\text{FWUE} = \frac{Y}{\text{WR}}$$

where,
 FWUE = field water use efficiency
 WR = water requirement



Measures/ Ways to improve water use efficiency:

A. Climatic factors: Plant transpiration and soil evaporation are dependent upon the temperature, wind velocity, relative humidity, sunshine hours and rainfall of a particular area. Evapotranspiration is directly correlated with temperature and wind velocity thereby reducing WUE. Similarly, evaporation is inversely proportional to humidity of climate which results in reduced consumption of water thereby increasing water use efficiency. Increased availability of light to plants increases photosynthesis resulting in greater production which consequently increases WUE of crops.

B. Nature of crops: Crops with higher canopies have greater growth and consequently higher photosynthesis which results in greater yield and concomitant higher WUE. Plants with shallow and less developed roots are able to absorb less water and fertilizers resulting in their lesser growth and production. Consequently, their WUE is reduced.

C. Cultural practices: Cultural practices which directly affect WUE are as under

1) Sowing time: The crops sown at proper time have greater production and hence higher water use efficiency. The crops grown latter have lesser growth and development produce low yield and hence lesser WUE.

2) Method of sowing: Compared to broadcasting method of sowing of crops, line sowing of crops has greater utilization and absorption of nutrients, water and light resulting in higher production which results in higher WUE. Grain yield of wheat, oats and pearl millet were also increased when crops were sown in the N-S direction.

3) Depth of sowing: Crops whose seeds are sown at optimum depth have greater growth since germination and hence higher production resulting in greater WUE.

4) Use of antitranspirants: Antitranspirants are those materials whose spray upon plants reduced transpiration. Kaolin, phenyl mercuric acetate and abscisic acid are a few well known anti-transpirants. The spraying of anti-transpirants upon plants results in their reduced transpiration which lessens their consumptive use thereby increasing WUE.

5) Use of growth retardants: Experiments have proved that there exist certain chemical substances like cycocel (CCC), phosphon etc. whose spraying upon plants in good production despite lack of water. Hence, it generates higher WUE.

6) Use of mulch: Mulches refers to the artificial or natural materials covered on the surface of soil with a object to reduce evaporation and destruction of weeds resulting in greater use of light, fertilizers, air and water by crops which results in higher production consequently higher WUE.

7) Method of irrigation: Compared to flooding method of irrigation, sprinkling and drip methods of irrigation results in lesser loss of water through evaporation and infiltration etc. which results in greater production using less water thereby increasing their WUE.

9) Fertilizer application: The optimum application of fertilizers at proper time increases the growth the development of crops thereby increasing their WUE.

10) Weed control: Weeds always compete with crops for the use of water, nutrients, air and light. Hence, destruction of weeds through proper methods is essential for the proper growth of crops and their consequent higher WUE.

11) Insect-pest and disease control: The insect-pest and disease management at proper time is imperative for production of a good crop. If crops are not saved from insect-pest and other diseases, their growth and development is lessened resulting in reduced WUE.

12) Use of shelter belts: There is greater irrigation water loss in areas having hot and high velocity winds through evaporation. In such area, use of shelter belts helps to reduce evaporation loss of water and ultimately increases WUE.

Besides all above factors, certain factors like crop rotation, soil testing, seed treatment, soil and water management practices, addition of organic matter in the soil and type of soil etc. which also affects the WUE of crops.

Irrigation scheduling

“Irrigation scheduling is the process of determining when to irrigate and how much water to apply”.

Importance of irrigation scheduling

1. For maximize water use efficiency
2. To maximize yield
3. To increase cropping intensity
4. Improve and quality produce
5. To maintain soil and environmental balance

Approaches/Criteria of irrigation scheduling:

Approaches /Criteria for schedule irrigations		
A) Soil moisture regime approaches	B) Climatological approaches	C) Plant indicator approaches
<ol style="list-style-type: none">1. Soil water content approach2. Depletion of available soil moisture3. Soil water potential or soil moisture tension	<ol style="list-style-type: none">1. PET measurement2. IW/CPE approach	<ol style="list-style-type: none">1. Visual plant symptoms2. Plant water content3. Leaf diffusion resistance4. Plant temperature5. Critical crop growth stage

1) Soil moisture depletion approach:

The available soil moisture in the root is a good criterion for scheduling irrigation. When the soil moisture in a specified root zone depth is depended to a particular level (which is different for different crops) it is too replenished by irrigation. **For practical purpose, irrigation should be started when about 50 percent of the available moisture in the soil root zone is depleted.** The available water is the soil moisture, which lies between field capacity and wilting point. The relative availability of soil moisture is not same field capacity to wilting point stage and since the crop suffers before the soil moisture reaches wilting point, it is necessary to locate the optimum point within the available range of soil moisture, when irrigation must be scheduled to maintain crop yield at high level. Soil moisture deficit represents the difference in the moisture content at field capacity and that before irrigation. This is measured by taking into consideration the percentage, availability, tension, resistance etc.

2) Climatological or Meteorological approach:

Evapotranspiration mainly depends up on climate. The amount of water lost by evapotranspiration is estimated from Climatological data and when ET reaches a particular level, irrigation is scheduled. The amount of irrigation given is either equal to ET or fraction of ET.

Different methods in Climatological approach are IW/CPE ratio method and pan evaporimeter method.

IW /CPE Approach

Prihar et al. (1974) developed IW:CPE approach. In IW/CPE approach, a known amount of irrigation water is applied when cumulative pan evaporation (CPE) reaches a predetermined level. The amount of water given at each irrigation ranges from 4 to 6 cm. The most common being 5 cm irrigation. Scheduling irrigation at an IW/CPE ratio of 1.0 with 5 cm. Generally, irrigation is given at 0.75 to 0.8 ratios with 5 cm of irrigation water. The irrigation scheduling is based on the cumulative pan evaporation and irrigation depth.

Irrigation at ratio of irrigation water (IW) and cumulative pan evaporation (CPE).

$$\text{IW /CPE ratio} = \frac{\text{Depth of water to be irrigated (IW)}}{\text{Cumulative pan evaporation for particular period (CPE)}}$$

Sunken Screen Evaporimeter: In order to simplify the measuring device of ET, Dastane and Sharma (1968) at IARI, New Delhi has developed sunken screen evaporimeter. They observed a ratio of evaporation and evapotranspiration (Eo/ET) to be 0.95 to 1.05 that is more precise measurement of ET compared to USWB pan evaporimeter. They suggested the use of still smaller evaporimeter such as can evaporimeter with 1 kg capacity and a pointer inside at 1.5 cm below the brim to facilitate the recording of water. The consumptive use may be computed from the following formula:

$$\text{Evapotranspiration} = \text{Pan evaporation} \times \text{Crop factor.}$$

3) Plant basis or plant indices:

As the plant is the user of water, it can be taken as a guide for scheduling irrigation. The deficit of water will be reflected by plants itself such as dropping, curling or rolling of leaves and change in foliage colour as indication for irrigation scheduling. However, these symptoms indicate the need for water. They do not permit quantitative estimation of moisture deficit. Growth indicators such as cell elongation rates, plant water content and leaf water potential, plant temperature leaf diffusion resistance etc. are also used for deciding when to irrigate. Some indicator plants are also a basis for scheduling irrigation e.g. sunflower plant which is used for estimation of PWP of soil is used in Hawaii as an indicator plant for irrigation sugar cane.

Critical stage or phenological stage approach

The stage at which the water stress causes severe yield reduction is also known as **critical stage of water requirement**. It is also known as **moisture sensitive period**. Under limited water supply conditions, irrigation is scheduled at moisture sensitive stages and irrigation is skipped at non-sensitive stages. In cereals, panicle initiation, flowering, and pod development are the most important moisture sensitive stages.

Table : Moisture sensitive stages of Important Crops

Crops	Critical stages / Sensitive stages
Rice	Panicle initiation, flowering and milky stage
Sorghum	Flowering and grain formation
Maize	Silking, tasseling
Pigeon pea	Flower initiation and pod formation
Groundnut	Flowering, pegging, and pod development
Greengram	Flower initiation and pod formation
Cotton	Flowering, boll formation
Wheat	Crown root initiation (CRI), jointing, milking
Chickpea	Pre-flowering, pod development
Mustard	Branching, siliqua development
Sunflower	Two weeks before & after flowering
Soybean	Blooming and seed formation
Safflower	Rosette to flowering
Sugarcane	Formative stage

Plant water status:

This is the latest approach for scheduling of irrigation. Plant is a good indicator of a soil moisture and climate factors. The water content in the plant itself is considered for scheduling irrigation. It is however, not yet common use for want of standard and low cost technique to measure the plant water status or potential.

METHODS OF IRRIGATION:

Irrigation methods refers to the manner in which water is applied to the land. Different methods are used to apply irrigation water to the crop depending on the source of supply of water, topography, quantity of water to be applied, the crop and method of cultivation of crop. These irrigation methods are classified as surface, sub-surface, sprinkler (over-head) and drip method of irrigation.

Methods of irrigation-

1. Surface methods-
 - a. Wild flooding
 - b. Check basin
 - c. Ring Basin method
 - d. Border strip
 - e. Furrow method-1. Corrugation
 - f. Surge irrigation
2. Sub surface irrigation
3. Sprinkler/ overhead irrigation
4. Drip/ Trickle irrigation
5. Automated Irrigation System

I. Surface Irrigation

It is the common method of irrigation practiced all over the world. In this method, water is applied directly to the surface by providing some checks to the water flow:

I. Surface irrigation

1. Wild or Free Flooding

1. Used for lowland rice and other crops.
2. Water is allowed from the channel into the field without much control on either sides of the flow.
3. It covers the entire field and move almost unguided.
4. The height of bunds around the field should be 15 cm for effective use of rainfall.
5. It is a minimum labour intensive method.
6. Most suitable to irrigated saline soils.

Advantages

1. Easy and cheap method
2. Skilled person is not required for controlling the water flow

Disadvantages

1. Wasteful use of water,
2. non-uniform distribution of water,
3. excessive soil erosion on steeper slopes and
4. Require drainage arrangement to reduce ponding.

2. Border Strip (Sara) method

- The land is divided into number of long parallel strips called borders.
- These borders are separated by low ridges.
- The border strip has a uniform gentle slope in the direction of irrigation.
- Each strip is irrigated independently by turning the water in the upper end.
- The water spreads and flows down the strip in a sheet confined by the border ridges.
- The application efficiency of this system is 75–85%.
- Not suited for very sandy soil and very clayey soil as they have too high and low infiltration rate, respectively.

Advantages

1. Uniform and even distribution of water
2. High water application efficiency
3. Large irrigation streams can be efficiently used
4. Good surface drainage
5. Less labour required for field lay out and irrigation.
6. Due to longer strip size inter-cultivation is possible.

Limitations

1. Require labour for layout of system
2. Expensive and time consuming
3. It is not suitable for sandy soils.

3. Check basin irrigation

Flooding of relatively leveled plots surrounded by borders is known as check basin method.

- It is the most common method in which the field is divided into smaller unit areas so that each has a nearly level surface.
- Bunds or ridges are constructed around the area forming basins within which the irrigation water can be controlled.
- The water applied to a desired depth can be retained until it infiltrates into the soil.
- The size of the basin varies from 4 m x 3 m to 6 m x 5m (10 m² to 25 m²) depending upon soil type, topography, stream size and crop.

Advantages

1. Check basins are useful when leaching is required to remove salts from the soil profile.
2. water can be retaining for desired depth
3. High water application and distribution efficiency.

Limitations

1. The ridges interfere with the movement of implements.
2. More area occupied by ridges and field channels.
3. The method impedes surface drainage
4. Precise land grading and shaping are required
5. Labour requirement is higher
6. Not suitable for crops which are sensitive to wet soil conditions around the stem.

4. Furrow irrigation

It is the common method adopted for row planted crops like cotton, maize, sugarcane, potato, beetroot, onion, sorghum, vegetable crops etc. In this method, small evenly spaced shallow furrows or channels are formed in the beds. Another method of furrow irrigation is forming alternate ridges and furrows to regulate water. The water is turned at the high end and conveyed through smaller channels. Water applied in furrows infiltrate slowly into the soil and spread laterally to wet the area between furrows. The dimension of furrows depend on the crop grown, equipment used and soil type. The length of the furrow ranges from 50 to 400 m and 'U' shaped furrows are better than 'V' shaped furrows. In heavy soils, furrows can be used to dispose the excess water.

Advantages

1. Water in furrows contacts only one half to one fifth of the land surface.
2. Labour requirement for land preparation and irrigation is reduced.
3. Compared to check basins there is less wastage of land in field ditches.
4. Reduces evaporation losses
5. High water use efficiency

Disadvantages:

1. Requires labourers to open furrows
2. Costly system
3. Leveling of field is necessary
4. Interculture operation is difficult

5. Ring basin

This method is mostly adopted for wide spaced orchard crops. The rings are circular basins formed around the individual trees. The rings between trees are interlinked with main lead channel by sub channels to get water to the individual rings. As water is allowed in rings only, wastage of water spreading the whole interspaces of trees as in the usual flooding irrigation method is reduced. Weed growth in the interspaces around the rings are discouraged. This method ensures sufficient moisture in the root zone and saves lot of irrigation water.

6. Surge Method

1. **Intermittent application of water** to the field surface under gravity flow which results in a series of “**On and Off**” modes of constant or variable time spans.

Advantages

1. Infiltration uniformity is increased,
2. Deep percolation is reduced compared to continuous water application due to intermittent wetting and drying process.

7. Cablegation: It is a automated method of irrigation.

II. Sub-surface (sub-soil) irrigation

Water is applied below the ground surface through the network of pipes or some devices. The main aim of this type of irrigation is to reduce the evaporation loss and to maintain an artificial water table near the root zone of the crop.

- ◆ In subsurface irrigation, water is applied through under ground perforated pipes or through deep trenches at 15-30 m interval.
- ◆ Water gradually wets root zone through capillary movement / action.
- ◆ Open ditches are preferred because they are relatively cheaper and suitable to all types of soil.
- ◆ The irrigation water should be of good quality to prevent soil salinity.
- ◆ It is suitable where water table is shallow.

Advantages

1. Minimum water requirement for raising crops
2. Minimum evaporation and deep percolation losses
3. No wastage of land
4. No interference to movement of farm machinery

5. Cultivation operations can be carried out without concern for the irrigation period.

Disadvantages

1. Requires a special combination of natural conditions.
2. There is danger of water logging and deep percolation through trenches
3. Possibility of choking of the pipes lay underground.
4. Initial cost is very high.
5. Maintenance of pipelines is difficult.

III. Pressurized Irrigation System

Micro-irrigation:

It is defined as the precise and slow application of water over a long period of time in the form of discrete or continuous or tiny streams of miniature sprays through mechanical devices directly into plant root zone, via a low pressure delivery system. The term micro irrigation refers to those systems operating at low flow rates and **low pressure (<-1.5 to -2.0 bar)** and providing localized distribution of water.

Eg. Drip irrigation, micro-jet irrigation, micro-sprinkler and bubbler irrigation etc.

1. Drip (Trickle) Irrigation

Drip or trickle irrigation is one of the latest methods of irrigation. Drip (Trickle) irrigation system was developed in 1964 by Symcha Blass, an Israeli Engineer. It is defined as the precise and slow application of water in the form of discrete or continuous or tiny streams of miniature sprays through mechanical device called emitters or drippers located at selected points along water delivery lines.

- It is suitable for water scarcity and salt affected soils.
- Water is applied in the root zone of the crop

Standard water quality test needed for design and operation of drip irrigation system.

Components of Drip Irrigation

A drip irrigation system consist essentially of main line, submains, laterals, drippers (emitters), filters and other small fitting and accessories like valve, presser, regulators, presser gauge, fertilizer application components etc.

1) Pump

The pump creates the pressure necessary to force water through the components of the system including the fertilizer tank, filter unit, main line, lateral and the emitters/ drippers. The lateral may be designed to operate under pressure as low as 0.15 to 0.2 kg/cm² and as large as 1 to 1.75 kg/cm². The water coming out of the emitters is almost at atmospheric pressure. The duty of the pump in terms of flow and pressure is determined after the diameter, length and discharge of all the mains, laterals and emitters are decided and the friction losses are estimated.

2)Filter

It is the heart of drip irrigation system. Filtration of irrigation water is essential to prevent clogging of emitters which can be a major problem in the system. The clogging may be due to presence of salts in water, microorganisms, suspended organic and inorganic matter, clays, silt etc., filter is connected to the central distribution system. There are two common types of filters:

3)Screen (mesh) filter

This is useful primarily for removing suspended inorganic particles in water containing sufficient amount of organic matter. The screen filter does not remove large amounts of suspended particles and organic particles without reducing the flow of water through the filter. It is therefore, necessary to frequently flush the screen mesh filter to remove accumulated particles.

4)Sand (Gravel) filter

Sand filter is most effective in the removal of inorganic and organic particles from water. It can extract and retain large quantity of suspended solids without reduction in delivery of the rated flow of filtrated water. The sand filter is normally provided with a back flushing arrangement.

5)Main line

The mainline conveys the water from filtration system to the submain. They normally made of rigid PVC pipes in order to minimize corrosion and clogging. Usually they are placed below the ground i.e. 60 to 90 cm (2 to 3 ft) so that will not interfere with cultivation practices. The main line system has changing flow capacity with respect to length. The mains are PVC pipes usually of 25 mm to 75 mm in diameter.

6)Sub-main

Sub-main distributes the same discharge to all the laterals fitted to it. They are also buried in ground 2 to 2.5 ft and made up of rigid PVC. The diameter is smaller than mainline. There are number of submains from one mainline depending upon the plot size and crop type. Usually pipes of 25-50 mm diameter and suitable length are used.

7)Laterals

Laterals are provided in the main line or sub-main for each row of the crop. Laterals are small diameter flexible pipes or tubing made of low density polythene (LDP) and linear low density polythene (LLDPE) and of 12 mm, 16 mm and 20 mm size. Their color is black to avoid the algae growth and effect of ultra violet radiation. On slopping ground, the laterals are placed along the counter with 1% extra for sagging purpose.

8)Drippers/ Emitters

It is the main component of drip irrigation system for discharging water from lateral to soil i.e. plant. They are made of plastic such as polythene or polypropaline. The discharge rate of emitters ranges from 1 to 15 liters per hour (LPH). Emitters may be on the lateral or inside the lateral, accordingly they are called as online or inline emitters.

9)Control valve (Ball valves)

These are used to control the flow through particular pipes. Generally they are installed on filtration system, main line and on all submains. These are made up of gunmetal, PVC, cast iron and their size ranges from ½” to more than 5”.

10)Flush valves

It is provided at the end of each submain to flush out the water bad dirt.

11)Air release cum vaccum breaker valves

It is provided at the highest point in the main lines to release the entrapped air during the starts of system and to break the vaccum during shut off. It is also provided on submain if submain length is more.

12)Non return valves

It is used to prevent the damage of pump from back flow of water hammer in rising main lines.

13)Presser gauge

It is used to indicate the operating presser of the drip system.

14)Grommet and take off

These are used to connect the lateral to submain. A hole is punched with hand drill of predetermined size in submain. Grommet is fixed in to the hole. Takeoff is pressed in to the grommet with takeoff punch up to the step provided. Grommet acts as a seal. The sizes are different for 12 mm, 16 mm and 20 mm lateral.

15)End caps (End sets)

These are used to close the lateral ends, submain ends, or main line end. Submains and mains are preferably provided with flush valve. They are convenient for flushing the line.

Advantages of Drip Irrigation

1. Well suited for areas of acute water shortage.
2. Minimization of soil erosion and deep percolation and runoff losses.
3. Water is maintained at field capacity.
4. Salt concentration is less.
5. No land leveling is necessary.
6. Herbigation and Fertigation can also be applied.
7. Less disease and weed infestation.

Disadvantages of Drip Irrigation

1. High initial cost on plastic pipes as extensive pipe net work is needed.
2. Drippers are susceptible to blockage and difficult to locate the clogging.
3. Interferes with farm operations and movement of implements and machineries.
4. Frequent maintenance is required.
5. Requires the clean water for irrigation.
6. Not suitable for closed spaced crops.

Fertigation:

This is the process of applying fertilizers through the irrigation system. The soil is negatively charged at high pH and PO_4^- will be precipitated with Ca^+ and absorbed with clay. Availability of P is very low as time proceeds due to this precipitation. Fertigation is problematic at high pH because the availability of micronutrients (Fe, Mn, etc.) is less due to the precipitation. Hence iron chelates (Sequestrene -138) are applied which prevents Fe from precipitation. Also zinc chelates are good to prevent Zn precipitation.

ADVANTAGES

1. Eliminates manual application
2. Quick and convenient
3. Uniformity in application
4. High efficiency and saving of fertiliser upto 30 - 40%
5. Less fertilizer leaching

6. Better penetration of P and K in the layers
7. Co-ordination of nutrition requirement with crop stage or development
8. Possibility of dosage control.
9. Others like herbicides, pesticides, acid, etc can also be applied

LIMITATIONS

1. Toxicity to field workers
2. Chance of backflow into water source, for that NRV and vacuum valve has to be installed
3. Insoluble fertilisers are not suitable (super phosphate)
4. Corrosive effect of fertiliser
5. Phosphate may get precipitated in the pipe line and dripper due to pH reaction
6. High cost

2. Sprinkler/over head Irrigation System

The sprinkler irrigation system conveys water from the source to the field through pipes under pressure and distribute over the field in the form of sprays of rain like droplets. In other words, the method of applying water to the surface of the soil in the form of spray, similar to rains, is known as sprinkler irrigation system. It is also known as overhead irrigation.

- This system is designed to distribute the required depth of water uniformly, which is not possible in surface irrigation.
- Water is applied at a rate less than the infiltration rate of the soil hence the runoff from irrigation is avoided.

Components of Sprinkler System

1)Pumping unit

A high speed centrifugal or turbine pump can be installed for operating the system for individual farm holdings. The pump usually lift water from the source and pushed it through the distribution system and sprinkler..

2)Main lines

Main pipelines carry water from the pumping plant to many parts of the field. In some cases sub main lines are provided to take water from the mains to laterals.

3)Lateral lines

The lateral pipelines carry the water from the main or sub main pipe to the sprinklers. The pipelines may be either permanent, semi permanent or portable.

4)Couplers

A coupler provides connection between two tubing and between tubing and fittings.

5)Sprinkler Head

Sprinklers may rotate or remain fixed. The rotating sprinklers can be adapted for a wide range of application rates and spacing. They are effective with pressure of about 10 to 70 m head at the sprinkler. Pressures ranging from 16-40 m head are considered the most practical for most farms. Fixed head sprinklers are commonly used to irrigate small lawns and gardens.

6)Debris screen

The function of screens is to keep the system free of trash that might plug the sprinkler nozzles

7)Booster pump

Booster pump should be used when a sprinkler irrigation system is used with an existing pumping system installed in a well and the pump capacity is insufficient to force the water through sprinkler.

8)Take off valves

These are generally needed to control the pressure in the lateral lines. The valves should always be used in places where there are significant differences in main line pressure at the various lateral take off points.

9)Flow control valves

Flow control valves are used to regulate the pressure and discharge of individual sprinkler and may be helpful to equal distribution of pressure along the lateral.

Other accessories / fittings

1. Water meters: It is used to measure the volume of water delivered.
2. Pressure gauge: It is necessary to know whether the sprinkler is working with the desired pressure in order to deliver the water uniformly.
3. Bends, tees, reducers, elbows, hydrants, butterfly valves, end plugs and risers
4. Debris removal equipment: This is needed when water is obtained from streams, ponds, canals or other surface supplies. It helps to keep the sprinkler system clear of sand, weed seeds, leaves, sticks, moss and other trash that may otherwise plug the sprinklers.
5. Fertilizer applicators: These are available in various sizes. They inject fertilizers in liquid form to the sprinkler system at a desired rate.

Advantages of Sprinkler System

1. Uniform distribution of water.
2. Saving of water from 25-50 per cent.
3. Saving of land 10-20 per cent.
4. Irrigation area is increased by 1-2 times with the same amount of the water.
5. No risk of runoff and erosion.
6. Suitable for undulating land and steep slopes.
7. Suitable for areas where water and labour scarcity.
8. Suitable for saline soils to leach salts.

Disadvantages of Sprinkler System

1. Not followed under high wind velocity (>12 km/hour).
2. High initial costs.
3. High energy is required (0.50 to >10 kg/cm²).
4. More spreading of diseases.
5. Can not be used for rice and jute crops.

3. Bubbler irrigation:

Bubbler irrigation is the application of water to flood the soil surface using small stream or fountain. The discharge rates for point source bubbler emitters are greater than for drip or sub-surface emitters, but generally, less than 1 gallon per minute (3.785 litre per minute). A small basin is usually required to contain or control the water.

4. Set, Mist and spray systems:

Jet, mist and spray irrigation are application of water by a small spray or mist to the soil surface. Jet, mist and spray irrigation systems are operate at low pressure and apply water at rates higher than drip, but typically less than 1 gallon per minute (3.785 litre per hour).

5. Automated Irrigation System (Based on Microcontroller)

- Irrigation is the artificial application of water to the land or soil.
- Irrigation system uses valves to turn irrigation ON and OFF. These valves may be easily automated by using controllers and solenoids.
- In this system an attempt has been made to automate farm or nursery irrigation that allows farmers to apply the right amount of water at the right time, regardless of the availability of labor to turn valves on and off.
- In addition, farmers using automation equipment are able to reduce runoff from over watering saturated soils, avoid irrigating at the wrong time of day, which will improve crop performance by ensuring adequate water and nutrients when needed.
- The Microcontroller based automated irrigation system consists/components:
 1. Moisture sensors,
 2. Analog to digital converter,
 3. Microcontroller,
 4. Relay driver,
 5. Solenoid valve,
 6. Solar panel and a battery.
- This system can be used in the areas where electrical power is difficult to obtain.
- This system is eco friendly and it uses a renewable source of energy.
- It also helps in time saving, removal of human error in adjusting available soil moisture levels and to maximize their net profits.

Chapter-11

Weed management

Concept of weed

Plants are differentiated into crops which meet the needs of man and weeds which compete with crops. Weed is a plant growing out of place. They are unwanted, non useful, persistent and prolific, effectively compete with the beneficial and desirable crop plants for space, nutrients, sunlight and water, interfere with agricultural operation and thereby reduce the yield and quality of the produce. Certain species with pernicious or even poisonous characteristics grow where they are not wanted. The **first person to use the word weed** in the present day meaning was **Jethro Tull** (1731) in the book “**Horse Hoeing Husbandry**”.

Definitions

1. Weeds are the plants, which grow where they are not wanted (Jethro Tull, 1731).
2. Weeds can also be referred to as plants out of place.
3. Weeds are unwanted or undesirable plants compete with crops for water, soil nutrients, light and space (i.e. CO₂) and thus reduce crop yields.
4. Weeds are unwanted and undesirable plant that interfere with utilization of land and water resources and thus adversely affect crop production and human welfare.

Weediness is a situation in which there is abundance of weeds. **Weeding** is a farm operation where mechanical methods of weed control are followed to provide best opportunity for the crop to establish and grow vigorously up to the harvest.

Weed science focuses on mitigating the negative impacts of weeds on crops.

CHARACTERISTICS OF WEEDS

- Weeds are highly competitive and are highly adaptable under varied adverse situations.
- Reproductive mechanism is far superior to crop plants particularly during unfavorable condition; therefore, weeds are constantly invading the field and try to succeed over less adapted crop plants.
- Produces larger number of seeds compared to crops.
- Most of the weed seeds are small in size and contribute a lot to the seed reserves.
- Weed seeds germinate earlier and their seedlings grow faster.
- They flower earlier and mature ahead of the crop they infest.

- They have the capacity to germinate under varied conditions. The peak period of germination always takes place in certain seasons in regular succession year after year.
- Weed seeds possess the phenomenon of dormancy, which is an intrinsic physiological power of the seed to resist germination even under favourable conditions.
- Weed seeds do not lose their viability for years even under adverse conditions. Most of the weeds possess C4 type of photosynthesis, which is an added advantage during moisture stress.
- They possess extensive root system, which go deeper as well as of creeping type.

Harmful effects of weeds

It has been estimated that in general weeds cause 5% loss to Agricultural production in most developed countries. 10% loss in less developed countries and 25% loss in least developed countries.

Of the total annual loss of agricultural produce from various pests in India, weeds account for 45%, insects 30%, diseases 20% & others 5%.

The losses due to weeds depends on

1. Type of weed
2. Severity of Infestation
3. Duration of infestation
4. Competitive ability of the crop plants with weeds
5. Climatic conditions which affect the growth of the crop and the weed

Losses Caused By Weeds

(1) Weed Menace in Agriculture:-

(A) Reduction in crop yield:- The reduction in yields due to uncontrolled growth of weeds is 34.3% to 89.8%. As the farmer adopts some kind of weeding on their field, it still leaves us with a conservative estimate of at least 10% reduction in crop yields.

In weedy fields farm operations like application of fertilizer, insecticides and irrigation become cumbersome. When spiny weeds invade the crop field it makes the harvesting difficult. Some weeds like bindweed bind the crop plants together so well that their harvesting becomes troublesome. Growing within and outside the fields weeds frequently provide shelter to insect pests and disease organisms of crops and act as alternate host to these, both during the crop season and off season.

(B) Erosion of crop Quality:- Weeds mar quality of farm produce in many ways. Contamination of food grain with weed seeds fetches low price. The weedy grains produce flour with bad odour. In warehouses the weed seeds and weed fragments continue respiration and thus cause the grain to heat and rot. In tea the presence of *Loranthus* leaves impair its quality. In cotton the dry weed fragments adhere to its lint and hinder its spinning process. In dry land agriculture weedy cause severe moisture stress and force the food grain to shrivel. The vegetation and fruits are discolored and deformed in the presence of weeds.

(2) Weed Menace in Animal Husbandry:- Growing with the forage crops, weeds often help to fill the carts and silos but it is the milk and meat returns that their damage becomes apparent. Certain weeds cause sickness in farm animals while others may prove fatal due to high levels of specific alkaloids, tannins, oxalates, glucosides or nitrates. Johnson grass at its tillering stage and *Xanthium pungens* at its cotyledon stage are poisonous to animal due to their high prussic acid contents. *Tribulus terrestris* a weed of dry lands, induces in sheep extra sensitivity to light. Also, its thorny fruits cause sores in the hooves of animals.

The leaves of lantana induce acute photosensitivity and jaundice in animals due to their toxic 'Lantradene-A'. Carrot grass cause contact dermatitis in livestock and it is reported to be poisonous to sheep. Leafy spurge (*Euphorbia esula*) cause scours and weakness in cattle and it is fatal to sheep. *Crotalaria* spp. is fatal to chick. *Datura* is another sickening weed for animals.

Under drought conditions weeds like *Chenopodium* and *Amaranths* develop nitrate levels as high as 1000 ppm or more which causes asphyxia in animals. Spines of *Tribulus terrestris* can puncture animals' skin. When ingested these can also injure the stomach.

(3) Weed Menace to Human Health:- Health comfort and work efficiency of men are adversely affected by weeds. Numerous people are plagued year after year with hay fever and asthma aggravated by pollens of Ambrosia. The airborne pollens and other biotic particles of several other weeds belonging to diverse families are known to cause rhinitis and conjunctivitis. Carrot grass is held responsible for different kinds of dermal allergies in humans. Weeds provide food, protection and habitat for the reproduction of vectors of fatal, human diseases. Aquatic weeds like water lettuce (*Pistia lanceolata*), salvinia (*Salvinia auriculata*) and alligator weed (*Alternanthera spp.*) shelter the alternate hosts and vectors of malaria, yellow fever, dengue fever and filariasis.

Wheat flour contaminated with the seeds of corncockel (*Agrostemma githago*) gives bread a bitter taste and irritates the gastric-tract of the consumer. Mexican poppy (*Agremone mexicana*) seeds crushed with mustard seeds have brought death and blindness to thousands of people in India. Milk from animals feeding upon this weed can cause glaucoma in humans.

(4) Weed Menace to Aquatic Ecosystems:- Not only on land, weeds are a nuisance also in and around water bodies. Aquatic weeds make the appearance of water bodies repulsive and decline their recreational values. In other water bodies they hinder navigation and fishing. Water-flow in irrigation canals and channels is slowed. The potable and drinking water-bodies are fouled by the presence of decomposing aquatic weeds.

(5) Weed Menace To Industry And Public Utilities:- Weeds growing on industrial sites and air fields are potential source of fire hazards, besides being unseemly. They hide industrial pipelines and valve and contribute to deterioration of stores, equipment, and material. Weeds force the fence lines to corrode and obstruct road signs and curves on highways. The working road widths are reduced by weeds. Some weeds penetrate through even asphaltic surfaces which get weakened. Weeds growing around electric poles prevent their ready access to the work crew. Weeds also weaken the rail tracks and air-strips.

(6) Weed Menace To Forests And Pasture-Land:- In the forests and pasture-lands in India weeds are great impedance to regeneration of natural vegetation. In outer Himalayas, lantana (*Lantana camera*) has made large areas of forests and pastures useless. Now carrot grass (*Parthenium hysterophorus*) is entering these areas in a big way. In Maharashtra, many forest nurseries, and in Karnataka and Andhra Pradesh large forest areas have also come under the grip of this weed. With the world's wood needs increasing every year by 64 million cu m, there is need to manage the weeds in our forests to allow natural regeneration of the desired forest species and increase the productivity of the existing trees. Also, weed free buffer strips are essential in forests for preventing fire hazards.

(7) Weeds and Aesthetics:- In many advanced countries lowering of the aesthetic values is the primary objection to weeds. Their presence around living and working places makes the surroundings dull and insipid.

Importance/Beneficial effects of weeds or economic uses of weeds

Several weeds have been put to certain economic uses since ages.

- 1. Weeds are useful as fodder** - Useful as good fodder for milch animals. Most weeds are preferred by cattle and weeds like *Rynchosia aurea*, *R. capitata* and *Clitoria terneata* are very good fodder legumes and also Hariyali and field bind weed / Chandvel (*Convolvulus arvensis*).
- 2. Weeds are useful as vegetables** - Used as green vegetables and weeds serve as human food e.g., *Amaranthus viridis* (Math) and *Digera arvensis* (Kunjru) used as greens.
- 3. Weed as soil binders** - *Panicum repense* is an excellent soil binder; keeps bunds in position and prevents soil erosion in high rainfall regions and hilly slopes. Hariyali, *Agropyron repens* (quack grass, kollukattai grass (*Cenchrus sp.*) etc., can be used as soil binders.
- 4. Weeds are useful as manure** - When weeds are ploughed in, they add to the soil plenty of humus. Excellent compost can be made out of many weed plants. E.g., *Calotropis gigantea* (Rui), *Croton sparsiflorus* and *Tephrosia purpurea* (Unhali) are used as green leaf manure for rice. In wetlands, weeds are said to form a sort of rotation with paddy and are valuable in preventing loss of nitrates. *Datura sp.* contains 3% N on dry weight basis, *Tephrosia purpurea* fix N @ 50-75 kg/ha.

5. **Weeds are useful as fuel** - *Prosopis juliflora* (Babul) very invasive in nature and notorious tree weed commonly used as fire wood. People make charcoal out of it and are marketed.
6. **Weeds have medicinal values** - Many weeds have great therapeutic properties and used as medicine. For example,
 - *Phyllanthus niruri* (Hazardani) – Jaundice
 - *Eclipta alba* – Scorpion sting
 - *Centella asiatica* – Improves memory
 - *Cynodon dactylon* (Haryali/Bermuda grass) – Asthma, piles
 - *Cyperus rotundus* (Lavala/purple nutsedge) – Stimulates milk secretion
 - *Leucas aspera* – Snake bite
 - *Calotropis procera* – Gastric trouble
 - *Abutilon indicum* (Petari) – Piles
7. **Weeds use in cottage industry** - *Typha* and *Saccharum* sp used for making ropes and thatch boards.
 - Weed as indicators - Weeds are useful as indicators of good and bad soils. *Echinochola colonum* (Bharad/ jungle rice) occurs in rich soils while *Cymbopogon* denotes poor light soil and Sedges are found in ill-drained soils.
 - NO₂ and SO₂air pollution determined by wild mustard and chick weed respectively.
 - Some weeds are useful to identify the metals (Indicator geobotany) through satellite imageries Eg *Commelina* sp. / Kenna (Copper), *Eichornia crassipes* (Copper Zinc, lead and cadmium in water bodies).
8. **Weeds in Breeding Programme** - In north India *Saccharum spontaneum* weed is used in breeding programme for developing the noble canes.
9. **Other economic uses**
 - Useful in manufacturing of agarbattis e.g., *Cyperus rotundus*
 - *Cymbopogon citrates* (Citronella oil) and *C. martinii* (Palmrosa) are used for manufacturing aromatic oil.
 - Aquatic weeds are useful in Paper, pulp and fiber industry.
 - *Argemone mexicana* (Piwala dhotra) is used to reclaim alkali soils.

- Ornamental flowers—*Lantana camera* is used for interior decoration.
- Used for fencing purposes. Ex.—Cactus, *Agave sp.* *Saccharum squarrosus*, etc.
- *Chenopodium album* used as mulch to reduce evaporation losses.

CLASSIFICATION OF WEEDS:

Knowledge of weed seed characteristics, morphology, ontogeny, nature of competition and degree of association with crops are pre-requisite for suggesting some efficient weed control measures. It makes the users/scientists quite acquainted with the nature and spectrum of weeds existing in the crop fields and accordingly guides them to adopt certain measures. Identification and naming of a particular weed based on its genus, species or certain biological characters may not be much useful to users since weed control usually, unless specific weed problem in certain area, aims at composite weed culture and not on individual species of weeds. Therefore, some common characteristics of the species, which are clearly visible and easily understandable by users, are to be exploited for making of their classes/groups and for recommending suitable control measures.

Out of 2,50,000 plant species, weeds constitute about 250 species, which are prominent in agricultural and non-agricultural system. Under world conditions about 30,000 species is grouped as weeds.

I. Based on life span/ life cycle/Ontogeny:

Based on life span (Ontogeny), weeds are classified as Annual weeds, Biennial weeds and Perennial weeds.

(a) Annual Weeds: Those that live only for a season or year and complete their life cycle in that season or year is called annuals.

The mode of propagation is commonly through seeds. After seeding the annuals die away and the seeds germinate and start the next generation in the next season or year following. Most common field weeds are annuals. The examples are *Commelina benghalensis*, *Boerhaavia erecta*, *Chenopodium album* etc.

(b) Biennials: It completes the vegetative growth in the first season, flower and set seeds in the succeeding season and then die. These are found mainly in non-cropped areas. Weeds are much limited as compared to annual weeds.

Eg. *Alternanthera echinata*, *Daucus carota*

(c) Perennials: Perennials live for more than two years and may live almost indefinitely. They adapted to withstand adverse conditions. They propagate not only through seeds but also by underground stem, root, rhizomes, tubers etc.

a. Stolon: Plants having horizontal creeping stem above the ground – *Cynodon dactylon*

b. Roots: Plants having enlarged root system with numerous buds – *Convolvulus arvensis*

c. Tubers: Plants having modified rhizomes adapted for storage of food – *Cyperus rotundus*

II. Based on place of occurrence/habitat/situation:

- (a) Weeds of crop lands: The majority of weeds infest the cultivated lands and cause hindrance to the farmers for successful crop production. Eg. *Philaris minor* in wheat
- (b) Weeds of pasture lands: Weeds found in pasture / grazing grounds. Eg. *Indigofera enneaphylla*
- (c) Weeds of waste places: Corners of fields, margins of channels etc., where weeds grow in profusion. Eg. *Gynandropsis pentaphylla*, *Calotropis gigantea*
- (d) Weeds of playgrounds, road-sides: They are usually hardy, prostrate perennials, capable of Withstanding any amount of trampling. Eg. *Alternanthera echinata*, *Tribulus terrestris*

III. Based on Origin

- (a) Indigenous weeds: All the native weeds of the country are coming under this group and most of the weeds are indigenous. Eg. *Acalypha indica*, *Abutilon indicum*
- (b) Introduced or Exotic weeds or anthrophytes: These are the weeds introduced from other countries. These weeds are normally troublesome and control becomes difficult. Eg., *Parthenium hysterophorus*, *Phalaris minor*, *Acanthospermum hispidum*

IV. Based on cotyledon number

Based on number of cotyledons it possess it can be classified as dicots and monocots.

- (a) Monocots Eg. *Panicum flavidum*, *Echinochloa colona*
- (b) Dicots Eg. *Crotalaria verucosa*, *Indigofera viscosa*

V. Based on soil pH

Based on pH of the soil the weeds can be classified into three categories.

- (a) Acidophile – Acid soil weeds eg. *Rumex acetosella*
- (b) Basophile – Saline & alkaline soil weeds eg. *Taraxacum stricta*
- (c) Neutrophile – Weeds of neutral soils eg *Acalypha indica*

VI. Based on morphology

Based on the morphology of the plant, the weeds are also classified in to three categories. This is the most widely used classification by the weed scientists.

- (a) Grasses: All the weeds come under the family Poaceae are called as grasses which are characteristically having long narrow spiny leaves. The examples are *Echinochloa colonum*, *Cynodon dactylon*
- (b) Sedges: The weeds belonging to the family Cyperaceae come under this group. The leaves are mostly from the base having modified stem with or without tubers. The examples are *Cyperus rotundus*, *Fimbristylis miliaceae*
- (c) Broad leaved weeds: This is the major group of weeds as all other family weeds come under this except that is discussed earlier. All dicotyledon weeds are broad leaved weeds. The examples are *Flavaria australacica*, *Digera arvensis*

VII. Based on nature of stem

Based on development of bark tissues on their stems and branches, weeds are classified as woody, semi-woody and herbaceous species.

- (a) Woody weeds: Weeds include shrubs and undershrubs and are collectively called brush weeds. Eg. *Lantana camera*, *Prosopis juliflora*

(b) Semi-woody weeds: eg. *Croton sparsiflorus*

(c) Herbaceous weeds: Weeds have green, succulent stems are of most common occurrence around us. Eg. *Amaranthus viridis*

VIII. Classification based on association

When two plants are living together i.e. called association. Based on association they are season bound weeds, crop bound weeds and crop associated weeds.

i. Season bound weeds:

They are seen in that particular season irrespective of crop. These are either summer annuals or winter annuals. *Sorghum halepans* (Perennial) is a summer perennial and *Cirium arvense* is winter perennial. *Phalaris minor* and *Avena fatua* are winter season annuals.

ii. Crop bound weeds:

Weeds which usually parasite the host crop partially or fully for their nourishment i.e parasitism also called as parasitic weeds. Those parasites which attack roots are termed as root parasites and those which attack shoot of other plants are called as stem parasites

A. Root parasites

a. Complete root parasite eg *Orobanche* (broom rape) in tobacco

b. Partial root parasite eg *Striga* spp (witch weed) on millets

2. Stem parasites

a. Complete stem parasite eg *cuscuta* (dodder) in lucern & burseem

b. Partial stem parasite eg *Loranthus* in fruit crops

iii. Crop associated weeds:

These are also crop specific due to mimicry, need for specific micro climate and ready contamination with the crops.

Mimicry

If weeds look exactly like crops morphologically & complete their life cycle, *Echinochloa colonum* (Jungle rice) mimic the rice crop.

Avena fatua (wild oat) and *Phalaris minor* (canary grass) both mimic the wheat and *Loranthus* in tea gardens. For example *Avena fatua* (wild oats) tends to grow to the height of winter grains and adjusts its ripening period to the crop over a wide varietal range and this type of mimicry is called phenotypic mimicry.

IX. Classification based on site of predominance:

Facultative weeds:

Also called apophytes. Weeds that grow primarily in wild community and migrated to crop fields or cultivated environment and associating themselves closely with the man's affairs, behave like more competitive weeds. Eg. *Opuntia dilleni*

Obligate weeds:

Occur only on cultivated land or other wise disturbed land. They can not withstand competition from volunteer vegetation in a closed community. Less competitive obligate weeds can't survive and can't withstand and disappears when the land is not disturbed for 2-3 years and kept as fallow. Obligate weeds may also be over taken by facultative weeds. Eg. *Convolvulus arvensis*

Noxious weeds :

These weeds are arbitrarily defined as being undesirable, trouble some & difficult to control. They have immense capacity of reproduction & high dispersal capacity. They adopt tricky ways to defy man efforts to remove them. These weeds are also known as special problem weeds.

Eg. *Cyperus rotundus*, *Cynodon dactylon*, *Cirsium arvense*, *Parthenium*, *Eichhornea crassipes*, *Lantana camara*, *Saccharum spontaneum*, *Imperata cylindrical* and *Striga spp*

Objectionable weed

It is a noxious weed whose seed is difficult to separate from the crop seed after contamination is called objectionable weeds.

Aquatic weeds: Unwanted plants, which grow in water and complete at least a part of their life cycle in water are called as aquatic weeds.

Control of weeds / Methods of weeds management

Weed control and weed management are the two terms used in weed science. **Weed control is the process of limiting infestation** of the weed plant so that crops can be grown profitably, where as **weed management includes prevention, eradication and control** by regulated use, restricting invasion, suppression of growth, prevention of seed production and complete destruction. Thus weed control is one of the aspects of weed management.

Important components or methods of weed management / control particularly in relation to agriculture are:

1. Cultural,
2. Physical,
3. Biological and
4. Chemical.

Every method of weed control has its own advantages and disadvantages. No single method is successful under all weed situations. Many a time, a combination of these methods gives effective and economic control than a single method.

I. CULTURAL/ ECOLOGICAL/ AGRONOMIC/ CROP HUSBANDRY WEED CONTROL:

Several cultural practices like tillage, planting, fertiliser application, irrigation etc., are employed for creating favourable condition for the crop. These practices if used properly, help in controlling weeds. Cultural methods, alone cannot control weeds, but help in reducing weed population. They should, therefore, be used in combination with other methods. In cultural methods, tillage, fertiliser application and irrigation are important. In addition, aspects like selection of variety, time of sowing, cropping system, cleanliness of the farm etc., are also useful in controlling weeds.

1. Field preparation:

The field has to be kept weed free. Flowering of weeds should not be allowed. This helps in prevention of build up of weed seed population.

2. Summer tillage:

The practice of summer tillage or off-season tillage is one of the effective cultural methods to check the growth of perennial weed population in crop cultivation. Initial tillage before cropping should encourage clod formation. These clods, which have the weed propagules, upon drying desiccate the same. Subsequent tillage operations should break the clods into small units to further expose the shriveled weeds to the hot sun.

3. Maintenance of optimum plant population:

Lack of adequate plant population is prone to heavy weed infestation, which becomes difficult to control later. Therefore practices like selection of proper seed, right method of sowing, adequate seed rate protection of seed from soil borne pests and diseases etc. are very important to obtain proper and uniform crop stand capable of offering competition to the weeds.

4. Crop rotation:

The possibilities of a certain weed species or group of species occurring is greater if the same crop is grown year after year. In many instances, crop rotation can eliminate at least reduce difficult weed problems. The obnoxious weeds like *Cyperus rotundus* can be controlled effectively by including low land rice in crop rotation.

5. Growing of intercrops:

Inter cropping suppresses weeds better than sole cropping and thus provides an opportunity to utilize crops themselves as tools of weed management. Many short duration pulses viz., green gram and soybean effectively smother weeds without causing reduction in the yield of main crop.

6. Mulching:

Mulch is a protective covering of material maintained on soil surface. Mulching has smothering effect on weed control by excluding light from the photosynthetic portions of a plant and thus inhibiting the top growth. It is very effective against annual weeds and some perennial weeds like *Cynodon dactylon*. Mulching is done by dry or green crop residues, plastic sheet or polythene film. To be effective the mulch should be thick enough to prevent light transmission and eliminate photosynthesis.

7. Soil Solarisation:

This is another method of utilization of solar energy for the desiccation of weeds. In this method, the soil temperature is further raised by 5 – 10 °C by covering a presoaked fallow field with thin transparent plastic sheet. The plastic sheet checks the long wave back radiation from the soil and prevents loss of energy by hindering moisture evaporation.

8. Stale seedbed:

A stale seedbed is one where initial one or two flushes of weeds are destroyed before planting of a crop. This is achieved by soaking a well prepared field with either irrigation or rain and allowing the weeds to germinate. At this stage a shallow tillage or non-residual herbicide like paraquat may be used to destroy the dense flush of young weed seedlings. This may be followed immediately by sowing. This technique allows the crop to germinate in almost weed-free environment.

9. Blind tillage:

The tillage of the soil after sowing a crop before the crop plants emerge is known as blind tillage. It is extensively employed to minimise weed intensity in drill sowing crops where emergence of crop seedling is hindered by soil crust formed on receipt of rain or irrigation immediately after sowing.

Merits of Cultural Method

1. Low cost for weed control
2. Easy to adopt
3. No residual Problem
4. Technical skill is not involved
5. No damage to crops
6. Effective weed control
7. Crop-weed ecosystem is maintained

Demerits of Cultural Method

1. Immediate and quick weed control is not possible
2. Weeds are kept under suppressed condition
3. Perennial and problematic weeds can not be controlled
4. Practical difficulty in adoption

II. MECHANICAL /MANUAL/ PHYSICAL WEED CONTROL

Mechanical or physical methods of weed control are being employed ever since man began to grow crops. The mechanical methods include tillage, hoeing, hand weeding, digging, cheeling, sickling, mowing, burning, flooding, mulching etc.

1. Tillage:

Tillage removes weeds from the soil resulting in their death. It may weaken plants through injury of root and stem pruning, reducing their competitiveness or regenerative capacity. Tillage also buries weeds. Tillage operation includes ploughing, discing, harrowing and leveling which is used to promote the germination of weeds through soil turnover and exposure of seeds to sunlight, which can be destroyed effectively later. In case of perennials, both top and underground growth is injured and destroyed by tillage.

2. Hoeing:

Hoe has been the most appropriate and widely used weeding tool. It is a very useful implement to obtain results effectively and cheaply. It supplements the cultivator in row crops. Hoeing is particularly more effective on annuals and biennials as weed growth can be completely destroyed. In case of perennials, it destroyed the top growth with little effect on underground plant parts resulting in re-growth.

3. Hand weeding:

It is done by physical removal or pulling out of weeds by hand or removal by implements called khurpi, which resembles sickle. It is probably the oldest method of controlling weeds and

it is still a practical and efficient method of eliminating weeds in cropped and non-cropped lands. It is very effective against annuals, biennials and controls only upper portions of perennials.

4. Digging:

Digging is very useful in the case of perennial weeds to remove the underground propagating parts of weeds from the deeper layer of the soil.

5. Cheeling:

It is done by hand using a cheel hoe, similar to a spade with a long handle. It cuts and shapes the above ground weed growth.

6. Sickling and mowing:

Sickling is also done by hand with the help of sickle to remove the top growth of weeds to prevent seed production and to starve the underground parts. It is popular in sloppy areas where only the tall weed growth is sickled leaving the root system to hold the soil in place to prevent soil erosion.

Mowing is a machine-operated practice mostly done on roadsides and in lawns.

7. Burning & Flaming:

Burning or fire is often an economical and practical means of controlling weeds. It is used to (a) dispose of vegetation (b) destroy dry tops of weeds that have matured (c) kill green weed growth in situations where cultivations and other common methods are impracticable.

Flaming

It is the momentary exposure of green weeds to as high as 1000°C from flame throwers to control in row weeds. Eg. Flaming is used in western countries for selective weed control in crops like cotton, onion, soybean and fruit orchards. Dodder is also controlled by flaming in lucern. Searing.

8. Flooding:

Flooding is successful against weed species sensitive to longer periods of submergence in water. Flooding kills plants by reducing oxygen availability for plant growth. The success of flooding depends upon complete submergence of weeds for longer periods.

Merits of Mechanical Method

- 1) Oldest, effective and economical method
- 2) Large area can be covered in shorter time
- 3) Safe method for environment
- 4) Does not involve any skill
- 5) Weeding is possible in between plants
- 6) Deep rooted weeds can be controlled effectively

Demerits of Mechanical Method

- 1) Labour consuming
- 2) Possibility of damaging crop
- 3) Requires ideal and optimum specific condition

III. BIOLOGICAL METHOD OF WEED CONTROL

Definition: Utilization of natural living organism, such as insects, herbivorous fish, other animals, disease organisms and competitive plants to limit their growth.

In biological control method, it is not possible to eradicate weeds but weed population can be reduced. This method is not useful to control all types of weeds. Introduced weeds are best targets for biological control. The control *Opuntia spp* (Prickly pear) in Australia and *lantana* in Hawaii with certain insect bioagents are two spectacular examples of early period biological control of weeds.

Criteria / Characteristics of successful bio-agent:

1. Host-specific 2. Bioagent hardiness 3. Feeding habit and ease of multiplication

Promising bioagents of weeds:

Weed	Bioagent	Reporting country	Kind of bioagents
<i>Chondrilla juncea</i>	<i>Puccinia chondrillina</i>	Australia	Plant pathogens
<i>Cirsium arvense</i>	<i>Septonia cirsii</i>	-	Plant pathogens
<i>Cyperus rotundus</i>	<i>Bactra vendana</i>	India, USA	Shoot boring moth
<i>Hydrilla verticillata</i>	<i>Hydrilla pakistanae</i>	USA	Shoot fly
<i>Orobanche cernua</i>	<i>Sclerotinia spp</i>	USA	Plant pathogens
<i>Parthenium hysterophorus</i>	<i>Zygogramma bicolorata</i> <i>Epiblema strenuana</i> <i>Conotrachelus spp</i>	India Australia Australia	Leaf eating insect Stem galling insect Stem galling insect
<i>Rumex spp</i>	<i>Uromyces rumicis</i> <i>Gastrophysa viridula</i>	USA USA	Plant pathogens Beetle

Integrated weed management:

System approach also called as integrated weed management. “Integrated method is a system which brings all feasible methods of weed control harmonizing them into a single and co-ordinated system designed to maintain weeds below those levels at which they cause economic loss”.

Principles of Integrated weed management

1. IWM place the crop in competitive advantage over the weeds by manipulating the crop habitat by utilizing some biological differences between crops and weeds.
2. In IWM measures should be directed to reduce the survival mechanism of weeds in the soil.
3. Crop cultural practices should be incorporated to discourage the establishment of the perennial and parasitic weeds. Eg: Crop rotation
4. Any individual element of the weed management should be eco friendly and it should not be harmful to the environment.
5. Weed management practices should be flexible to accommodate possible innovations and experiences of progressive farmers.

Why IWM

1. One method of weed control may be effective and economical in a situation and it may not be so in other situation.
2. No single herbicide is effective in controlling wide range of weed flora
3. Continuous use of same herbicide creates resistance in escaped weed flora or causes shift in the flora.
4. Continuous use of only one practice may result in some undesirable effects. Eg. Rice –wheat cropping system – *Philaris minor*
5. Only one method of weed control may lead to increase in population of particular weed.
6. Indiscriminate herbicide use and its effects on the environment and human health.

Advantages of IWM

1. It shifts the crop-weed competition in favour of crop
2. Prevents weed shift towards perennial nature
3. Prevents resistance in weeds to herbicides
4. No danger of herbicide residue in soil or plant
5. No environmental pollution
6. Gives higher net return
7. Suitable for high cropping intensity

Chapter-12

Cropping systems

Cropping System:

It is an important component of farming system. It represents cropping patterns used on a farm and their interaction with farm resources, other farm enterprises and available technology which determine their makeup.

It is defined as the order in which crops are cultivated on a piece of land over a fixed period. Or cropping system is the way in which different crops are grown. In the cropping systems, sometimes a number of crops are grown together or they are grown separately at short intervals in the same field.

Cropping pattern:

The yearly sequence and spatial arrangement of crops and fallow on a same piece of land is called cropping pattern. OR It is the pattern of crops for a given piece of land or cropping pattern means the proportion of area under various crops at a point of time in a unit area

Crop rotation practiced by the majority of the farmers in a given area or locality.

Crop Rotation:

Recurrent succession of crops on the same piece of land either in a year or a longer period of time is called as crop rotation. OR Growing of different crops in succession of crops on the same piece of land in a specific period of time.

Crop rotation is the reverse of land rotation. In this, crop is rotated year after year.

Classification of Cropping System

A. Monocropping

B. Multiple Cropping

C. Fallowing / Fallow in rotation

Parallel Multiple Cropping

1. Intercropping

ex. Soybean + pigeon pea 4: 2

a. Parallel cropping

ex. Greengram/ blackgram + maize
Greengram/ blackgram /soybean + cotton

b. Companion cropping

ex. Mustard / wheat/ with sugarcane

c. Synergistic cropping

ex. Sugarcane + potato

d. Multistoried cropping

ex. Sugarcane + Potato + Onion
Sugarcane + Mustard + potato
Coconut + black pepper +cocoa + pine
apple

Based on % Plant population

- a. Additive series
- b. Replacement series

2. Mixed Cropping

a. Mixed crop

b. Companion crop

ex. Two rows of mustard in 8 rows of wheat

c. Augmenting crop

ex. Japanese mustard with berseem

d. Guard crop

ex. Safflower around pea

3. Relay cropping

Ex. Sowing of lucern/berseem in standing crop of Paddy /
cotton just before they are ready for harvesting

4. Alley cropping

Ex. Sorghum/Maize between 2 rows of leguminous shrubs

5. Strip cropping

Ex. Blackgram + maize

6. Polyculture

Ex. Subabul + Papaya + Pigeon pea+ Dinanath grass
Mango+ Pineapple + Turmeric
Banana + Marigold + Berseem

Sequential Multiple Cropping

1.Sequence cropping

a. Double cropping

Ex. Greengram/ blackgram – R.Sorghum
Greengram/ blackgram – Safflower

b. Triple cropping

Ex.Sorghum-sunflower-summer
groundnut

c. Quadruple cropping

Ex. Maize - Potato-Wheat- V. Mung
June Oct. Dec. - April.

2. Ratoon cropping/ Ratooning

Ex. Sole red gram in *kharif* –Ratoon
redgram in *rabi* (IPCL-87)

A. Monocropping :

Growing of single crop in a year is called as monocropping.

For example, growing of *kharif* sorghum.

It may be due to the climatological or socioeconomic condition of the farmer or due to specialization of the farmer in growing that crop.

- Under rainfed condition, Soybean, cotton, pigeon pea etc are grown year after year due to limitation of rainfall
- Growing only zaid crops in diara land is due to the climatic condition of that crop.
- Growing of flue cured tobacco in Guntur district of A.P is due to specialization of the farmers in growing that crop.
- In canal irrigated areas, under waterlogged condition, only rice crop is grown as there is no option with the farmer to grow any other crop

Monoculture:

Repetitive growing of the same crop on the same piece of land irrespective of its intensity is called as monoculture.

For example, growing of Rice – Rice- Rice in Tamil Nadu.

B. Multiple Cropping / Polycropping

Growing of two or more crops on the same piece of land in one calendar year is called as multiple cropping.

It is the intensification of cropping in time and space dimensions i.e. more numbers of crops within a year and more numbers of crops on the same piece of land at any given period.

Merits

- i. Efficient utilization of available resources viz. land, labour, capital, water, fertilizers, etc.
- ii. Inclusion of leguminous crop helps in increasing the fertility of soil.
- iii. Helps to fulfill the needs of farmer's family and his livestock.
- iv. Provides more employment and more income to the family members of farmers and others.

Demerits

- i. More investment in terms of labour and capital.
- ii. Supervision is difficult.
- iii. Marketing of different crop produce is difficult.

Multiple cropping can be divided into two types viz. Parallel multiple Cropping and sequential multiple cropping.

Parallel Multiple Cropping:

Growing of two or more than two crops simultaneously on the same piece of land is called as parallel multiple cropping.

Different types of parallel multiple cropping is as follows:

1. Intercropping :

Growing of two or more crops simultaneously on the same piece of land with definite row proportion is called as intercropping.

Ex. Growing of soybean + pigeon pea in the row proportion of 4 : 2.

Cotton + Black gram (1:1), Sorghum + Pigeonpea (2:1),

Pearl millet + Pigeon pea (3:3)



Fig. Intercropping of pigeonpea + maize

Intercropping may be divided into following four groups (Singh, 1990)

a. Parallel cropping :

In this cropping two crops are selected which are having different growth habits and have a zero competition between each other and both of them express their full yield potential.

Ex. Greengram/ blackgram /soybean + cotton

Greengram/ blackgram / Soybean + maize

b. Companion cropping

In this cropping the yield of one crop is not affected by other. In other words, the yield of both the crops is equal to their pure crop. Thus, the standard plant populations of both crops are maintained.

Or

System in which production of both intercrops is equal to that of its solid planting is called companion cropping.

Ex. Mustard / wheat + sugarcane

Onion +sugarcane

c. Synergistic cropping:

In this cropping system, the yield of both the crops grown together is found to be higher than the yields of their pure crops/sole crops on unit area basis.

Ex. Sugarcane + potato

d. Multistoried cropping:

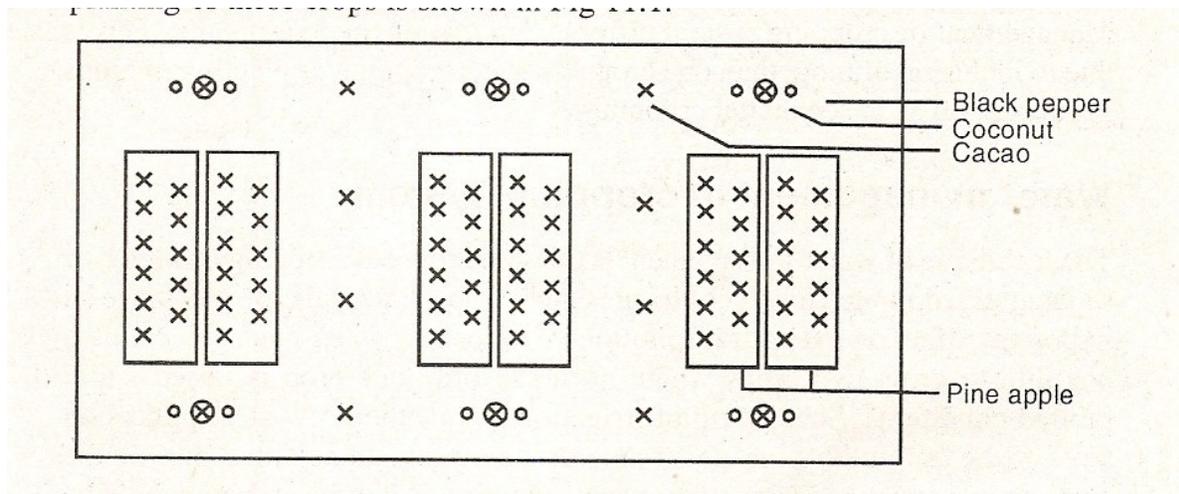
Growing plants of different heights in the same field at the same time is termed as multistoried cropping.

- The main objective is to utilize the vertical space more effectively.
- Mostly practiced in orchards and plantation crops for maximum use of solar energy even under normal planting density.
- In multistoried cropping, the leaf canopies of intercrops occupy different vertical layers.
- The tallest intercrops have foliage tolerant of strong light and high evaporative demand and shorter intercrops with foliage requiring shade or relatively high humidity.

Ex. Sugarcane + potato + Onion

Sugarcane + Mustard + potato

Coconut + Black pepper + Cocoa + Pine apple



Based on per cent plant population intercropping may be again divided into following two types

- a. Additive series b. Replacement series

a. Additive series:

In this series one crop is sown with 100% of its recommended population in pure stand which is known as base crop. Another crop known as intercrop is introduced into the base crop by adjusting or changing crop geometry.

- The population of intercrop is less than its recommended population in pure stand.

- LER of additive series is greater than replacement series.
- Additive series is more efficient than replacement series in ICS.
- This system is mostly adopted in India.

b. Replacement series:

In this series both the crops are called as component crops.

- By scarifying certain proportion of population of one component, another component crop is introduced.
- This type of cropping is popular in Western Countries.

Advantages of Inter Cropping

1. Greater stability of yield over different seasons,
2. Better use of growth resources,
3. Better control of weeds, pests and diseases,
4. One crop provides physical support to the other crop,
5. One crop provides shelter to the other crop,
6. Erosion control through providing continuous leaf cover over the ground surface, and
7. It is the small farmers of limited means who is most likely to benefit.

Disadvantages of Intercropping

1. Yield decrease because of adverse competition effect,
2. Allelopathic effect,
3. Creates obstruction in the free use of machines for intercultural operations and
4. Large farmers with adequate resources may likely to get less benefit out of intercropping.

2. Mixed Cropping

It is defined as growing of two or more crops simultaneously intermingled without any row pattern.

- Mixed cropping is a common practice in dryland tracts of India.
- It is subsistence farming.
- Main objective is to lessen the risk of total crop failure, and to satisfy the Farmers in food and fodder.
- Mixed cropping needs irrigation throughout the year.



Fig. Mixed cropping

Mixed Cropping may be divided into following four groups based on their methods of sowing (Singh, 1990).

a. Mixed crops

Here the seeds of different intercrops are mixed together and then sown either in lines or broadcasted. This method is not scientific and usually causes problem while performing various agricultural operations and harvesting of the crops.

b. Companion crop

The seeds of different crops are not mixed together but different crops are sown in different rows.

Ex. Two rows of mustard in 8 rows of wheat

Three rows of groundnut in pigeon pea

This method of sowing facilitates in performing various agricultural operations like weeding, interculture, plant protection and even in harvesting.

c. Augmenting crop

When sub crops are sown to supplement the yield of the main crops, then the sub crops are called as augmenting crops. Ex. Japanese mustard with berseem. Here, Mustard (Sub crop) helps in getting higher yield of fodder in spite of the fact that Berseem (main crop) gives poor yield in the first cutting.

d. Guard crop

In this system of cropping, the main crop is grown in the centre, surrounded by hardy or thorny crops such as safflower around pea or mesta around sugarcane, sorghum around maize etc. with a view to provide protection to main crop.

Ex. Safflower around pea

Principles of mixed cropping:

1. the crop mixture should contain leguminous crops to minimize soil fertility depletion continuously
2. tall and short growing crops be mixed to avoid competition for light at the same height
3. deep and shallow rooted crops should form the mixture to avoid competition for plant nutrients at a particular horizon,

4. mixture contain crops of different durations

Intercropping is the new concept of mixed cropping. The major difference between mixed and intercropping is that there is definite row arrangement for each crop in intercropping.

3. Relay cropping (Overlapped cropping)

It refers to planting of succeeding crop before harvesting of the preceding crop. In this cropping, the succeeding crop is planted after the preceding crop has reached to reproductive stage of growth but before it reaches to harvesting stage.

Ex. Sowing of lucerne /berseem in standing crop of Paddy /cotton just before they are ready for harvesting

Paira (Bihar & West Bengal) and Utera (Madhya Pradesh) cropping are also referred as an example of relay cropping. Paira/Utera cropping means sowing of *Lathyrus* or lentil before the harvest of rice in lowland area with an objective to use the residual moisture of rice field.

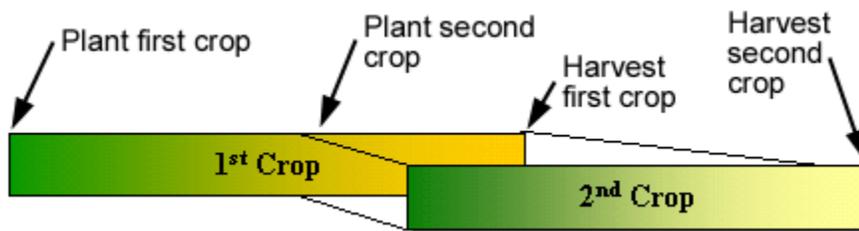


Fig. Relay cropping

4. Sequence/Sequential multiple cropping (Non-over lapping cropping)

1.Sequence cropping: It refers to growing of two or more crops in a succession on the same piece of land in a farming year. Crop intensification is only in time dimension.

Depending on the number of crops grown in a year, it is classified in to three types:

a. **Double cropping:** Growing of two crops in a sequence on the same piece of land in a year is called as double cropping.

Ex. Green gram/blackgram- rabi sorghum; Green gram/ blackgram- safflower

b. **Triple Cropping:** Growing of three crops in a sequence on the same piece of land in a year is known as triple cropping.

Ex. Sorghum-sunflower-summer groundnut

c. **Quadruple cropping:** Growing of four crops in a sequence on the same piece of land in a year is called as quadruple cropping.

Ex. Maize-potato-wheat-vaishaki mung

2.Ratoon cropping/Ratooning: Raising a crop with regrowth coming out of the roots or stalks after the harvested of the crop is called as ratooning.

Ex. Sole redgram in *kharif*- ratton red gram in *rabi* (ICPL-87)

5. Alley cropping

It is a system of raising arable (field) crops like sorghum, maize etc. in the alleys between two subsequent rows of leguminous shrubs/trees (subabul) Ex. Sorghum/Maize between two rows of leguminous shrubs.

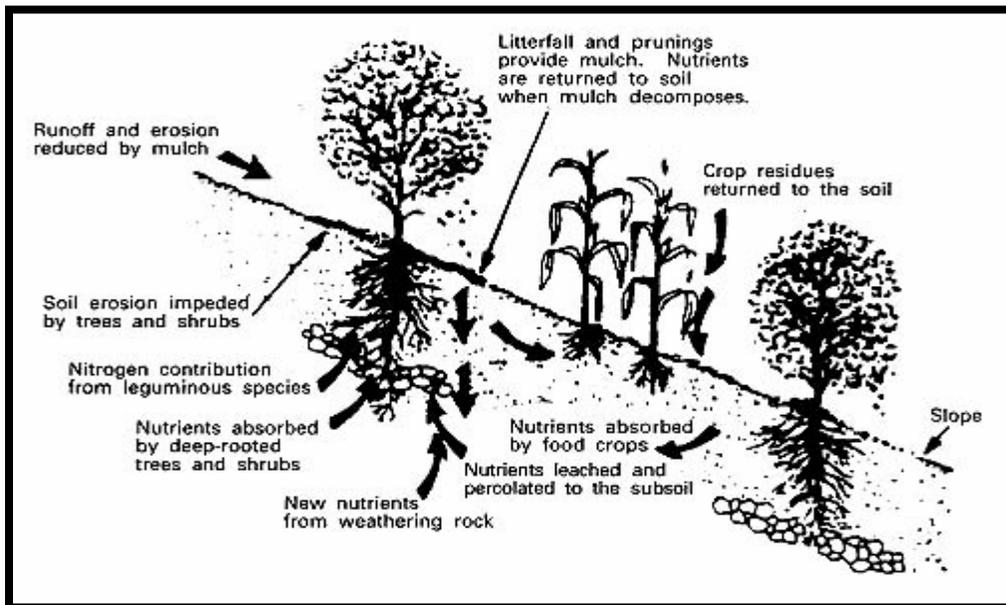


Fig. Alley cropping concept

- It is also known as **hedge row intercropping** and is recommended for humid tropics.
- **International Institute for Tropical Agriculture (IITA), Nigeria has developed this Agro forestry system in 1970.**
- Alley cropping is an important step in meeting the fodder, fuel and food requirements of the farmer.
- Essential feature of this system is that hedgerow are cut back at about 1 meter height at planting and kept pruned during cropping to prevent shading and to reduce competition with field crops.
- *Leucaena leucocephala* (subabul) is mostly used as a hedge row species in the system. The other tree species like *Glyricidia* and *Sesbania* can be used for hedge rows.



Fig. Fast-growing trees and shrubs in alleys

The following are three types of alley system

- i. **Forage cum food system:** Farmers get both food and fodder e.g. *Leucaena leucocephala* (subabul) pigeon pea, castor, *Sesbania*.
- ii. **Forage cum mulch system:** It provides fodder as well as mulch e.g. subabul.
- iii. **Forage cum pole system:** System provides fodder as well as pole e.g. subabul, eucalyptus etc.

Benefits

- i. Green fodder from the hedge-rows is obtained in the dry season.
- ii. Reasonable quantity of grain and stover is produced in the alleys during cropping season.
- iii. Off season precipitation is utilized.
- iv. Hedge-rows can be served as barrier to runoff.
- v. Hedge-row topping can be utilized as mulch during crop season and forage during off season.

6. Strip cropping

Growing of two or more crops simultaneously wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically.

Ex. Black gram + maize

- In strip cropping long and narrow strips of erosion resisting crops (close growing crops) are alternated with strips of erosion permitting crops (erect growing crops).
- The strips are laid across the slope.
- Strips of close growing crops reduce the transporting and eroding power of water by forming obstructions to run off and filter out the soil from the runoff and retains it in the field.
- Erosion resisting crops : (Pulses) Groundnut, Mothbean (matki), Horse bean
(Kulthi/hulga)
- Erosion permitting crops : (Millets) Sorghum, maize, bajra.

7. Polyculture

Cultivation of more than two types of crops grown together on a piece of land in a crop season is called as polyculture.

Ex. Subabul + Papaya + Pigeon pea + Dinanath grass

Mango + Pineapple + Turmeric

Banana + Marigold + Berseem

C) Fallowing/Fallow in rotation

It refers to keeping the land vacant without raising any crop during a particular season/year. The main objective of fallow in rotation is to give rest to the soil and conserve the soil moisture in the field.

There are two types of fallowing/fallow in rotation viz.:

- 1) Barren fallow:** Here the land is kept vacant without disturbing the soil during the particular season/year.
- 2) Ploughed fallow:** In this type, the land is ploughed & left vacant/no crop is raised in that field during a particular season/year.

Chapter-13

SUSTAINABLE AGRICULTURE

Sustainable Agriculture:

The term sustainable agriculture was coined by an Australian agricultural scientist Gordon McClymont and **Wes Jackson** has written the first publication on sustainable agriculture in his 1980 book '**New Roots for Agriculture**'. The term became popularly used in the late 1980s.

Definition : Sustainable Agriculture is a form of agriculture aimed at meeting the needs of food and fuel of present generation without endangering the resource base of future generation.

Or

It is a balanced management system of renewable resources including soil, wildlife, forest, crops, fish, livestock, plant genetic resources and ecosystems without degradation and to provide livelihood for current and future generations maintain or improving productivity and ecosystem services of these resources.

Concept of sustainable Agriculture

- ❖ Protecting natural resources needed for production and cooking fuels from soil.
- ❖ Expanding production to meet the need of growing population
- ❖ More efficient use of arable lands and water supplies
- ❖ Development and adoption of improved agricultural practices and technologies to increase yield.
- ❖ Avoiding over use of chemical fertilizers, expansion of agriculture into steep slopes or marginal soils and careful use of water.
- ❖ Minimize the purchase of off farm inputs such as pesticides and fertilizers and rely on farm renewable resources.
- ❖ Substitution of external resources by internal resources to reduce production cost.
- ❖ Maintaining and enhancing biological and economic productivity of crops.
- ❖ Exchanging adverse environmental impacts on adjacent and downstream environments
- ❖ Minimizing the magnitude and rate of soil degradation and increasing soil productivity.
- ❖ Use of renewable resources
- ❖ Profitability in production.
- ❖ It should improve the quality of human life with carrying capacity of the ecosystem.

Components of Sustainable Agriculture

Following are the major components of sustainable agriculture :

1. Soil and water conservation practices so as to prevent the degradation and productivity of soil.
2. Increasing crop growing season for optimum crop production.
3. Crop rotations to reduce the weed, pest and disease erosion and eventually to increase the soil productivity.
4. Integrated nutrient management (judicious combination of organics, inorganics and biofertilizer) to reduce the use of chemical fertilizers, improve soil health and to minimize environmental pollution.
5. Integrated pest management through crop rotation, weather monitoring, use of resistant cultivars, planting time and bioagents to reduce the use of agrochemicals.
6. Integrated weed management for weed control (by preventive measures, tillage, interculturing & crop rotation).

Management of Sustainable Agriculture/Sustainability:

The management practices are aimed at obtaining sustainable production with limited or no chemical inputs with preference to farm grown inputs without pollution and minimum damage to natural resource base.

1. **Watershed management:** The important development activities in watershed management for drylands are soil and moisture conservation measures, land use based on land capability, wasteland management, afforestation and efficient crop production practices.
2. **Conservation of genetic resources:** Use of improved varieties over large area for preservation and for future use.
3. **Tillage:** Tillage practices aimed at reducing soil degradation, improving weed control and helping in timely decomposition of organic matter. A common aim is to provide optimal conditions for beneficial soil organisms, thereby enhancing organic matter decomposition and nutrient recycling. Managing the top 8 cm of soil is vital because most of the biological activity, microorganisms and organic matter is in this layer.
4. **Nutrient management:** Sustainable agriculture mainly depends on organic matter for nutrient management through farm yard manure, compost and green manures. Crop rotation with legumes for building soil fertility.
5. **Efficient water management:** Water management can be subdivided into rain water management and irrigation water management. The important aspects of rain water management are water harvesting, supplement irrigation and reduction of evapotranspiration. Irrigation management practices involves scheduling irrigation at appropriate time with adequate quantity of water without causing water logging, salinity and alkalinity.
6. **Weed management:** Weed control methods include cultural, physical, biological and chemical methods. In sustainable agriculture, cultural, mechanical, biological are greater importance. Weeds are generally controlled by rotation, hand weeding and tillage. Weed population to an extent can be tolerated at certain periods of crop growth as they help in nutrient recycling, pest control, soil conservation and organic matter improvement.
7. **Pest management:** Integrated pest control which combines cultural and biological methods and use of resistant varieties reduce dependence on ecologically aggressive chemical pesticides. Plant derived compounds such as neem and microbial control agents such as

bacteria and fungi can be used instead of harmful insects. Helpful insects and spiders are encouraged.

- 8. Crop rotation:** The selection of optimal crop rotation is very important for successful sustainable agriculture. Crop rotation is very improving soil fertility; weed control, insect and diseases control. Legumes are essential in any rotation and should comprise 30 to 50 % of the crop land. A mixed cropping, pasture and livestock system is desirable or even essential for the success of sustainable agriculture.

Pollution and Pollutants:

Pollution refers to the introduction of harmful materials into the environment, which are known as pollutants. These pollutants can originate from both natural sources and human activities. Understanding pollution involves recognizing its types, sources, and impacts on health and ecosystems.

Types of Pollution

There are three major types of pollution: air pollution, water pollution, and land pollution. Each type has distinct characteristics and consequences.

- 1. Air Pollution:** This occurs when harmful substances are released into the atmosphere. Common sources include vehicle emissions, industrial discharges, and burning fossil fuels. Air pollutants can be visible, such as smoke or smog, or invisible gases like carbon monoxide and sulfur dioxide. The effects of air pollution can lead to respiratory diseases, cardiovascular problems, and even premature death.
- 2. Water Pollution:** Water becomes polluted when harmful chemicals or waste products contaminate bodies of water such as rivers, lakes, and oceans. Sources include agricultural runoff (fertilizers and pesticides), industrial discharge (toxic chemicals), sewage overflow, and oil spills. Polluted water poses serious health risks for humans and wildlife alike; it can lead to diseases from pathogens or toxic exposure through consumption or recreational activities.
- 3. Land Pollution:** This type of pollution occurs when hazardous waste is improperly disposed of on land. Common contributors include landfills overflowing with trash, agricultural chemicals seeping into the soil, and mining operations leaving behind contaminated sites. Land pollution can degrade soil quality, harm plant life, and pose risks to human health through contaminated food sources.

Sources of Pollutants

Pollutants can be categorized based on their origin:

- **Natural Pollutants:** These include volcanic ash from eruptions or naturally occurring oil seeps that release hydrocarbons into the environment.
- **Anthropogenic (Human-Made) Pollutants:** Most pollutants fall under this category due to human activities such as industrial manufacturing processes that emit gases into the air or agricultural practices that introduce fertilizers into waterways.

Common examples of specific pollutants include:

- **Carbon Monoxide (CO):** A colorless gas produced by incomplete combustion in vehicles.
- **Nitrogen Oxides (NO_x):** Gases formed during combustion processes in vehicles and power plants.
- **Sulfur Dioxide (SO₂):** Emitted from burning fossil fuels like coal.
- **Heavy Metals:** Such as mercury or lead found in industrial waste.
- **Plastics:** Found in landfills or oceans contributing to land and water pollution.

Impacts of Pollution

The consequences of pollution extend beyond environmental degradation; they also affect public health significantly:

- Air pollution is linked to millions of premature deaths annually due to respiratory illnesses.
- Waterborne diseases caused by polluted water sources result in thousands of child fatalities each day globally.
- Land contamination affects food safety through bioaccumulation of toxins in crops consumed by humans.

In summary, understanding pollution involves recognizing its various forms—air, water, and land—and identifying both natural and anthropogenic sources that contribute to environmental degradation. The impacts on human health are profound and necessitate urgent action for mitigation.

Chapter-14

Allelopathy: Meaning and importance in crop production

Allelopathy is a biological phenomenon by which an organism produces one or more biochemical that influences the germination, growth, survival, and reproduction of other organisms. Allelochemicals, which are the secondary metabolites of plant, algae, bacteria and fungi, are responsible for allelopathy. The crop having allelopathic property can be used for nutrient management, weed control, disease, pest management and abiotic stress management in field crops. The allelochemicals also enhance and regulates crop growth. Allelochemicals produced by microorganisms, insects, higher animals and plants could provide new strategies for maintaining and increasing forest and agricultural production in the future. The application of allelopathic substances in the crop field reduces the utilization of agrochemicals, which have a detrimental effect on the environment and human life.

Importance in crop production:

Allelopathy in weed management

Allelochemicals have the potential to be used as a herbicide. Allelopathy may help in weed management through the inhibition of weed seed germination and seedling growth. Weed-suppressing ability in several crops is either due to the exudation of allelochemical compounds released from living plant parts or from decomposing residue. As these are free from all the problems associated with present herbicides, they could be used directly as herbicides, and their chemistry can also be used to develop new herbicides. A lot of secondary compounds are produced by plants and microorganisms, and many of these are phytotoxic to weeds, thus having the potential to be used as herbicides. Glufosinate -AM, a synthetic analogue of bialaphos (microbial toxin/allelochemical is found in bacterium *Streptomyces hygroscopicus*) is extensively used for weed control in cropped and non-cropped situations. AAL toxin is a metabolite produced by *Alternaria alternate* f.sp. *Lycopersici* used as a natural herbicide. Many crops have been reported with their alleged allelopathic effect. For *e.g.*, Barley produces phenolic compounds and two alkaloids *viz.*, gramine and hordenine. Gramine inhibited the growth of chickweed, even in small concentrations. In *Sinapis alba*, root length and vigour of root tips decreased due to both hordenine and gramine. Radicle tips exposed to hordenine and gramine of *Sinapis alba* showed damage to cell walls, increase in both size and number of

vacuoles, autophagy, and disorganization of organelles. Rye residues have been used to control weeds in fruit orchards (Narwal and Haouala, 2013).

Allelopathy and crop nutrition

Allelochemicals play a significant role in plant nutrition. These allelochemicals released into the rhizosphere, produced by plant, algae, bacteria and fungi, regulate solubilization, mobilization, release and chelation of mineral nutrients. Allelopathy can help to improve Nitrogen use efficiency (NUE). To improve N use efficiency (NUE) in agricultural systems, the nitrification rate in soil should be decreased, which is an important strategy to minimize N losses. Allelopathy offers an attractive and natural option to decrease nitrification for improving NUE in agricultural systems (Jabran *et al.* 2013).

Allelopathy in insect pest management

Extensive use of synthetic insecticides usually have a negative effect on the environment, human and animal health, and most critically, develops resistance against insects. Scientists are therefore turning towards the discovery and use of natural insect suppressants. Azadirachtin, an allelochemical from neem plant, effectively inhibit insect cicadellid, whitefly and *Ashbya gossypii*. Neem seed oil is reported to exhibit antifeedant properties against nymph and adult strawberry aphids. Eucalyptus contains a volatile oil which severely effects post-embryonic development and adult emergence of rice moth when sprayed during the larval period of rice moth. Common rue plant contains allelochemicals, coumarin and flavonoids, which have the potentiality to suppress Mediterranean fruit fly and mosquitoes. Ethanol produced from California pepper tree's leaf extract imparts insecticidal effect on elm leaf beetle. *Ambrosia trifida*, *Ageratum conyzoides*, and *Lantana camara* have allelopathic activity against insect and other pests (Farooq *et al.* 2011).

Allelopathy in disease management

Plant disease is a serious issue causing damage to many crops. The soil-born pathogen causes substantial losses to crop production as it disturbs the crop stand and lowers the quality of production. Although cultural practices such as burning infected plant debris and using resistant cultivar have long been used, diseases still cause abundant losses in crop yields. Chemical disease control is not very effective and also very harmful to the environment. Another approach for the suppression of plant-pathogen is by using allelopathic crops in different ways. For

reducing disease intensity, an allelopathic crop can be intercropped with the main crop, which creates a microclimate congenial for disease suppression. Intercropping of tomato with Chinese chive (*Allium tuberosum*) inhibit the multiplication of bacterial wilt (*Pseudomonas solanacearum*) without any negative effect on tomato. Marigold, when intercropped with tomato, suppress early blight of tomato caused by *Alternaria solani*. Neem leaves or neem cake applied to soil have a long term effect on the management of root node nematodes. Dried cabbage (*Brassica oleracea* L. var. *capitata*) incorporated into the soil significantly reduced the yellow cabbage pathogen (*F. oxysporum* sp. *conglutinan*) population and produced near disease-free cabbage plants. Methanethiol, dimethyl sulfide and dimethyl disulfide from the residues were suggested to have contributed to disease suppression (Ramirez Villapudua and Munneche 1988).

Allelochemical as growth regulator

In modern agriculture, the role of plant growth regulators is very important. These are the substances which are known to control the plant's physiological and biochemical processes at low concentration. The growth-promoting effects of allelopathy can be used in different ways. Foliar application of plants extracts which having promotive effects can be beneficial for other crops. At higher concentration, the allelochemicals have an inhibitory effect, and at low concentration, the allelochemicals have a promotive effect, *i.e.* concentration of allelochemicals is inversely related to the promotive effect of the plant. Moringa water extracts contain a growth hormone *i.e.* Zeatin, which is the source of cytokinin, has been widely used for growth promotion in agronomic and horticultural crops. It increases yields by 25%-30% for a number of crops such as soyabean, maize and coffee. So, the juice from fresh Moringa leaves can be used to produce an effective plant growth hormone. (Maishanu *et al.* 2017)

Allelochemicals in abiotic stress management

The abiotic stresses, increase in daily mean temperature, changed patterns of precipitation, increase in episodes of drought, and floods may pose threats to crop production and food security in the future. Plants have evolved several mechanisms to cope with abiotic stresses. Production and release of secondary metabolites among organisms induce tolerance mechanism against abiotic stresses in ecosystems. Production of allelochemicals at higher rates induces resistance in plants against stresses and helps them grow vigorously under such conditions. The production of allelochemicals is influenced by the age of the plant, type of stress,

the intensity of stress and surroundings. For example, when drought-resistant plants are exposed to drought condition, cyanogenic glucoside synthesis is enhanced. Biosynthesis of ferulic acid is increased under drought condition in wheat. Cucumber, when exposed to dry conditions, produces more phenolics and flavonoids. Similarly, temperature fluctuations also cause a change in the production rate of allelochemicals. Plants have to make necessary metabolic and structural adjustments to cope with the stress conditions. Stress-induced changes in plant metabolism and development can often be attributed to altered patterns of gene expression. In response to stress, some genes are expressed more intensively, whereas others are repressed. The protein products of stress-induced genes, named stress proteins, are helping plants to survive under stress conditions and minimizing the effectiveness of the stress agents. (Pedrol *et al.* 2006)

Chapter-15

Growth and development of crops

INTRODUCTION:

The term growth is applied to quantitative changes occurring during development and it may define as **growth** is an irreversible change in the size of cell, organ or whole organism. It may be evaluated by measurements of mass, length or height, surface area or volume.

Growth is also defined as a vital process which brings about a permanent change in any plant or its part in respect to its size, form, weight and volume.

Development is applied in its broadcast sense to the whole series of changes which an organism goes through during its life cycle, but it may be equally be applied to individual organ, to tissues or even to cells. Plant development involves both growth and differentiation.

Growth curve

All plants pass through various stages of growth. Growth is being expressed by means of curve plotted against time. Growth curve helpful in understanding the general pattern of growth. The S-shaped or sigmoid curve is typical of growth pattern of individual organs of a whole plant and of population of plants.

It consists of five distinct phages:

1. An initial lag period during which internal changes occur that are preparatory to growth. The increase in size and weight is very slow or negligible during this period.
2. It is followed by the phase or log period of growth or grand period of growth during straight line during this phase.
3. subsequently, a phase in which growth gradually diminishes
4. A point at which the organism reaches maturity and growth ceases.
5. Later, senescence and death of organism sets in giving rise to another component of the growth curve.

PLANT AND ENVIRONMENTAL FACTORS:

Factors involved in crop growth and production can be classified as:

1. **Internal factors:** plant/genetic/hereditary factors,
2. **Environmental factors:** climate, edaphic, biotic and physiographic factors.

1. Internal or Genetic Factors

Genetic makeup decided the crop growth & its production. Crops vary in the genetic makeup which included desirable & undesirable characters as well. Breeders try to incorporate maximum desirable characters in one strain of crop & also try to exploit the hybrid vigour.

Desirable characters include:

1. High yielding ability under given environment condition.
2. Early maturity
3. Better resistance to lodging
4. Drought flood & salinity tolerance
5. Greater tolerance to insect & diseases
6. Chemical composition of grains (Oil & Proteins)
7. Quality of grains (Fineness, coarseness etc)
8. Quality of straw (Sweetness juiciness)

These characters are inherent in each individual and are transmitted from one generation to another by genes.

2. Environmental factors (External):

Climate: Another factor that influences the growth, development, & production of crop is the climate which is out of control by the man but mgt. practices of the crops can be altered to harvest maximum yield. Climate is the most dominating factor influencing the suitability of a crop to a particular region. The yield potential of a crop mainly depends on climate. More than 50% of variation in yield of crops is solar radiation, temperature & rainfall. Relative humidity & wind velocity also influence crop growth to some extent. Atmospheric factors which affect the crop plants are called climatic factors which include.

1. Precipitation,
2. Temperature,
3. Atmospheric humidity,
4. Solar radiation,
5. Wind velocity and atmospheric gases.

1. Precipitation: - It results from evaporation of water from sea water and land surfaces. The process involved in the transfer of moisture from the sea to the land & back to the sea again what is known as the hydrologic cycle. Continuous circulation of water between hydrosphere, atmosphere & lithosphere called as hydrologic cycle. Precipitation includes rainfall, snow or hail, Fog drip & dew also contribute to moisture. Fog consists of small water droplets while dew is the condensation of the water vapour present in the air. Precipitation influences the vegetation of a place. Most of crops receive their water supply from rainwater which is the source of soil

moisture so essential for the life of a plant. The yearly precipitation, both in total amount & seasonal distribution greatly affects the choice of cultivated crops of a place.

Reduced Rainfall- Drought

Water availability directly affects the growth of plants and how much crop they produce. The occurrence of moisture stress during flowering, pollination, and grain-filling is harmful to most crops and particularly so to corn, soybeans, and wheat. Increased evaporation from the soil and accelerated transpiration in the plants themselves will cause moisture stress; as a result there will be a need to develop crop varieties with greater drought tolerance.

Increased Rainfall

Excessive rainfall results in floods. Waterlogged soil causes plant roots to rot and heavy rainfall damages tender young plants. Increased rainfall without flooding may be beneficial in very dry areas and allow limited crop growth.

2. Temperature: It is considered as a measure of intensity of heat energy. The range of maximum growth for most agricultural plants is between 15 & 40⁰C, every plant community has its own minimum, optimum & maximum temperature known as their cardinal points. Temperature is determined by the distance from the equator (latitude) and the altitude; Apart from the reduction in yield many injuries such as cold injury which included chilling injury, freezing injury, suffocation & heaving and heat injury. Maize & sorghum (8-10⁰C, 30⁰C, 40⁰C) Rice (10-11⁰C, 35⁰C) Wheat (50C, 25⁰C, 30⁰-32⁰C)

3. Atmospheric humidity: Water which is present in the atmosphere in the form of invisible water vapor, termed as humidity of the air, ET of crop plants increases with the temperature but decreases with high relative humidity affecting the quantity of irrigation water, Moist air favors the growth of many fungi & bacteria which affect seriously the crop. Relative humidity of 40-60 % is suitable for most of the crop plants. At high relative humidity the chance for the outbreak of pests and diseases, increases. Eg. Brown plant hopper in rice multiplies very fast. Blight diseases of potato and tea spread fast during moist weather. Different kinds of insect parasites like aphids and jassids thrive well under moist weather.

4. Solar radiation: Solar energy provides two essential needs of plants:

a) Light required for photosynthesis & for many other functions of the plant including seed germination, leaf expansion, growth of stem & shoot, and flowering, fruiting & even dormancy.

b) Thermal conditions required for the normal physiological functions of the plant. Light helps in synthesis of chlorophyll pigment.

Light affects the plants in four ways: intensity, quality (wave length), duration (Photoperiod) and direction.

Light intensity:

Very low light intensity (<500 candles) reduces the rate of photosynthesis resulting in reduced growth. Similarly very high intensities inhibit photosynthesis. It causes rapid loss of water through transpiration. High light intensity is very harmful as it oxidizes the cell contents. Based on responses to light intensities the plant are classified as follows:

1. **Shade loving plants (Sciophytes):** the plants grow better under particularly shaded conditions. Eg. Betel vine, buck wheat.
2. **Sun loving plants (Heliophytes):** many species of plants produce maximum dry matter under high light intensities when the moisture is available at optimum level. Eg. Maize, sorghum, rice etc.

Duration of light:

It is important from farmer's point of view in selecting the variety of the crop. The length of day has greater influence than light intensity. The response of plant to the relative length of the day and night is termed as photoperiodism. The plants are classified on the extent of response to day length which is as follows:

1. **Long day plants:** the plants which develop and bloom normally when the photoperiod is greater than the critical minimum (>12 hours). Eg. Wheat, barley, sugarbeet, potato
2. **Short day plants:** : the plants which develop and bloom normally when the photoperiod is greater than the critical maximum (<12 hours). Eg. Rice, sorghum, maize, sugarcane
3. **Day neutral plants:** those plants which are not affected by photoperiod eg. Cotton, sweet potato, sunflower, tomato.

If the time of exposes to light is longer than the critical period, the plants will develop vegetative without completing their reproductive cycle. If a long day plant is subjected to short day length, the stem will be shorten and flowering is delayed till the long days come in the season. Similarly, when short day plants are subjected to long day periods, there will be abnormal vegetative growth and there will not be any floral imitation.

5. Wind velocity: It affects growth mechanically (damage to crop) and physiologically (evaporation & transpiration), Hot dry winds may adversely affect photosynthesis & hence productivity, by causing closure of the stomata even when soil moisture is adequate. Moderate winds have a beneficial effect on photosynthesis by continuously replacing the CO₂ absorbed by the leaf surfaces. The basic function of wind is to carry moisture and heat. Mild wind is essential for crop production. Wind movement for 4-6 kg/hr is suitable for most crops. When speed of wind is high, moisture loss is more and frequent irrigation is needed. When wind movement is static then the availability of CO₂ is less and flow of nutrients is also less. It also helps in pollination. Wind affects crop growth by means of:

2) Edaphic or Soil factors: Soil can be defined as: Soil is a thin layer of the earth's crust which serves as a natural medium for the growth of plants. Soils are formed by the disintegrations & decomposition of parent rocks due to weathering and the action of soil organisms & also the interaction of various chemical substances present in the soil. Soil is formed from parent rock by the process of weathering over a long period by the action of rain water, temperature and plant & animal residues.

A vertical cut of 1.5 to 2 m deep soil indicates a layer varying from a few cm to about 30 cm of soil, called surface soil, below that a layer of sub soil & at the bottom, the unrecompensed material which is the parent rock.

3) Plant /Biotic factors: Biotic factors include plant, symbiosis & animals.

Plant: The soil & water are two variables which either has to be suitably adjusted for the plant to grow or the plant should be so bred & selected that it will adjust to a given soil & water condition, growing season, climatic requirement, etc. Some of the crops grow on only rain while some required irrigation water, Plant breeders are constantly at work to evolve varieties which will suit the given soil & water condition e.g. drought resistant, disease resistant, more nutrients absorbing capacity etc.

Animals: **1)** Soil flora (plant kingdom) & **2)** soil fauna (animal Kingdom). Soil flora is of two types: **i)** Macro flora e.g. Roots of higher plants **ii)** Micro flora e.g. Bacteria, fungi, actinomycetes & algae.

4) Anthropic or Management /Man or skillful management by the man:

Finally, man must so manage the soil-water-plant complex to produce efficiently food & fodder and for that purpose a number of mechanical devices & useful cultivation practices have been evolved such as ploughs for ploughing, harrows for seeded preparation, hoes for hoeing, seed cum fertilizer driller for sowing the seeds & application of fertilizers.