

Fundamentals of agronomy

Syllabus -Theory

Agronomy and its scope; Seeds and sowing, tillage and tith, crop density and geometry; Crop nutrition, manures and fertilizers, nutrient use efficiency; Water resources, crop water requirement, water use efficiency,; Irrigation, scheduling criteria, methods, and water logging.

Weeds, importance, classification, crop weed competition, concepts of weed management, principles and methods; Herbicides, classification, selectivity, resistance, allelopathy.

Growth and development of crops, factors affecting growth and development, plant Ideotypes; crop rotation and its principles; Adaptation and distribution of crops, crop management technologies in problematic areas; harvesting and threshing of crops.

References

1. Reddy, S.R. 2016. Principles of Agronomy. Kalyani Publishers. Ludhiana -5th Edition
2. Yellamanda Reddy, Y. and Shankar Reddy, G.H. 2016. Principles of Agronomy. Kalyani Publishers. Ludhiana
3. Gopal Chandra De. 1989. Fundamentals of Agronomy. Oxford and IBH Publishing Co. Pvt. Ltd., new Delhi
4. Gupta, O.P.2011.Modern Weed management. Agrobios (india), Jodhpur.

Fundamentals of Agronomy

Agriculture – Agronomy and its scope – Role of Agronomists in resource management for crop production

Agriculture helps to meet the basic needs of human and their civilization by providing food, clothing, shelters, medicine and recreation. Hence, agriculture is the most important enterprise in the world

Agriculture provides food, feed, fibre, fuel, furniture, raw materials and materials for and from factories; provides a free fare and fresh environment, abundant food for driving out famine.

Meaning of Agriculture:

The term agriculture is derived from the Latin words “ager” or “agri” meaning “soil” and ‘cultra’ meaning ‘cultivation’

Agriculture may be defined as science, art, and business of the producing crops and livestock for man’s use and employment.

Agriculture is the cultivation of lands for production of crops for a regular supply of food and other needs for progress of the nation.

Agriculture is influenced by a large number of factors, some of which can be controlled by man (soil and irrigation) which others are beyond the control (climate)

Agriculture as art, science and business of crop production

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

As an art, it embraces knowledge of the way to perform the operations of the farm in a skillful manner. The skill is categorized as;

Physical skill: It involves the ability and capacity to carry out the operation in an efficient way for *e.g.*, handling of farm implements, animals etc., sowing of seeds, fertilizer and pesticides application etc.

Mental skill: The farmer is able to take a decision based on experience, such as (i) time and method of ploughing, (ii) selection of crop and cropping system to suit soil and climate, (iii) adopting improved farm practices etc.

As a science: It utilizes all modern technologies developed on scientific principles such as crop improvement/breeding, crop production, crop protection, economics etc., to maximize the yield and profit.

For example, new crops and varieties developed by hybridization, transgenic crop varieties resistant to pests and diseases, hybrids in each crop, high fertilizer responsive varieties, water management, herbicides to control weeds, use of bio-control agents to combat pest and diseases etc.

As the business: As long as agriculture is the way of life of the rural population, production is ultimately bound to consumption. But agriculture as a business aims at maximum net return through the management of land, labour, water and capital, employing the knowledge of various sciences for production of food, feed, fibre and fuel. In recent years, agriculture is commercialized to run as a business through mechanization.

Scope of agriculture in India

In India, population pressure is increasing while area under cultivation is static (as shown in the land utilization statistics given below) or even shrinking, which demand intensification of cropping and allied activities in two dimensions *i.e.*, time and space dimension

Total geographical area	:	328.848 million ha.
Total reporting area	:	304.300 million ha.
Area under cultivation	:	143.000 million ha.
Total cropped area	:	179.750 million ha.
Area sown more than once	:	36.750 million ha.
Area not available for cultivation	:	161.300 million ha.
Area under forest	:	66.400 million ha.

India, food grain production increased almost four folds from about 50 million tons at independence and it is estimated to be 314.5 million tons in 2021-22.

Despite variation in the performance of individual crops and regions, total food grain production maintained a growth of 2.7% per annum, which kept ahead of population growth at about 2.2% per annum. In future, agriculture development in India would be guided not only by the compulsion of improving food and nutritional security, but also by the concerns for environmental protection, sustainability and profitability.

Branches of agriculture

Agriculture is the branch of science encompassing the applied aspects of basic sciences. The applied aspects of agricultural science consists of study of field crops and their management (**Arviculture**) including soil management.

Crop production - It deals with the production of various crops, which includes food crops, fodder crops, fibre crops, sugar, oil seeds, etc. It includes agronomy, soil science, entomology, pathology, microbiology, etc. The aim is to have better food production and how to control the diseases.

Horticulture - Branch of agriculture deals with the production of flowers, fruits, vegetables, ornamental plants, spices, condiments (includes narcotic crops-opium, etc., which has medicinal value) and beverages.

Agricultural Engineering - It is an important component for crop production and horticulture particularly to provide tools and implements. It is aiming to produce modified tools to facilitate

proper animal husbandry and crop production tools, implements and machinery in animal production.

Forestry - It deals with production of large scale cultivation of perennial trees for supplying wood, timber, rubber, etc. and also raw materials for industries.

Animal Husbandry - The animals being produced, maintained, etc. Maintenance of various types of livestock for direct energy (work energy). Husbandry is common for both crop and animals. The objective is to get maximum output by feeding, rearing, etc. The arrangement of crops is done to get minimum requirement of light or air. This arrangement is called geometry. Husbandry is for direct and indirect energy.

Fishery Science - It is for marine fish and inland fishes including shrimps and prawns.

Home Science - Application and utilization of agricultural produces in a better manner. When utilization is enhanced production is also enhanced. *e.g.*, a crop once in use in south was found that it had many uses now.

On integration, all the seven branches, first three is grouped as for crop production group and next two for animal management and last two as allied agriculture branches. Broadly in practice, agriculture is grouped in four major categories as,

Development of scientific agriculture

Early man depended on hunting, fishing and food gathering. To this day, some groups still pursue this simple way of life and others have continued as roving herdsmen. However, as various groups of men undertook deliberate cultivation of wild plants and domestication of wild animals, agriculture came into being. Cultivation of crops, notably grains such as wheat, rice, barley and millets, encouraged settle- ment of stable farm communities, some of which grew into a town or city in various parts of the world. Early agricultural implements-digging stick, hoe, scythe and plough-developed slowly over the centu- ries and each innovation caused profound changes in human life. From early times too, men created indigenous systems of irrigation especially in semi-arid areas and regions of periodic rainfall.

The industrial revolution, after the late 18th century, swelled the population of towns and cities and increasingly forced agriculture into greater integration with general economic and financial patterns.

The era of mechanized agriculture began with the invention of such farm machines as the reaper, cultivator, thresher, combine harvesters and tractors, which continued to appear over; the years leading to a new type of large scale agriculture. Modern science has also revolutionized food processing.

Breeding programmes have developed highly specialized animal, plant and poultry varieties thus increasing production efficiency greatly. All over the world, agricultural colleges and government agen- cies attempt to increase output by disseminating knowledge of improved agricultural practices through the release of new plant and animal types and by continuous intensive research into basic and applied scientific principles relating to agricultural production and economics.

History of agriculture

Excavations, legends and remote sensing tests reveal that agriculture is 10,000 years old. Women by their intrinsic insight first observed that plants come up from seeds. Men concentrated on hunting and gathering (Paleolithic and Neolithic periods) during that time. Women were the pioneers for cultivating useful plants from the wild flora. They dug out edible roots and rhizomes and buried the small ones for subsequent harvests. They used animal meat as main food and their skin for clothing.

Shifting Cultivation

A primitive form of agriculture in which people working with the crudest of tools, cut down a part of the forest, burnt the underneath growth and started new garden sites. After few years, when these plots lost their fertility or became heavily infested with weeds or soil-borne pests, they shifted to a new site. In India, shifting cultivation existed in different states, with different names as *jhum* cultivation in Assam, *podu* in Andhra Pradesh and Orissa, *kumari* in Western Ghats, *walra* in south east Rajasthan, *penda bewar* in Madhya Pradesh and *slash and burn* in Bihar.

Subsidiary Farming

Rudimentary system of settled farming, which includes cultivation, gathering and hunting. People in groups started settling down near a stream or river as permanent village sites and started cultivating in the same land more continuously, however the tools, crops and cropping methods were primitive.

Subsistence Farming

Advanced form of primitive agriculture *i.e.*, agriculture is considered as a way of life based on the principle of "Grow it and eat it" instead of growing crops on a commercial basis. Hence, it is referred as raising the crops only for family needs.

Mixed Farming

It is the farming comprising of crop and animal components. Field crop-grass husbandry (same field was used both for cropping and later grazing) was common. It is a stage changing from food gathering to food growing.

Advanced Farming

Advanced farming practices includes selection of crops and varieties, seed selection, green manuring with legumes, crop rotation, use of animal and crop refuse as manures, irrigation, pasture management, rearing of milch animals, bullocks, sheep and goat for wool and meat, rearing of birds by stall feeding etc.

Scientific Agriculture (19th Century)

During 18th century, modern agriculture was started with crop sequence, organic recycling, introduction of exotic crops and animals, use of farm implements in agriculture etc. During 19th century, research and development (R&D) in fundamental and basic sciences were brought under applied aspects of agriculture. Agriculture took the shape of a teaching science.

Laboratories, farms, research stations, research centres, institutes for research, teaching and extension (training and demonstration) were developed. Books, journals, popular and scientific articles, literatures were introduced. New media, and audio-visual aids were developed to disseminate new research findings and information to the rural masses.

Present Day Agriculture (21st Century)

Today agriculture is not merely production oriented but is becoming a business consisting of various enterprises like livestock (dairy), poultry, fishery, piggery, sericulture, apiary, plantation cropping etc.

According to World Bank projections, the world population could reach a stationary level of just under 10 billion by around the end of 21 century, compared with 6.2 billions during 2000 A.D. Significance of these projections is faster growth in population than in food requirements. Almost all the population increase (95%) takes place in the present day developing countries, which have low per capita consumption levels. Simple lesson from projection is that world demand could increase by 50 per cent in the next 20 years, would more than double again in the first half of the next century.

Agronomy

The Agronomy is derived from Greek words “Agros” meaning field and “nomos” meaning to “manage”

Agronomy is a branch of agricultural science which deals with principles and practices of soil, water and crop management.

Agronomy deals with methods which provide favourable environment to the crop for higher productivity.

Importance of basic sciences for development of Agriculture science

Basic science is the study of basic principles and fundamentals of the respective subject.

Applied science is the study in which the basic principles and fundamentals of respective field.

Agricultural sciences are essentially applied sciences and are dependent on basic sciences of Botany, Physiology, Bio chemistry, ecology, zoology, chemistry, physics, mathematics, economics etc.

For example

1. Knowledge of Botany is helpful in plant breeding and plant genetics and is making possible for evolution of different varieties in crops suitable to particular agro-climatic condition.
2. The knowledge of zoology (basic science of entomology) is helping the farmer to identify the insect pests which are responsible for damage to agricultural produce.
3. Soil chemistry helps in understanding the plant nutrient status in the soil and the deficiency symptoms in plants.
4. physics helps in understanding the weather phenomena and soil conditions

5. Mathematics is helpful in agricultural research and experimentation through statistics and Agricultural economics.

6. Study of economics is helpful in estimating the costs and returns and existing conditions of farmers in villages for effecting the improvements.

Without basic science there can be no development in applied science. In the field of Agriculture basic and applied sciences are interrelated to each other.

Scope of Agronomy

Agronomy is a dynamic discipline with the advancement of knowledge and better understanding of plant and environment, agricultural practices are modified and new practices developed for high productivity, for example availability of chemical fertilizer has necessitated the generation of knowledge on the method, quantity and time of application of fertilizers. Similarly availability of herbicides for the control of weeds has led to development of knowledge about selectivity, time and method of application of herbicides. To overcome the problems different management practices are developed.

Population pressure is increasing but area under cultivation is static, therefore more number of crops have to be grown on the same piece of land to increase the yield. As a result, intensive cropping has come into practice.

New technology has to be developed to overcome the effect of moisture stress under dryland conditions. As new varieties of crops with high yield potential become available package of practices have to be developed to exploit their full potential.

Restoration of soil fertility, preparation of good seed bed, use of proper seed rates, correct dates of sowing for each improved variety, proper conservation and management of soil moisture and proper control of weeds are agronomic practices to make our limited land and water resources more productive.

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. Soil physical, chemical and biological properties have to be understood thoroughly to effect modification of soil environment. Similarly it is necessary to understand the physiology of crops to meet their requirements. Advances in economic analysis helped in production of crops economically.

Agronomist aims to obtain maximum production at minimum cost. He exploits the knowledge developed by basic and applied science for higher crop production. Whatever may be the research findings of other scientists. Agronomist has to test their suitability in the field and accept them finally and also judge the reactions of farming community. He is a key person with working knowledge of all agricultural disciplines and coordinator of different subject matter specialists.

Tillage

Tillage and tilth – Objectives of tillage – characteristics of ideal seed bed – effect of tillage on soil properties.

Tillage: Tillage is as old as Agriculture, Primitive man used to disturb the soil for placing seed. *Jethro Tull* is considered as '**Father of Tillage**' Who Written '**Horse hoeing Husbandry**' book.

After the harvest of crop the soil becomes hard and compact because of:

1. Beating action of rain drops.
2. Irrigation and subsequent drying
3. Movement of implements and labourers.

Tillage:

Tillage consists of breaking the hard compact surface of soil to a certain depth and other operations that are followed for plant growth.

It is the physical manipulation of soil with tools and implements to result in good tilth for better germination and subsequent growth of crops.

Objectives of Tillage:

1. To facilitate adequate soil aggregation for gaseous exchange in the seed and root zone.
2. Adequate seed-soil contact to permit water flow to seed and seedling roots.
3. A non crusted soil to permit seedling emergence.
4. To increase infiltration rate.
5. To produce a satisfactory seed bed for good germination and good crop growth.
6. A low density soil that permits root elongation and proliferation.
7. To create an environment that provides adequate light to the seedlings (weed free environment)
8. To create pest and pathogen free environment
9. To mix the applied manures and fertilizers with the soil.
10. To remove the hard pan, if any to increase the soil depth for water absorption.

Effects of Tillage on soil physical properties:

1. Soil Structure: Arrangements of soil particles with crumbly and granular nature is considered good. Best size of soil aggregate for good growth of crop is (1-5mm) smaller aggregates may clog soil pores and larger ones may have large pore space.

Tillage improves soil structure when done at optimum soil moisture level. Tilling a soil when it is too wet spoils the structure. Ploughing a dry soil is difficult and will not help in improving structure.

2. Soil texture: Relative proportion of different soil particles namely sand, silt and clay.

Coarse sand - 2.0 - 0.2mm.

Fine sand - 0.2 - 0.02mm.

Silt - 0.02 - 0.002mm.

Clay - <0.002mm.

Tillage has no effect on soil texture.

3. Pore space: When a field is ploughed the soil particles are loosely arranged 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 soil.

4. Bulk Density: (B.D) When the soil is loosened, the soil volume increase without any affect on weight. BD of Clay soils is low (1.05 m³ and that of sandy soils is high (1.25 – 1.30 m³) and Bulk density of tilled soil is less than that of untilled soil. Particle density is always more than BD.

5. Particle density: Particle density is not altered by tillage.

6. 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.

Tilth: It is the physical condition of soil resulting from tillage.

Characteristics of good tilth

1. A soil should be mellow, friable, crumbly and adequately aerated.

2. A soil in good tilth is porous. Capillary and non capillary pores are equal. This facilitates free movement of air and water.

i. Higher percent of larger aggregates (more than 5 mm in diameter) are necessary for irrigated agriculture, while higher percentage of smaller aggregates (1 to 2 mm diameter) are desirable for dry land agriculture.

ii. Tilth can be coarse or fine. For sandy soils fine kind of tilth is required and for heavy black soils rough cloddy conditions or coarse tilth is enough.

iii. With very fine tilth the surface gets caked up when it dries after a rain. because of this the soil is unable to absorb rain water and it results in runoff loses.

Types of tillage – preparatory tillage – factors affecting preparatory cultivation, after cultivation, puddling

Tillage operations are grouped into two types based on the time at which they are carried out.

1. Preparatory cultivation – carried before sowing of crops

1. Primary tillage- ploughing
2. Secondary tillage –harrowing
3. Seed bed preparation
2. After cultivation – After sowing of the crop

Factors influencing preparatory tillage:

1.The previous crop grown: Stubble of previous crop influence the tillage (Redgram, cotton stubbles are very deep rooted and require deep tillage to remove them)

2. The crop to be grown: Crops like sorghum can be grown with rough tilth for very small seeded. Crops like tobacco, chilles etc fine tilth is required. Deep tillage is required for crops like tuber crops and sugarcane.

3. Types of soil: Clay soil can be ploughed only with in a narrow range of soil moisture and the power or drought required is high. Light textured soils can be ploughed under a wide range of soil moisture and require less drought.

4. Climate: Deep tillage is not permitted in shallow soils in low rainfall areas as it leads to rapid drying and loss of stored soil moisture. Deep cultivation is possible in high rainfall areas.

5. Type of farming: Intensive cropping requires intensive tillage.

Preparatory Cultivation:

- Primary tillage or ploughing:

Ploughing is the opening of compacted soil with the help of different ploughs. Ploughing is done mainly to open the hard soil. In addition, ploughing should ensure inversion of soil, uprooting of weeds and stubbles.

- Optimum time for ploughing

The correct time for ploughing depends on soil moisture. When soil is dry, it is difficult to open the soil. More energy is used and large sized clods will result.

When the soil is ploughed under wet condition, the soil sticks to the plough, the soil below 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 50 -75% of available soil moisture.

- Depth of ploughing:

Depth of ploughing mainly depends on the effective root zone depth of the crop. Generally crops with tap root require greater depth of ploughing while fibrous shallow rooted crops require shallow ploughing.

- Number of ploughings:

The number of ploughings necessary to obtain good tilth depends on the soil type, weed problem and crop residues on soil surface. In heavy soils more number of ploughings are necessary, the range is 3-5 ploughings. Light soils require 1-3 ploughings to obtain proper tilth of the soil. When weed growth and plant residues are higher, more number of ploughings are necessary.

- Selection of ploughs:

Depending on the purpose, soil condition and nature of weed problem, different ploughs are used.

Ploughs	Purpose
1. Mould board plough (Tractor drawn)	Deep ploughing and inversion
2. Mould board plough (Animal drawn)	Incorporation of manures , fertilizers and plant residues
3. Disc plough	Cutting and creeping or spreading grass and inversion
4. Country plough	Multipurpose

Types of primary tillage:

Depending on the purpose and necessity, different types of tillage are carried out. They are deep ploughing, sub soiling and year round tillage.

- Deep tillage (25-30 cm and in western countries 50cm in rainfed and 70 cm in irrigated)

Deep ploughing turns out large sized clods, which are baked by 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. Summer ploughing kills pests. Deep tillage for long duration crops is advantageous.

- Sub soiling:

Subsoiling is breaking the hardpan without inversion and with less disturbance of top soil.

- Year round tillage:

Tillage operations carried throughout the year are known as year round tillage.

Secondary tillage:

Lighter or finer operations performed on the soil after primary tillage is known as secondary tillage. In this harrowing is done to crush the clods and uproot the remaining weeds and

stubbles. Field is made ready for sowing after ploughing by harrowing and planking. Generally, sowing operations are also included in secondary tillage.

Layout of seed bed and sowing:

After seed bed preparation, the field is laid out properly for irrigation and sowing or planting. After field preparation sowing is done with seed drills/ dropping behind country plough. The seeds are covered by running blade harrow to a shallow depth, followed by planking so as to level and impart necessary compaction.

After cultivation:

It includes intercultivation and various other special operations carried out in a standing crop. They include.

1. Thinning and Gap filling.
2. Rogueing in crops for seed purpose.
3. Earthing up in crops, sugarcane, banana, and groundnut.
4. Cropping in banana
5. Desuckering oper in banana
6. Wrapping and propping in sugarcane
7. Nipping in castor
8. Topping, Trimming and desuk in tobaccor basal leaves are removed
9. Defoliation in cotton
10. Hand pollination in sunflower.

Fertilizer app in irrigation also comes under after cultivation.

● **Intercultivation:**

Intercultivation starts from very early stage of crop i.e., two to three weeks from sowing. Short duration crops require two-three intercultivation while long duration crop require 3-4 weeks.

Tillage operations done between the crop rows with the objectives of

- Destroying the weeds
- To form a soil mulch
- To prevent cracking of soil
- To prevent crust formation

Tillage implements:

Primary tillage implements- Wooden plough , Soil turning plough (MB plough, disc plough, reversible or one way plough), Special ploughs (subsoil plough, chisel plough, ridge plough, rotary plough /hoes, basin lister).

Secondary tillage implements (Tractor drawn cultivator, sweep cultivator, harrows, disc harrow, blade harrow and big blade harrow).

Implements for sowing (plough, seed drill, ferti-cum – seed drill) and mechanical seed drill) and inter cultivation (Different sizes of blade harrows of different sizes)

Concepts of tillage –Minimum tillage, Zero tillage, conservation tillage and their advantages and limitations.

Modern concepts of tillage:

- **Conventional tillage:**

In conventional tillage, the soil is opened with mould board plough for primary tillage. The soil mass is broken in to loose system of clods of mixed sizes. Subsequently a fine seedbed is prepared by secondary tillage in which crushing of clods, repacking, incorporation of plant residues, fertilizers, smoothing of soil surface etc. are done.

- **Minimum tillage:**

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

Tillage can be reduced two ways-by omitting operations which donot give much benefit when compared to the cost and by combining agricultural operations like seeding and fertilizer application.

Advantages:

- Improved soil condition due to decomposition of plant residues in situ,
- Higher infiltration caused by the vegetation present on the soil and channel formed by decomposition of dead roots,
- Less resistant to root growth due to improved structure
- Less soil compaction due to reduced movement of heavy tillage vehicles and less erosion compared to conventional tillage.

Dis advantages:

- Germination is lower with minimum tillage
- Nodulation is less in certain legume crops –peas and broad beans
- Sowing operations are difficult with ordinary equipment
- Continuous use of herbicides cause pollution problems and dominance of perennial problem weeds

Minimum tillage can be practiced by different methods

- Row zone tillage; after primary tillage with MB plough, secondary tillage operatiuons like discing and harrowing are reduced. The secondary tillage is done in row zone only.
- Plough plant tillage; After the soil is ploughed, a special planter is used and is run over the field, the row zone is pulverized and seeds are sown.
- Wheel track planting: Ploughing is done as usual. Tractor is used for sowing and the wheels of the tractor pulverize the row zone.

- **Zero Tillage:**

Zero tillage is the extreme form of minimum tillage. Primary tillage is completely avoided and secondary tillage is restricted to seed bed preparation in the row zone only. It is also known as

no till and is resorted where soils are subjected to wind and water erosion, trimming of tillage operations is too difficult and requirements of energy and labour for tillage are too high.

Before sowing, the vegetation present has to be destroyed for which broad spectrum, nonselective herbicides with relatively short residual effect (Paraquat, Glyphosate etc.) are used.

Advantages:

- 1) Soils are homogenous in structure with more no. of earth worms.
- 2) Organic matter content increased due to less mineralization.
- 3) Surface runoff is reduced due to presence of mulch. Several operations are performed by using only one implement. In these weeds are controlled by spraying of herbicides.

Disadvantages:

- 1) Higher nitrogen is too applied due to slower mineralization of org. matter.
- 2) Large population of perennial weeds appears.
- 3) Buildup of pests is more.

- **Stubble mulch tillage:** A new approach for keeping soil protected at all times whether by growing crop or by crop residues left on the surface during fallow periods. It is known as stubble mulch tillage or stubble mulch farming. It is year round system of managing plant residue with implements that undercut residue, loosen the soil and kill weeds.

it presents the practical problem as the residues left on the surface interfere with seedbed preparation & sowing operations. The traditional tillage and sowing equipment is not suitable under these conditions.

Modern methods of tillage are not practiced in Indian condition because:

- a) Left over residue is a valuable fodder and fuel.
- b) Limited use of heavy machinery & therefore problem of soil compaction is rare.

Puddling

Rice growth and yield are higher when grown under submerged conditions. Maintaining standing water throughout the crop period is not possible without puddling. Puddling is ploughing the land with standing water so as to create an impervious layer below the surface to reduce deep percolation losses of water to provide soft seedbed for planting rice.

Puddling operation consists of ploughing repeatedly in standing water until the soil becomes soft and muddy. Initially, 5cm to 10 cm of water is applied depending on the water status of the soil to bring it to saturation and above and the first ploughing is carried out.

After 3 to 4 days, another 5 cm of water is applied and later after 2 to 3 days second ploughing is carried out. By this operation, most of the clods are crushed and majority of the weeds are incorporated. Within 3 to 4 days, another 5 cm of water is given and third ploughing is done in both the directions. The third ploughing can be done either with a wetland plough or with a wetland puddler. Planking or leveling board is run to level the field. To know whether puddling is thorough or not, a handful of mud is taken into the hand and pressed. If it flows freely through

fingers and if there are no hard lumps, puddling is considered to be thorough. Unlike in other tillage operations, puddling aims at destroying soil structure. The individual soil particles viz., sand, silt and clay are separated during puddling operation. The soil layer with high moisture below the plough sole is compacted due to the weight of the plough. The soil particles separated during puddling settle later. The sand particles reach the bottom, over which silt particles settle and finally clay particles fill the pores thus making impervious layer over the compacted soil.

Puddling is done with several implements depending on the availability of equipment and nature of the land. Soils with bulk density less than 1.0 are considered as problem soils as puddling with animal-drawn implements is difficult. The feet of the animals sink very deep during puddling. Under such a situation, puddling is done with spades by manual labour. Most of the farmers use wetland plough or worn out dryland plough or mouldboard plough. Wetland puddler consists of a series of blades attached to a beam at an angle. When it is worked, the soil is churned and puddling operation is completed quickly compared to the country plough. Generally green manure is applied to rice field which is incorporated by green manure trampler. Tractor drawn implements can be used for puddling by attaching cage wheels to prevent sinking.

Seeds and Sowing

Seed:

Seed is a unit of reproduction of a flowering plant capable of developing in to another such plant.

Seed is any material used for planning and propagation whether it is in the form of seed (grain) of food, fodder, fiber or vegetable crop or seedlings, tubers, bulbs, rhizomes, roots, cuttings, grafts or other vegetative propagated material.

Seed material:

1. Seeds –Grains used for sowing
2. Vegetative propegules –Stem cuttings, tubers and rhizomes
 Stem cuttings --- Sugar cane, rose
 Rooted slips --- Fodder crops
 Tubers -Potato
 Rhizomes—Turmeric

Characteristics of good seed:

1. Purity
 Free from rogues (off types), other crop seeds, weed seeds and inert material.
2. Fully matured and well developed
3. Free from storage pests and seed borne diseases
4. Free from dormancy (dormancy problems are seen in ground nut, rice, sunflower)
5. Viable (Soybean loses viability quickly)
6. High percentage of germination (98-99%),germination percent of many grasses is 20-25%

Seed germination

The resumption of growth by embryo and development of a young seedling from the seed.

Germination is an activation of dormant embryo to give rise to radical (root development) and plumule (stem development). Germination is the awakening of the dormant embryo.

The process by which the dormant embryo wakes up and begins to grow is known as Germination.

Seedling Emergence means actually coming above and out of the soil surface by the seedling.

Changes during germination:

1. Swelling of seed due to imbibition of water by osmosis.
2. Initiation of physiological activities such as respiration & secretion of enzyme.
3. Digestion of stored food by enzymes.
4. Translocation & assimilation of soluble food.

Seed treatment:

The seeds are subjected to special treatment for different purposes. They are for convenience in sowing, enhancing germination, improvement of nutrition and control of pests. The seed treatment is mainly done for control of diseases and insect pests. Eg. Mancozeb, Carbendazim, Captan, Thioram etc.

Reasons for poor establishment

1. Use of poor quality seed with low germination percentage
2. Improper seed bed preparation
3. Low moisture, low temperature at the time of sowing
4. Salinity and alkalinity of soil.

Factors affecting the germination

External Factors

1. Moisture: It enables the resumption of physiological activities, swelling of seed due to absorption of moisture & causes bursting of seed coat & softening the tissue due to which embryo awakes & resumes its growth.

2. Temperature: A suitable temperature is necessary for proper germination. Germination does not take place beyond certain minimum & maximum temperature i.e. 0°C & above 50°C. Optimum temperature range for satisfactory germination of seed is 25 to 30°C.

3. Oxygen: It is essential during germination for respiration & other physiological activities.

4. Light: It is not considered as essential for germination & it takes place without light. The seedlings grow more vigorously during darkness rather in light. However, for survival of germinating seedling, light is quite essential.

5. Substratum: It is the medium used for germinating seeds.

Internal Factors

Food and auxins: An Embryo feed on the stored food material until young seedlings prepares its own food. Auxins are the growth promoters, hence quite essential during the germination.

Viability: All seeds remain viable for certain definite period of time and thereafter embryo becomes dead. It depends on maturity of seed, storage conditions & vigour of parents and type of species. Generally, it is for 3-5 years and they remain for more than 200 years also as in lotus.

Dormancy:

Is a period in an organism's life cycle when growth, development are temporarily stopped. It is the failure of mature viable seed to germinate under favorable condition of moisture. Many seeds do not germinate immediately after their harvest, they require rest period for certain physiological activities.

Breaking Dormancy:

Scarification:

The process of breaking, scratching, mechanically altering or softening the seed coats to make them permeable to water and gases is known as scarification. Generally it is done by pounding.

Scarified seeds are susceptible to pathogenic organisms; hence, hence, scarification is done at the time of sowing or few days before sowing.

Stratification:

Placing of seeds close together in layers in moist sand or peat to preserve them or to help them germinate. Seed layer altered with layers of moist sand or appropriate material to store at low temperature. E.g.: Mustard & Groundnut.

Hot water treatment:

Seeds are dropped in water of 75 to 100° C. The seed is soaked gradually cooling water for 12 to 24 hrs. Following this, the un swollen seeds are separated from the swollen ones and treated gain. The seeds are to be planted within a few days after hot water treatment.

Acid treatment:

Acid scarification is done usually with the concentrated sulphuric acid. Dry seeds are placed in containers (glass, earthen ware or wood but not plastic or metal) and concentrated sulphuric acid twice the volume of seed is added. The mixture of seed and acid are stirred continuously and periodically for uniform treatment for 10 minutes to six hours or more depending on seed coat of plant species. The treatment is completed when thickness of seed is reduced. At the end of the treatment period, the acid is poured off and seeds are washed to remove the acid. Seeds are placed in large quantity of water with a small amount of baking soda (sodium bicarbonate) to neutralize any adhering acid. The extra acid can be removed by washing the seeds in running water for 10 minutes. The acid treated seeds can be sown immediately or dried and stored for subsequent use.

Leaching:

The purpose of leaching is to remove germination inhibitors by soaking or placing them in frequent changes of water for 12 to 24 hrs.

Hormonal treatment:

Treating the seeds with gibberilic acid (GA3) breaks the dormancy of seeds caused by physiological reasons. The concentration is 500ppm and duration of soaking is 12 hrs. Similarly cytokinins and ethylene are also used to break dormancy.

Rhizobium treatment

In case of legumes – specific Rhizobium cultures are available depending upon the crop. These are helpful in fixing atmospheric – N. use 125g. jaggery in 1 litre of water – boil – cool – add Rhizobium culture (500g) and then thoroughly mix with seed (for 1 hour) and shade dry before sowing (R.japonicum, R.melilotus. are some examples)

Extension of viability:

Simple hydration midway during storage folloed by immediate drying back helps in extending seed viability. However, soaking and drying treatment does not extend storage life of harvest fresh seed.

Methods of sowing

1. Direct sowing
 - a) Boad casting
 - b) Line sowing
 - i) Drilling
 - ii) Dibbling
2. Transplanting

1.Broadcasting:

In broadcasting method, seeds sre spread uniformly over well prepared land and is covered by ploughing or planking. It is most primitive method of sowing. Seeds fallen at shallow depth emerge early if moisture is available and later with subsequent rains if moisture is not available. Seeds fallen deep in the soil may not germinate and even if they germinate may emerge from the soil after considerable time.

Advantages:

- Quickest & cheapest method
- Skilled labour is not required.
- Implement is not required.

Disadvantages:

- Seed requirement is more
- Crop stand is not uniform.
- Spacing is not maintained within rows & lines.

2.Line sowing

Sowing in lines at definite spacing, depth and covered with soil and compacted. To overcome the problems of broad casting, drilling the seeds in lines has come in to practice. Drilling or line sowing resulting in uniform crop stand. Seed rate can be considerably reduced by drilling

In this method, sowing implements are used for placing the seeds into the soil. Both animal drawn and power operated (seed drills) implements are available. Seeds are drilled continuously or at regular intervals in rows. In this method, depth of sowing can be maintained and fertilizer can also be applied simultaneously. Crops like Jowar, wheat Bajara, etc. are sown by this method.

Advantages:

- Seeds are placed at proper & uniform depths,
- Along the rows, intercultivation can be done,
- Uniform row to row spacing is maintained,
- Seed requirement is less than ‘broad casting’

Disadvantages:

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

3.Dibbling:

Dibbling is the process of placing seeds in holes made in seedbed and covering them. The equipment used for dibbling is called dibbler. This method is time consuming process and is not suitable for small seeds. This method is followed in crops like Groundnut, Castor, and Hybrid Cotton, etc. which are having bold size and high value.

Advantages:

- Spacing between rows & plants is maintained,
- Seeds can be dibbled at desired depth in the moisture zone,
- Optimum plant population can be maintained,
- Seed requirement is less than other method,

Disadvantages:

- Laborious & time consuming method,
- Only high value & bold seeds are sown,
- Require strict supervision.

4.Putting seeds behind the plough:

It is dropping of seeds behind the plough in the furrow with the help of manual labour by hand. This method is followed for crops like gram in some areas for better utilization of soil moisture.

Planting:

When individual seeds or seed material is placed in the soil by manual labour or by machine, it is called planting. Planting is done for crops like cotton, maize, potato, sugarcane etc.

Transplanting:

Seeds are sown in small area called nursery and all the care is taken to raise the seedlings. After seedlings grow to a certain stage, they are pulled out from nursery and transplanted in the main field. The advantages of transplanting are saving in irrigation water, good stand establishment and increase intensity of cropping

Types of Sowing

Dry sowing:

Dry sowing is adopted in black soils where sowing operation are difficult to carry out once rains commence. Field is prepared with summer rains and seeds are sown in dry soil around 7 to 10 days before the anticipated rains. The seeds germinate after the receipt of rains. By this method, rainfall is efficiently utilized.

Wet sowing:

Wet sowing is the most common method of sowing of crops. The minimum amount of rainfall necessary for taking up sowing is 20 mm. Two to three days after rain, sowing can be taken and continued for two to three days.

Time of sowing:

1. Sowing very early in the season may not be advantageous.
Eg: sowing rainfed groundnut early may result in failure of crop if there is prolonged dry spell from the 2nd week of June to 2nd week of July.
2. Delayed sowing invariably reduces yields
 - a. Eg: rainfed sorghum yields are reduced due to delay in sowing beyond June season – sorghum sown late is subjected to severe attack of shoot borer.
 - b. Eg: In rainfed groundnut sowing beyond July reduced the yields of all varieties at Tirupathi.
3. Advancing sowing of Rabi sorghum. From November-September to October.
Increase the yields considerably as more moisture would be available for early sown crop.
4. Sowing the crop at optimum time.

Increases yields due to suitable environment at all the growth stages of the crop.

1. Optimum time of sowing for Kharif crop – June or July.
2. Optimum time for Rabi crop - last week of October to first week of November.
3. Summer crop - First fortnight of January.

Depth of Sowing:

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 uniformity in maturity.

The thumb rule is to sow seeds to a depth approximately 3-4 times their diameter.

The optimum depth of sowing for most of field crops ranges between 3-5 cm. Shallow depth of sowing of 3-5 cm is enough for small seeds like sesamum finger millet and pearl millet.

Very small seeds like tobacco are placed at a depth of ICM. Bold seeded crops like castor, groundnut, cotton, and maize etc. 6-7 cm.

Seed rate:

1. Tobacco - 30g per hectore
2. Mustard - 2-3 Kg/ha
3. Pulses - 10-12Kg/ha
4. Soybean - 80-100 Kg/ha
5. Groundnut - 100-120 Kg/ha
6. Forage grasses (rooted slips) - 2-3 tons/ha
7. Potato tubers - 5-7 tons/ha
8. Sugarcane (selts) - 7 tons/ha

Crop density and geometry

Crop density and geometry- Crop stand establishment, factors affecting optimum stand establishment.

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.

In crops grown on stored soil moisture under rainfed conditions, population should not be high to deplete most of the moisture before crop matures and not low to leave moisture is utilized.

Under conditions of sufficient soil moisture and nutrients, higher population is necessary to utilize other growth factors efficiently. Once soil moisture and nutrients are not limiting, yield of crop is limited by solar radiation. The level of plant population should be such that maximum solar radiation is intercepted.

Yield of individual plants and community:

The full yield potential of individual plant is achieved when sown at wider spacing. When sown densely, competition among plants is more for growth factors resulting in reduction in size and yield of the plant.

Competition – types of competition, plant population, intra and inter plant growth and yield, optimum plant density and planting pattern.

What is competition?

Competition is the struggle between individuals within a population for available resources, when the level of resources is below the combined need of the members of the population.

How does competition occur in plants?

Crop plants are not grown in isolation but in closely spaced populations. In the early phase of growth, individual plants are small and widely spaced and do not interfere with each other. At some point, as the plants grow, they start to interfere with their neighbours and competition begins. Two plants, no matter how close, do not compete with each other so long as the growth resources are in excess of the needs of both. When the immediate supply of a single necessary factor falls below the combined demand of the two plants, competition begins.

Types of competition

1. Competition for nutrients: Nutrient uptake increases with increase in plant population. Higher population under low fertility conditions leads to development of nutrient deficiency symptoms because of competition.

2. Competition for light: Competition for light may occur whenever one plant casts a shadow on another or within a plant when one leaf shades another leaf. In early plant growth stages, there will be little mutual shading and even at relatively low light intensities the plant will be able to photosynthesize with full efficiency. As the plants develop, mutual shading increases and light becomes a limiting factor.

3. Competition for water: The success of any plant in a community for water depends on the rate and competitiveness with which it can make use of the soil water supply.

4. Intra-specific and inter-specific competition: In populations of similar genotypes, in the absence of weeds, the competition is intra-specific (within species), where different species of crops are grown, in mixtures and where weeds are present, the competition is inter-specific (between species).

Plant population and growth

- High plant density brings out certain modifications in the growth of plants.
- Plant height increases with increase in plant population due to competition for light.
- Sometimes it may happen that moderate increase in plant population may not increase but decrease plant height due to competition for water and nutrients but not for light.
- Leaf orientation is also altered due to population pressure. The leaves are erect, narrow and are arranged at longer vertical intervals under high plant densities. This is a desirable architecture.

Plant population and yield

- Decrease in yield of individual plant at high plant density is due to the reduction in the no. of ears or panicles.
- Ex: - Redgram produces about 20 pods per plant at 3.33 lakh plants/ha (30x10cm) while it produces more than 100 pods per plant at 50,000 plants/ha (80x25cm).
- Under very high population levels plant become barren, hence optimum plant population is necessary to obtain maximum yield.

Optimum plant population

Optimum plant population for any crop varies considerably due to environment under which it is grown. It is not possible to recommend a generalized plant population since the crop is grown in different seasons with different management practices.

E.g.:- Redgram plants sown as winter crop will have half the size of those grown in monsoon season. Optimum plant population is 55,000 plants/ha. For monsoon season crop of redgram and this is increased to 3.33 lakh plants/ha for winter crop; as low temperature retards the rate of growth, higher population is established for quicker ground cover.

In sorghum, when the climate is favourable during pre-anthesis period, the optimum population is two lakh plants/ha and when it is not congenial for growth during pre-anthesis, it is four lakh plants/ha.

Planting pattern

Planting pattern influences crop yield through its influence on light interception, rooting pattern and moisture extraction pattern. Different planting patterns are followed to suit different weed control practices and cropping systems.

Plant geometry refers to the shape of plant while crop geometry refers to the shape of space available for individual plants. Crop geometry is altered by changing inter and intra-row spacing.

Square planting

It is reasonable to expect that squares arrangement of plants will be more efficient in the utilization of light, water and nutrients available to the individuals than in a rectangular arrangement. In wheat, decreasing inter-row spacing below the standard 15-12 cm i.e., reducing rectangularity, generally increases yield slightly. In crops like Tobacco, intercultivation in both directions is possible in square planting and helps in effective control of weeds. However, square planting is not advantageous in all crops. Groundnut sown with a spacing of 30x10cm (3.33 lakh/ha) gave higher pod yield than with same amount of population in square planting. Pod yield is reduced either by increasing rectangularity or approaching towards square planting.

Rectangular planting

Sowing the crop with seed drill is the standard practice. Wider inter-row spacing and closer intra-row spacing is very common for most of the crops, thus attaining rectangularity. This rectangular arrangement is adopted mainly to facilitate intercultivation. Sometimes only inter-

row spacing is maintained and intra-row spacing is not followed strictly and seeds are sown closely as solid rows.

Miscellaneous planting arrangements

Crops are sown with seed drills in two directions to accommodate more number of plants and mainly to reduce weed population. Crops like rice, finger millet are transplanted at the rate of 2-3 seedlings per hill. Transplanting is done either in rows or randomly. Skipping of every alternate row is skipped, and the population is adjusted by decreasing intra-row spacing, it is known as paired row planting. It is generally restored to introduce an intercrop.

Crop Nutrition

Crop nutrition- essential plant nutrients-primary, secondary and micro nutrients _ Nutrient uptake –Nutrient use efficiency.

The term mineral nutrient is generally used to refer to an inorganic ion obtained from soil required for plant growth. The process of absorption, translocation and assimilation of nutrients by the plants is known as mineral nutrition.

Essential elements:

Plants need 16 elements for their growth and completion of life cycle.

They are: Carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, zinc, copper, boron, molybdenum and chlorine.

In addition four more elements – sodium, cobalt, vanadium and silicon are absorbed by some plants for special purpose.

Criteria of essentiality:

Plant analysis indicates that plant body contains 30 to 60 elements. The presence of several elements in plant does not mean that all these are essential for plants.

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

Nutrient transport:

Nutrient transport occurs through mass flow, diffusion and root interception.

Mass flow: Driven by the physiological process of transportation (Water loss through leaves), water moves from the soil pores to the plant root.

Diffusion: Diffusion is the movement of nutrients to the root surface in response to a concentration gradient. When nutrients are found in higher concentrations in one area than another, there is a net movement to the low concentration area so that equilibrium is reached.

Root interception: Soil particles of various sizes (sand, silt and clay) with organic matter acting as a glue are formed in soil aggregates of various sizes and shapes. The aggregates contain most of the plant nutrients. However, the growth and development, plant roots come in contact with a very limited soil surface within the aggregates – about 1 to 2 %. The process of roots making direct contact with soil aggregates (root interception), though important can't be a major mechanism for nutrients to reach the surface of the root.

Classification of essential elements:

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

Amount of nutrients:

Depending on the quantity of nutrients present in the plants, they can be grouped into three basic nutrients, macro nutrients and micro nutrients.

Basic nutrients: Carbon, hydrogen and oxygen which constitute 96 percent of total dry weight of plants. Among them carbon and oxygen constitute 45% each.

Macro nutrients: The nutrients required in large quantities are known as macro nutrients. They are N,P,K, Ca, Mg and S. Among these NPK are called primary nutrients and Ca, Mg and S are known as secondary nutrients. The latter are known as secondary nutrients as they are inadvertently applied to the soils through NPK fertilizers which contain these nutrients.

Micro nutrients: The nutrients which are required in small quantities are known as micro nutrients or trace elements. They are Fe, Zn, Cu, B, M, Mn and Cl. These elements are very efficient and minute quantities produce optimum effects. On the other hand, even a slight deficiency or excess is harmful to the plant.

Functions of nutrients in the plant:

The basic nutrient C, H and O are constituents of carbohydrates and several biochemical compounds.

Nitrogen is a constituent of proteins, hormones, vitamins, alkaloids, chlorophyll etc. Plant growth is adversely affected due to deficiency of nitrogen as it is a constituent of enzymes, chlorophyll and proteins.

Phosphorus is a constituent of sugar phosphates, nucleotides, nucleic acids, co-enzymes and phospholipids.

Potassium is not a constituent of any organic compound. However, it is required as a co – factor for 40 or more enzymes. It controls movement of stomata and maintains electroneutrality of plant cells.

Calcium is a constituent of cell wall as calcium pectate. It is required in hydrolysis of ATP and phospholipids.

Magnesium is a constituent of chlorophyll and is required in several enzymes involved in phosphate transfer.

Sulphur is a constituent of several amino acids and fatty acids.

As a constituent of various enzymes, iron plays the part of a vital catalyst in the plant. Consequently, it is a key element in various redox reaction of respiration,, photosynthesis and reduction of nitrates and sulphates.

Manganese is a constituent of several cation activated enzymes and essential for the formation of chlorophyll, reduction of nitrates and for respiration.

Copper and Zinc are involved in cation activated enzymes.

Boron helps in carbohydrate transport. It is necessary for germination of pollen, formation of flowers and fruits and for the absorption of cations.

Molybdenum is required for the assimilation of nitrates as well as for the fixation of atmospheric nitrogen.

Chlorine is involved in reaction reaction relating to oxygen evolution.

Nutrient uptake:

Nutrient uptake is the amount of each nutrient required for the crop to complete its life cycle at a given yield level.

Nutrien removal is calculated by taking the concentration of each nutrient in harvested material and multiplying by the harvest yield.

Nutrient Use Efficiency (NUE)

Nutrient use efficiency (NUE) may be defined as yield per unit input. Nutrient use efficiency is the fraction of nutrients removed from the field with the crop harvest. In agriculture this is usually related to the input of manures and fertilizer. The nutrients most commonly limiting plant growth are N, P, K and S. NUE depends on the ability to efficiently take up the nutrient from the soil, but also on transport, storage, mobilization, usage within the plant, and even on the environment.

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

Apparent N use efficiency=

N uptake by plant with N application – Nuptake by plant without N application/

The amount of N applied

Soil fertility and productivity

Soil fertility and productivity – Soil organic matter and its maintenance.

Soil fertility: The inherent capacity of the soil to supply plant nutrients in adequate quantities and in suitable proportions is termed as soil fertility.

Soil productivity: Soil productivity refers to the capacity of a soil to produce crops

A productive soil must be fertile, but a fertile soil may not be productive.

Soil productivity is influenced by:

1. Soil fertility
2. Physical condition of the soil (depth, structure, texture)
3. Activity of soil micro organisms
4. Soil moisture
5. Inhibitory factors like acidity, alkalinity, salinity, water logging etc.

Nutrients are lost from the soil in the following ways

1. Removal by crop: Rice crop removes 90-100kgN, 20-25 kg P and 130-150 kg K per ha.
2. Removal by weeds
3. Leaching losses (more in sandy soils)
4. Loss through erosion
5. Loss in gaseous form (N-by denitrification and Volatilization)

Hence, it is necessary to add nutrients periodically to the soil.

Soil fertility	Soil productivity
1. It is considered as an Index of available nutrients to plants	It is a broader term used to indicate yield of crops
2. It is one of the factors for crop production. The other factors are water supply, slope of the land, depth of water table etc.	It is the interaction of all the factors that determine the magnitude of yield.
3. It can be analysed in the laboratory	It can be assessed in the field under particular climatic conditions
4. It is the potential status of the soil	It is the resultant of various factors influencing soil management to produce crops

Soil fertility can be maintained by

- a) Cultural practices:
Fallowing, Crop rotation, Mixed cropping
- b) By addition of materials
 1. Organic manures (bulky and concentrated)
 2. Inorganic fertilizers
 3. Bio fertilizers
 4. Soil amendments –lime, zypsum, paddy husk, ground nut shells etc.
 5. Green manuring or green leaf manuring
 6. Crop residues (Stubbles etc.)

Soil organic matter:

Any material of plant or animal origin found in the soil is known as organic matter.

Organic matter that is well decomposed and digested by many kinds of soil micro organisms and converted in to fairly stable amorphous, brown to black material in termed as humus.

Uses of organic matter:

1. Helps in aggregation of soil particles and improves the structure, permeability and water holding capacity and aeration.
2. It serves as a reservoir of plant nutrients.
3. Organic acids and CO₂ produced during decomposition helps to dissolve minerals like P,K and make them more available.
4. It helps in maintaining soil pH.
5. Leaching of certain cations ;like K,Ca, Mg, NH₄ is prevented because of its higher CEC.
6. It is the source of microorganisms, earth worms and other living things.
7. Helps to maintain soil temperature
8. Alkalinity is reduced

The rate of decomposition of organic matter is dependent on the activity of soil microorganisms, which in turn is dependent on

Soil moisture content, temperature, and aeration and C: N ration of the original material added.

Manures and fertilizers

Manures

Manures are plant and animal wastes that are used as sources of plant nutrients. They release nutrients after their decomposition.

Types of Manures

Bulky organic manures

FYM, Compost, Green manure

Concentrated

Oil seed *cakes*

Advantages of Bulky organic manures

1. They supply plant nutrients including micronutrients,
2. They improve soil physical properties like structure, water holding capacity etc.,
3. They increase the availability of nutrients,
4. Carbon dioxide released during decomposition acts as a CO₂ fertilizer, and
5. Plant parasitic nematodes and fungi are controlled to some extent by altering the balance of microorganisms in the soil.

Farmyard Manure (FYM)

The decomposed mixture of dung and urine of farm animals along with litter and left over material from roughages or fodder fed to the cattle.

The FYM contains 0.5% N, 0.2% P₂O₅ and 0.5% K₂O and Urine contains 1.0% N and 1.35% K₂O. The N present in urine is mostly in the form of urea which is subjected to volatilization losses.

Sheep and Goat Manure

The dropping of sheep and goats contain higher nutrients than farm yard manure and compost. On an average, the manure contains 3% N, 1% P₂O₅ and 2% K₂O. It is applied to the field in two ways. The sweeping of sheep or goat sheds are placed in pits for decomposition and it is applied later to the field. The nutrients present in the urine are wasted in this method. The second method is sheep penning, wherein sheep and goats are allowed to stay overnight in the field and urine and fecal matter is added to the soil which is incorporated to a shallow depth by running blade harrow or cultivator.

Poultry Manure

The excreta of birds ferment very quickly. If left exposed, 50% of its nitrogen is lost within 30 days. The average nutrient content is 3.03% N, 2.63% P₂O₅ and 1.4% K₂O.

Night Soil

It is nothing but human excreta, both solid and liquid. It is richer in N, P and K than FYM and compost. On an average, night soil contains 5.5 % N, 4.0 % P₂O₅ and 2.0 % K₂O.

Sewage and sludge

In the modern system of sanitation adopted in cities and towns, home waste material is flushed out with water. The black muddy solid portion of the drain is called sludge and the liquid is called sewage. Both the components are separated and are given a preliminary fermentation and oxidation treatments to reduce bacterial contamination and offensive smell.

Concentrated organic manures

Concentrated organic manures have higher nutrient content than bulky organic manure. The important concentrated organic manures are oilcakes, blood meal, fish manure etc. These are also known as organic nitrogen fertilizer. Before their organic nitrogen is used by the crops, it is converted through bacterial action into readily usable ammonical nitrogen and nitrate nitrogen. These organic fertilizers are, therefore, relatively slow acting, but they supply available nitrogen for a longer period.

Oil-cakes

After oil is extracted from oilseeds, the remaining solid portion is dried as cake which can be used as manure.

The oil-cakes are of two types:

Edible oil-cakes which can be safely fed to livestock *e.g.* Groundnut cake, coconut cake etc., and

Non-edible oil-cakes which are not fit for feeding livestock *e.g.* Castor cake, neem cake, mahua cake etc. The nutrient range from 2 to 8 % in N, 1 to 3% in P₂O₅ and 1 to 2 % in K₂O.

Other Concentrated Organic Manures

Blood-meal when dried and powdered can be used as manure. The meat of dead animals is dried and converted into meat-meal which is a good source of nitrogen. Nutrient content of animal based concentrated organic manures range from 1 to 10% in N, 2-25% in P₂O₅ and 1 to 15% in K₂O.

Green Manuring

It is a practice of ploughing in the green plant tissues grown in the field or adding green plants with tender twigs or leaves from outside and incorporating them into the soil for improving the physical structure as well as fertility of the soil. It can be defined as a practice of ploughing or turning into the soil, un decomposed green plant tissues for the purpose of improving the soil fertility.

The object of green manuring is to add an organic matter into the soil and thus, enrich it with 'N' which is most important and deficient nutrient.

Types of green manuring: There are two types of green manuring:

1. **Green manuring in-situ:** When green manure crops are grown in the field itself either as a pure crop or as intercrop with the main crop and buried in the same field, it is known as Green manuring In-situ. *E.g.:* Sannhemp, Dhaicha, Pillipesara, Shervi, Urd, Mung, Cowpea, Berseem, Senji, etc.
2. **Green leaf manuring:** It refers to turning into the soil green leaves and tender green twigs collected from shrubs and tress grown on bunds, waste lands and nearby forest area. *E.g.:* Glyricidia, wild Dhaicha, Karanj.

Stage of green manuring: A green manuring crop may be turned in at the flowering stage or just before the flowering. The majority of the G.M. crops require 6 to 8 weeks after sowing at which there is maximum green matter production and most succulent.

Advantages of green manuring:

- It adds organic matter to the soil and stimulates activity of soil micro-organisms.
- It improves the structure of the soil thereby improving the WHC, decreasing run-off and erosion caused by rain.
- The G.M. takes nutrients from lower layers of the soil and adds to the upper layer in which it is incorporated.
- It is a leguminous crop, it fixes 'N' from the atmosphere and adds to the soil for being used by succeeding crop. Generally, about 2/3 of the N is derived from the atmosphere and the rest from the soil.

- It increases the availability of certain plant nutrients like P_2O_5 , Ca, Mg and Fe.

Disadvantages of green manuring:

- Under rain fed conditions, the germination and growth of succeeding crop may be affected due to depletion of moisture for the growth and decomposition of G.M.
- G.M. crop inclusive of decomposition period occupies the field least 75-80 days which means a loss of one crop.
- Incidence of pests and diseases may increase if the G.M. is not kept free from them.

Application of phosphatic fertilizers to G.M. crops (leguminous) helps to increase the yield, for rapid growth of Rhizobia and increase the 'P' availability to succeeding crop.

Stage of incorporation:

Best stage of incorporation is flowering stage. The plants used for green leafy manuring should be incorporated into soil before they mature or attain woody nature.

The success of green manuring depends on the correct time of trampling green matter into the soil and giving sufficient interval before sowing or planting the crop. After incorporation sufficient time is allowed for decomposition to take place and only after this, the main crop is sown or planted. Usually about six to eight weeks time is found to be sufficient for the decomposition.

Decomposition of green manure:

Mineralization of organic matter (OM)

Mineralization is the process by which chemicals present in organic matter are decomposed or oxidized into easily available forms to plants. It is driven by micro biota-fungi and bacterial along with earth worms.

1. Wide C:N ratio 50:1
2. Close C:N ratio 30:1 or 20:1

Composting

Composting is the natural process of 'rotting' or decomposition of organic matter by microorganisms under controlled conditions. Raw organic materials such as crop residues, animal wastes, food garbage, some municipal wastes and suitable industrial wastes, enhance their suitability for application to the soil as a fertilizing resource, after having undergone composting.

A mass of rotted organic matter made from waste is called compost.

The compost made from farm waste like sugarcane trash, paddy straw, weeds and other plants and other waste is called farm compost. The average nutrient contents of farm compost are 0.5 per cent N, 0.15 per cent P_2O_5 and 0.5 per cent K_2O . The nutrient value of farm compost can

be increased by application of superphosphate or rock phosphate at 10 to 15 kg/t of raw material at the initial stage of filling the compost pit.

Composting is essentially a microbiological decomposition of organic residues collected from rural area (rural compost) or urban area (urban compost).

Vermicompost

Vermicompost is the use of earthworms for composting organic residues. Earthworms can consume practically all kinds of organic matter. Earthworms have the capacity to eat as much matter as their own weight and produce the same amount of manure per day in the form of castings.

Castings or excreta of earthworms are rich in nutrients and bacterial and actinomycetes population

The potential benefits include:

- Reduction of noxious qualities of a wide variety of organic waste, elimination of smell, reduction of harmful microorganisms
- Production of marketable organic fertilizer
- Production of aqua life, birds and animal food or even human food by drying earthworms
- Additional benefit to the farmers
- Increases soil fertility and bacterial activity in the soil
- Increases micro grains in the soil and enhances water absorption capacity
- Helps the plant root get air easily
- Increases plant resistance to pests, fungus and other deceases

Vermiwash

- Liquid fertilizer collected over passage of water through a column of worms in action useful as foliar spray
- Collection of excretory products and mucus secretion of earthworms along with micro nutrients from solid organic molecules.

Fertilizer

Fertilizer is any material of natural or synthetic origin added to the soil to supply one or more plant nutrients.

Classification of fertilizers

Fertilizers

1. Straight fertilizers: Straight fertilizers are those which supply only one primary plant nutrient, namely nitrogen or phosphorus or potassium. eg. Urea, ammonium sulphate, potassium chloride and potassium sulphate.

2. Complex fertilizers: Complex fertilizers contain two or three primary plant nutrients of which two primary nutrients are in chemical combination. These fertilizers are usually produced in granular form. eg. Diammonium phosphate, nitrophosphates and ammonium phosphate.

3. Mixed fertilizers: are physical mixtures of straight fertilizers. They contain two or three primary plant nutrients. Mixed fertilizers are made by thoroughly mixing the ingredients either mechanically or manually.

Fertilizers can also be classified based on physical form:

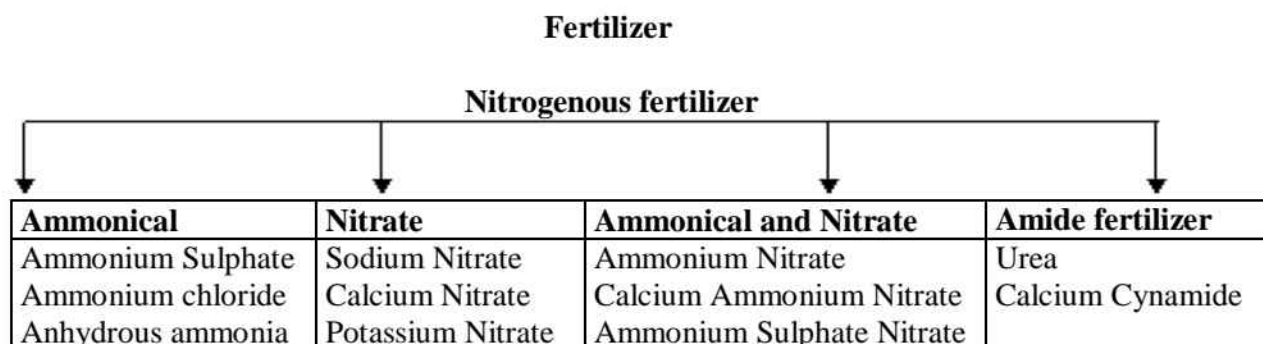
1. Solid
2. Liquid fertilizers

Solid fertilizers are in several forms *viz.*

1. Powder (single superphosphate),
2. Crystals (ammonium sulphate),
3. Pills (urea, Di-ammonium phosphate, superphosphate),
4. Granules (Holland granules),
5. Super granules (urea super granules) and
6. Briquettes (urea briquettes).

Liquid fertilizers:

1. Liquid form fertilizers are applied with irrigation water or for direct application.
2. Ease of handling, less labour requirement and possibility of mixing with herbicides has made the liquid fertilizers more acceptable to farmers.



Nitrogenous fertilizers

1. Nitrogenous fertilizers take the foremost place among fertilizers since the deficiency of nitrogen in the soil is the foremost and crops respond to nitrogen better than to other nutrients.
2. More than 80 per cent of the fertilizers used in this country are made up of nitrogenous fertilizers, particularly urea.
3. It is extremely efficient in increasing the production of crops and the possibilities of its economic production are unlimited

The nitrogenous fertilizers can be further classified as given below:

1. Ammonical fertilizers

1. Ammonical fertilizers contain the nutrient nitrogen in the form of ammonium or ammonia.
2. Ammonical fertilizers are readily soluble in water and therefore readily available to crops.
3. Except rice, all crops absorb nitrogen in nitrate form. These fertilizers are resistant to leaching loss, as the ammonium ions get readily absorbed on the colloidal complex of the soil.

Example:

a) *Ammonium sulphate* [(NH₄)₂SO₄]

It is a white salt completely soluble in water containing 20.6 per cent of nitrogen and 24.0 per cent of sulphur.

b) *Ammonium chloride* (NH₄Cl)

It is a white salt contains 26.0 per cent of nitrogen.

c) *Anhydrous ammonia* (NH₄)

It is a colourless and pungent gas containing 82.0 per cent nitrogen.

A. Nitrate Fertilizers

Nitrate fertilizers contain the nitrogen in the form of NO₃

a) *Sodium nitrate* (NaNO₃)

Sodium nitrate is a white salt containing about 15.6 per cent of nitrogen.

b) *Calcium nitrate* [Ca(NO₃)₂]

It is a white crystalline hygroscopic solid soluble in water containing 15.5 per cent nitrogen and 19.5 per cent calcium.

c) *Potassium nitrate* (KNO₃)

The purified salt contains 13.0 per cent nitrogen and 36.4 per cent potassium.

B. Ammonical and nitrate fertilizers

These fertilizers contain nitrogen in both ammonium and nitrate forms. The nitrates are useful for rapid utilization by crops and the ammonical is gradually available.

a) *Ammonium nitrate* (NH₄NO₃)

It is white, water soluble and hygroscopic crystalline salt containing 35 per cent nitrogen half as nitrate nitrogen and half in the ammonium form.

b) *Calcium ammonium nitrate* (CAN)

Calcium ammonium nitrate is a fine free-flowing, light brown or grey granular fertilizer, containing 26 per cent of nitrogen.

c) *Ammonium sulphate nitrate* [(NH₄)₂SO₄ NH₄NO₃]

It contains 26 per cent nitrogen, three fourths of it in the ammoniacal form and the rest (6.5 per cent) as nitrate nitrogen.

C. Amide fertilizers

Amide fertilizers are readily soluble in water and easily decomposable in the soil.

a) Urea [$\text{CO}(\text{NH}_2)_2$]

It is the most concentrated solid nitrogenous fertilizer, containing 46 per cent nitrogen.

b) Calcium cyanamide (CaCN_2)

Calcium cyanamide or nitrolime contains 20.6 per cent of nitrogen.

2. Phosphatic fertilizers

Phosphatic fertilizers are chemical substances that contain the nutrient phosphorus in absorbable form (Phosphate anions) or that yield after conversion in the soil.

a) Super phosphate [$\text{Ca}(\text{H}_2\text{PO}_4)_2$]

This is the most important phosphatic fertilizer in use and it contains 16 Per cent P_2O_5 in available form.

b) Triple super phosphate:

The concentrated super phosphate is called as *Triple super phosphate* and it contains 46 per cent P_2O_5 .

3. Potassic fertilizers

Potassic fertilizers are chemical substances containing potassium in absorbed form (K^+). There are two potassium fertilizers viz., muriate of potash (KCl) and sulphate of potash (K_2SO_4). They are water soluble and so are readily available to plants.

a) Potassium chloride (KCl)

Potassium chloride or muriate of potash is a white or red, crystal containing 60.0 per cent K_2O .

b) Potassium sulphate (K_2SO_4)

Potassium sulphate or sulphate of potash is a white salt and contains 48 per cent K_2O .

Bio fertilizers

Bio fertilizers are defined as preparations containing living cells or latent cells of efficient strains of microorganisms that help crop plants' uptake of nutrients by their interactions in the rhizosphere when applied through seed or soil. They accelerate certain microbial processes in the soil which augment the extent of availability of nutrients in a form easily assimilated by plants.

Use of bio fertilizers is one of the important components of integrated nutrient management, as they are cost effective and renewable source of plant nutrients to supplement the chemical fertilizers for sustainable agriculture. Several microorganisms and their association with crop plants are being exploited in the production of bio fertilizers. They can be grouped in different ways based on their nature and function.

S. No.	Groups	Examples
N₂ fixing Bio fertilizers		
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>

P Solubilizing Bio fertilizers		
1.	Bacteria	<i>Bacillus megaterium</i> var. <i>phosphaticum</i> , <i>Bacillus subtilis</i> <i>Bacillus circulans</i> , <i>Pseudomonas striata</i>
2.	Fungi	<i>Penicillium</i> sp, <i>Aspergillus awamori</i>
P Mobilizing Bio fertilizers		
1.	Arbuscular mycorrhiza	<i>Glomus</i> sp., <i>Gigaspora</i> sp., <i>Acaulospora</i> sp., <i>Scutellospora</i> sp. & <i>Sclerocystis</i> sp.
2.	Ectomycorrhiza	<i>Laccaria</i> sp., <i>Pisolithus</i> sp., <i>Boletus</i> sp., <i>Amanita</i> sp.
3.	Ericoid mycorrhizae	<i>Pezizella ericae</i>
4.	Orchid mycorrhiza	<i>Rhizoctonia solani</i>
Bio fertilizers for Micro nutrients		
1.	Silicate and Zinc solubilizers	<i>Bacillus</i> sp.
Plant Growth Promoting Rhizobacteria		
1.	<i>Pseudomonas</i>	<i>Pseudomonas fluorescens</i>

Rhizobium

Rhizobium is a soil habitat bacterium, which can able to colonize the legume roots and fixes the atmospheric nitrogen symbiotically. They are the most efficient biofertilizers as per the quantity of nitrogen fixed concerned. They have seven genera and highly specific to form nodule in legumes, referred as cross inoculation group.

Azotobacter

Of the several species of *Azotobacter*, *A. chroococcum* happens to be the dominant inhabitant in arable soils capable of fixing N₂ (2-15 mg N₂ fixed /g of carbon source) in culture media.

Azospirillum

Azospirillum lipoferum and *A. brasilense* (*Spirillum lipoferum* in earlier literature) are primary inhabitants of soil, the rhizosphere and intercellular spaces of root cortex of graminaceous plants. They perform the associative symbiotic relation with the graminaceous plants.

Cyanobacteria

Both free-living as well as symbiotic cyanobacteria (blue green algae) have been harnessed in rice cultivation in India. A composite culture of BGA having heterocystous *Nostoc*, *Anabaena*, *Aulosira* etc. is given as primary inoculum in trays, polythene lined pots and later mass multiplied in the field for application as soil based flakes to the rice growing field at the rate of 10 kg/ha. The final product is not free from extraneous contaminants and not very often monitored for checking the presence of desired algal flora.

Azolla

Azolla is a free-floating water fern that floats in water and fixes atmospheric nitrogen in association with nitrogen fixing blue green alga *Anabaena azollae*. Azolla is used as biofertilizer

for wetland rice and it is known to contribute 40-60 kg N/ha per rice crop.

Phosphate solubilizing microorganisms(PSM)

Several soil bacteria and fungi, notably species of *Pseudomonas*, *Bacillus*, *Penicillium*, *Aspergillus* etc. secrete organic acids and lower the pH in their vicinity to bring about dissolution of bound phosphates in soil.

AM fungi

The transfer of nutrients mainly phosphorus and also zinc and sulphur from the soil *milieu* to the cells of the root cortex is mediated by intracellular obligate fungal endo symbionts of the genera *Glomus*, *Gigaspora*, *Acaulospora*, *Sclerocysts* and *Endogone* which possess vesicles for storage of nutrients and arbuscles for funneling these nutrients into the root system.

Silicate solubilizing bacteria (SSB)

Microorganisms are capable of degrading silicates and aluminum silicates. During the metabolism of microbes several organic acids are produced and these have a dual role in silicate weathering.

Plant Growth Promoting Rhizobacteria (PGPR)

The group of bacteria that colonize roots or rhizosphere soil and beneficial to crops are referred to as plant growth promoting rhizobacteria (PGPR).

Liquid Biofertilizers

Biofertilizers are such as *Rhizobium*, *Azospirillum* and Phosphobacteria provide nitrogen and phosphorous nutrients to crop plants through nitrogen fixation and phosphorous solubilization processes. These Biofertilizers could be effectively utilized for rice, pulses, millets, cotton, sugarcane, vegetable and other horticulture crops.

Liquid Bio-fertilizer application methodology

There are three ways of using Liquid Bio-fertilizers

1. Seed treatment
2. Root dipping
3. Soil application

Irrigation –Importance of irrigation –Objectives of irrigation,-Methods of irrigation and water use efficiency

Water Resources

About 97 per cent of water in this world is the oceans and this is not useful for irrigation. Of the total quantity of water only 2.6 per cent is fresh water. Only small fraction of water resources of the earth that are present in the ground, lakes, rivers and atmosphere can be harvested for irrigation of crops and domestic purposes.

Water resources of the world

Particulars	Amount of water (KM ³)	Percentage of total
Oceans	1,348,000,000	97.39
Polar ice, glaciers	27,820,000	2.01
Ground water and soil moisture	8,062,000	0.58
Lakes and rivers	225,000	0.02
Atmospheric water	13,000	0.0001
Total	1,384,120,000	100.000

Water resources of India

The average annual rainfall of India is 1194 mm. When considered over the geographical area of 328 m ha, this rainfall amounts to 392 million hectare meters (million ha m). This may be rounded off to 400 million ha m by including the contribution of snow fall. Out of 400 million ha m of rainfall, 75% of it is received during south-west monsoon period (June to Sep) and rest in remaining 8 months. A major portion of the water (215 million ha m) soaks into the soil while 70 million ha m is lost as evapo- transpiration and surface flow is 115 million ha m (Rain fall 105 million ha m and snow fall 10 million ha m). Of the 215 million ha m of infiltration soil moisture is 165 million ha m and ground water 50 million ha m.

Irrigation

Irrigation may be defined as the artificial application of water to the soil for the purpose of crop production in supplement to rainfall and ground water contribution.

Importance of water to plants

1. Plants contain 90% water which gives turgidity and keeps them erect
2. Water is an essential part of protoplasm
3. It regulates the temperature of the plant system
4. It is essential to meet the transpiration requirements
5. It serves as a medium for dissolving the nutrients present in the soil
6. It is an important ingredient in photosynthesis

Objective of irrigation:

The main objectives of irrigation supply are to:

1. Ensure enough moisture essential for plant growth.
2. Provide crop insurance against short duration drought.
3. Cool the soil and atmosphere to provide a suitable surrounding
4. Wash out or dilute harmful salts and chemicals in the soil
5. Reduce hazards of soil piping.
6. Soften the tillage pan

Advantages of irrigation

1. For proper nourishment of crops certain amount of water is required. If rainfall is insufficient there will be deficiency in fulfillment of water requirement. Irrigation tries to remove this deficiency caused due to inadequate rainfall. Thus, irrigation comes to rescue in dry years.
2. Irrigation improves the yield of crops and makes people prosperous. The living standards of the people are thereby improved.
3. Irrigation also adds to the wealth of the country in two ways. Firstly as bumper crops are produced due to irrigation it makes country self-sufficient in food requirements. Secondly as the irrigation water is taxed when it is supplied to the cultivators, it adds to the revenue.
4. Irrigation makes it possible to grow cash crops which give good returns to the cultivators than the ordinary crops they might have grown in absence of irrigation. Fruit gardens, sugarcane, potato, tobacco etc., are the cash crops.
5. Sometimes large irrigation channels can be used as a means of communication.
6. Along the banks of large irrigation channels plantation can be successfully done which not only helps introducing social forestry but also improves environmental status of the region.
7. New irrigation works are started at the time of famines to provide employment to a large number of populations. These works are called famine works or relief works.
8. When watering facility is provided to a barren land, the value of this land gets appreciated.

Crop water requirement

Crop water requirement is the quantity of water regardless of source, needed for normal crop growth and yield in a period of time at a place and may be supplied by precipitation or by irrigation or by both.

Water is needed mainly to meet the demands of evaporation (E), transpiration (T) and metabolic needs of the plants, all together is known as consumptive use (CU). Since water used in the metabolic activities of plant is negligible, being only less than one percent of quantity of water passing through the plant, evaporation (E) and transpiration (T), i.e. ET is directly considered as equal to consumptive use (CU). In addition to ET, water requirement (WR) includes losses during the application of irrigation water to field (percolation, seepage, and run off) and water required for special operation such as land preparation, transplanting, leaching etc.

$WR = CU + \text{application losses} + \text{water needed for special operations.}$

Water requirement (WR) is therefore, demand and the supply would consist of contribution from irrigation, effective rainfall and soil profile contribution including that from shallow water tables (S)

$$WR = IR + ER + S$$

Under field conditions, it is difficult to determine evaporation and transpiration separately. They are estimated together as evapotranspiration (ET). IR is the irrigation requirement.

Water Use Efficiency (WUE):

Water use efficiency is defined as yield of marketable crop produced per unit of water used in evapotranspiration.

$$WUE = Y / ET \text{ (kg/ha/mm)}$$

Where,

WUE = Water use efficiency (kg/ha/mm of water)

Y = marketable yield (kg/ha)

ET= Evapotranspiration (mm)

If yield is proportional to ET, water use efficiency has to be constant but it is not so. Actually, Y and ET are influenced independently by crop management and environment. Yield is more influenced by crop management practices, while ET is mainly dependent on climate and soil moisture. Fertilization and other cultural practices for high yield usually increase in water use accompanying fertilization is often negligible. Crop production can be increased by judicious irrigation without markedly increasing ET. Under optimum water supply, ET is not dependent on kind of plant canopy provided the soil is adequately covered with crop.

Factors effecting water use efficiency:

1. Nature of plant
2. Climatic conditions
3. Soil moisture content
4. Fertilizers
5. Plant population etc.

Criteria of irrigation scheduling

An ideal irrigation schedule must indicate when to apply irrigation water and how much quantity of water to be applied; several approaches for scheduling irrigation have been used by scientist and farmers. These are as under

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 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.

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.

3) Critical stage approach

In each crop, there are some growth stages at which moisture stress leads to irrevocable yield loss. These stages are known as critical periods or moisture sensitive periods. If irrigation water is available in sufficient quantities, irrigation is scheduled whenever soil moisture is depleted to critical moisture level say 25 or 50 percent of available soil moisture. 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 crops

Sr. No.	Crop	Moisture Sensitive Stages
1	Rice	Panicle Initiation, Flowering
2	Wheat	Crown Root Initiation, Jointing, Milking
3	Sorghum	Seedling, Flowering
4	Maize	Silking, Tasseling
5	Bajara	Flowering, Panicle Initiation
6	Nachani	Panicle Initiation, Flowering
7	Ground Nut	Rapid Flowering, Pegging, Early Pod Formation
8	Red Gram	Flowering & Pod Formation
9	Green Gram	Flowering & Pod Formation
10	Black Gram	Flowering & Pod Formation
11	Sugarcane	Formative Stage
12	Sesame	Blooming stage to Maturity
13	Sunflower	Two weeks before & after flowering
14	Safflower	From rosette to flowering
15	Soybean	Blooming & seed formation
16	Cotton	Flowering & Ball Formation
17	Tobacco	Transplanting to Full Bloom

Remote Sensing

In project areas, where a single crop is growing in large area, irrigation scheduling can be done with the help of remote sensing data. Reflectance of solar radiation by the plants with sufficient amount of water is different from that of stressed plants. This principle can be used for scheduling irrigation.

Methods of irrigation

1. Irrigation Methods are mainly classified into :

1. Surface Irrigation or Gravity Irrigation
2. Subsurface Irrigation or Sub-irrigation
3. Sprinkler or overhead irrigation
4. Drip or Trickle irrigation

Surface irrigation

- Irrigation water flows across the field to the point of infiltration
- Primarily used for field crops and orchards
- Water is applied to the soil surface and the water flows by gravity either through furrows, strips or basins.
- Water is applied from a channel located at the upper reach of the field.
- Loss of water by conveyance and deep percolation is high and the efficiency of irrigation is only 40-50% at field level in surface method of irrigation.
- Properly constructed water distribution systems to give sufficient control of water to the fields and effective land preparation to permit uniform distribution of water over the field are very important.

Water is applied to the field in either the controlled or uncontrolled manner.

- Controlled: Water is applied from the head ditch and guided by corrugations, furrows, borders, or ridges.
- Uncontrolled: Wild flooding.
- Surface irrigation is entirely practised where water is abundant.
- Low initial cost of development is later offset by high labour cost of applying water.
- Deep percolation, runoff and drainage problems

1. Furrow irrigation 2. Border irrigation 3. Basin irrigation

Furrow irrigation - in which the water poured on the field is directed to flow through narrow channels dug between the rows of crops, instead of distributing the water throughout the whole field evenly.

The furrows must all have equal dimensions, in order to guarantee that the water is distributed evenly. Like flood irrigation, furrow irrigation is rather cheap in areas where water is inexpensive.

In furrow irrigation, only a part of the land surface (the furrow) is wetted thus minimizing evaporation loss. Irrigation can be by corrugation using small irrigation streams. Furrow irrigation is adapted for irrigating on various slopes except on steep ones because of erosion and bank overflow.

Border Irrigation System

In border irrigation, controlled surface flooding is practised whereby the field is divided up into strips by parallel ridges or dykes and each strip is irrigated separately by introducing water upstream and it progressively covers the entire strip..

Basin method of irrigation is adopted mainly in orchards.

- Usually round basins are made for small trees and square basin for large trees.
- These basins allow more water to be impounded as the root zones of orchard plants are usually very deep.
- Each basin is flooded and water is allowed to infiltrate into the soil.
- Basin irrigation is suitable for many field crops. Rice grows best when its roots are submerged in water and so basin irrigation is the best method to use for this crop. Other crops which are suited to basin irrigation include: Pastures, e.g. alfalfa, clover; Citrus, banana; Crops which are broadcast, such as cereals, and to some extent row crops such as tobacco.

Sprinkler irrigation

- It is a method of applying irrigation water which is similar to natural rainfall. □ Water is distributed through a system of pipes usually by pumping.
- Water under pressure is carried and sprayed into the air above the crop through a system of: □ Overhead perforated pipes, nozzle lines, or through nozzles fitted to riser pipes attached to a system of pipes laid on the ground.
- Nozzles of fixed type or rotating under the pressure of water are set at suitable intervals in the distribution pipes. Sprayed water wets both the crop and the soil and, hence, has a refreshing effect. Water is applied at a rate less than the intake rate of soil so that there is no runoff.
- Measured quantity of water is applied to meet the soil water depletion.
- Sprinkler irrigation is suited for most row, field and tree crops and water can be sprayed over or under the crop canopy.
- Large sprinklers are not recommended for irrigation of delicate crops such as lettuce because the large water drops may damage the crop. Suitable slopes
- Sprinkler irrigation is adaptable to any farmable slope, whether uniform or undulating.
- Lateral pipes supplying water to the sprinklers should always be laid out along land contour.
- This will minimize the pressure changes at the sprinklers and provide a uniform irrigation.
- Sprinklers are best suited to sandy soils with high infiltration rates although they are adaptable to most soils.
- Application rate from the sprinklers (in mm/hour) is always chosen to be less than the basic infiltration rate of the soil - so that surface ponding and runoff can be avoided.
- Sprinklers are not suitable for soils which easily form a crust.

Drip or trickle irrigation

In this irrigation system:

- Water is applied directly to the crop ie. entire field is not wetted
- Water is conserved
- Weeds are controlled because only the places getting water can grow weeds.
- There is a low pressure system.
- There is a slow rate of water application somewhat matching the consumptive use. Application rate can be as low as 1 - 12 l/hr.
- There is reduced evaporation, only potential transpiration is considered.
- There is no need for a drainage system.

Drip irrigation / trickle irrigation - involves dripping water onto the soil at very low rates (2-20 litres/hour) -from a system of small diameter plastic pipes fitted with outlets called emitters or drippers. Water is applied close to plants so that only part of the soil in which the roots grow is wetted. With drip irrigation water, applications are more frequent (usually every 1-3 days). This provides a very favourable high moisture level in the soil in which plants can flourish.

Time of irrigation

Crops draw water from the moisture stored in the soil. When the moisture present in the soil is low, then the plant requirements are not met with. When the soil is supplied with moisture in excess the supply of air is reduced that limits the plants growth. In between, there is a range of moisture content that is called as optimum soil moisture range for plant growth.

The upper limit of the optimum soil moisture range is the field capacity (-0.01 to -0.03 Mpa) and the lower limit is just above the wilting point (-1.5 Mpa). The objective of irrigation is to store the moisture in the soil between these limits. Immediately after irrigation, all the macro and micropores will be filled with water. All the water present in macropores will drain to subsoil within 48 hours and moisture in micropores will be available to plants. As the soil dries due to loss of water by evaporation and transpiration, the plant wilts during day time to conserve moisture and become normal at night. When the same condition continues, the plant will wilt without dieing. This condition is called as wilting coefficient. The irrigation is given whenever plants require water. This is decided by the crop and soil appearance.

Water logging

The problem associated with excessive irrigation on poorly drained soils is called water logging. This occurs in poorly drained soils where water can't penetrate deeply. For example, there may be an impermeable clay layer below the soil. It also occurs on areas that are poorly drained topographically. What happens is that the irrigation water (and/or seepage from canals) eventually raises the water table in the ground, the upper level of the groundwater from beneath.

The raised water table results in the soils becoming waterlogged. When soils are water logged, air spaces in the soil are filled with water, and plant roots essentially suffocate -- lack oxygen. Waterlogging also damages soil structure.

Drainage

Drainage is the artificial removal of water in excess of the quantity required for the crop. Drainage includes removal of excess water of both surface and subsurface in the root zone of crops. Irrigation and drainage go together and are not mutually exclusive. Irrigation aims at supplying optimum quantities of water throughout the crop period, whereas, drainage aims at removing excess quantity of water in a short time. Often, both may be required together to assure sustained and high level production of crops.

Role of drainage

1. Draining the land provides conditions favorable for crop production.

2. The greatest benefit of drainage relates to aeration. Good drainage facilitates the ready diffusion of oxygen to the root zone and escape of carbon dioxide from the root zone into the atmosphere. Several harmful gases also escape from the root zone into the atmosphere.
3. The activity of aerobic organisms which influence the availability of nutrients such as nitrogen and sulphur to plants depends on soil aeration and hence, drainage improves aerobic organisms.
4. Toxicity in acid soils due to excess iron and manganese is decreased by drainage (due to presence of oxygen in the root zone).
5. Drainage permits roots to grow deeper and spread wider thereby increasing the volume of soil from which nutrients can be extracted.
6. The removal of excess water helps in drying of the soil quickly and optimum soil temperature permits timeliness of field operations.
7. The provision of a good drainage system permits the removal of excess salts in the soil or irrigation water and prevents their build up in the upper soil layers.

Fundamentals of agronomy

Syllabus -Theory

Agronomy and its scope; Seeds and sowing, tillage and tith, crop density and geometry; Crop nutrition, manures and fertilizers, nutrient use efficiency; Water resources, crop water requirement, water use efficiency,; Irrigation, scheduling criteria, methods, and water logging.

Weeds, importance, classification, crop weed competition, concepts of weed management, principles and methods; Herbicides, classification, selectivity, resistance, allelopathy.

Growth and development of crops, factors affecting growth and development, plant Ideotypes; crop rotation and its principles; Adaptation and distribution of crops, crop management technologies in problematic areas; harvesting and threshing of crops.

References

5. Reddy, S.R. 2016. Principles of Agronomy. Kalyani Publishers. Ludhiana -5th Edition

6. Yellamanda Reddy, Y. and Shankar Reddy, G.H. 2016. Principles of Agronomy. Kalyani Publishers. Ludhiana
7. Gopal Chandra De. 1989. Fundamentals of Agronomy. Oxford and IBH Publishing Co. Pvt. Ltd., new Delhi
8. Gupta, O.P.2011.Modern Weed management. Agrobios (india), Jodhpur.

Fundamentals of Agronomy

Agriculture – Agronomy and its scope – Role of Agronomists in resource management for crop production

Agriculture helps to meet the basic needs of human and their civilization by providing food, clothing, shelters, medicine and recreation. Hence, agriculture is the most important enterprise in the world

Agriculture provides food, feed, fibre, fuel, furniture, raw materials and materials for and from factories; provides a free fare and fresh environment, abundant food for driving out famine.

Meaning of Agriculture:

The term agriculture is derived from the Latin words “ager” or “agri” meaning “soil” and ‘cultra’ meaning ‘cultivation’

Agriculture may be defined as science, art, and business of the producing crops and livestock for man’s use and employment.

Agriculture is the cultivation of lands for production of crops for a regular supply of food and other needs for progress of the nation.

Agriculture is influenced by a large number of factors, some of which can be controlled by man (soil and irrigation) which others are beyond the control (climate)

Agriculture as art, science and business of crop production

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

As an art, it embraces knowledge of the way to perform the operations of the farm in a skillful manner. The skill is categorized as;

Physical skill: It involves the ability and capacity to carry out the operation in an efficient way for *e.g.*, handling of farm implements, animals etc., sowing of seeds, fertilizer and pesticides application etc.

Mental skill: The farmer is able to take a decision based on experience, such as (i) time and method of ploughing, (ii) selection of crop and cropping system to suit soil and climate, (iii) adopting improved farm practices etc.

As a science: It utilizes all modern technologies developed on scientific principles such as crop improvement/breeding, crop production, crop protection, economics etc., to maximize the yield and profit.

For example, new crops and varieties developed by hybridization, transgenic crop varieties resistant to pests and diseases, hybrids in each crop, high fertilizer responsive varieties, water management, herbicides to control weeds, use of bio-control agents to combat pest and diseases etc.

As the business: As long as agriculture is the way of life of the rural population, production is ultimately bound to consumption. But agriculture as a business aims at maximum net return through the management of land, labour, water and capital, employing the knowledge of various sciences for production of food, feed, fibre and fuel. In recent years, agriculture is commercialized to run as a business through mechanization.

Scope of agriculture in India

In India, population pressure is increasing while area under cultivation is static (as shown in the land utilization statistics given below) or even shrinking, which demand intensification of cropping and allied activities in two dimensions *i.e.*, time and space dimension

Total geographical area ha.	:	328.848 million
Total reporting area ha.	:	304.300 million
Area under cultivation ha.	:	143.000 million

Total cropped area ha.	:	179.750 million
Area sown more than once	:	36.750 million ha.
Area not available for cultivation ha.	:	161.300 million
Area under forest ha.	:	66.400 million

India, food grain production increased almost four folds from about 50 million tones at independence to more than 253 million tones in 2013.

Despite variation in the performance of individual crops and regions, total food grain production maintained a growth of 2.7% per annum, which kept ahead of population growth at about 2.2% per annum. In future, agriculture development in India would be guided not only by the compulsion of improving food and nutritional security, but also by the concerns for environmental protection, sustainability and profitability.

Branches of agriculture

Agriculture is the branch of science encompassing the applied aspects of basic sciences. The applied aspects of agricultural science consists of study of field crops and their management (**Arviculture**) including soil management.

Crop production - It deals with the production of various crops, which includes food crops, fodder crops, fibre crops, sugar, oil seeds, etc. It includes agronomy, soil science, entomology, pathology, microbiology, etc. The aim is to have better food production and how to control the diseases.

Horticulture - Branch of agriculture deals with the production of flowers, fruits, vegetables, ornamental plants, spices, condiments (includes narcotic crops-opium, etc., which has medicinal value) and beverages.

Agricultural Engineering - It is an important component for crop production and horticulture particularly to provide tools and implements. It is aiming to produce modified tools to facilitate proper animal husbandry and crop production tools, implements and machinery in animal production.

Forestry - It deals with production of large scale cultivation of perennial trees for supplying wood, timber, rubber, etc. and also raw materials for industries.

Animal Husbandry - The animals being produced, maintained, etc. Maintenance of various types of livestock for direct energy (work energy). Husbandry is common for both crop and animals. The objective is to get maximum output by feeding, rearing, etc. The arrangement of crops is done to get minimum requirement of light or air. This arrangement is called geometry. Husbandry is for direct and indirect energy.

Fishery Science - It is for marine fish and inland fishes including shrimps and prawns.

Home Science - Application and utilization of agricultural produces in a better manner. When utilization is enhanced production is also enhanced. *e.g.*, a crop once in use in south was found that it had many uses now.

On integration, all the seven branches, first three is grouped as for crop production group and next two for animal management and last two as allied agriculture branches. Broadly in practice, agriculture is grouped in four major categories as,

Development of scientific agriculture

Early man depended on hunting, fishing and food gathering. To this day, some groups still pursue this simple way of life and others have continued as roving herdsmen. However, as various groups of men undertook deliberate cultivation of wild plants and domestication of wild animals, agriculture came into being. Cultivation of crops, notably grains such as wheat, rice, barley and millets, encouraged settle- ment of stable farm communities, some of which grew into a town or city in various parts of the world. Early agricultural implements-digging stick, hoe, scythe and plough-developed slowly over the centu- ries and each innovation caused profound changes in human life. From early times too, men created indigenous systems of irrigation especially in semi-arid areas and regions of periodic rainfall.

The industrial revolution, after the late 18th century, swelled the population of towns and cities and increasingly forced agriculture into greater integration with general economic and financial patterns.

The era of mechanized agriculture began with the invention of such farm machines as the reaper, cultivator, thresher, combine harvesters and tractors, which continued to appear over; the years leading to a new type of large scale agriculture. Modern science has also revolutionized food processing.

Breeding programmes have developed highly specialized animal, plant and poultry varieties thus increasing production efficiency greatly. All over the world, agricultural colleges and government agen- cies attempt to increase output by disseminating knowledge of improved agricultural practices through the release of new plant and animal types and by continuous intensive research into basic and applied scientific principles relating to agricultural production and economics.

History of agriculture

Excavations, legends and remote sensing tests reveal that agriculture is 10,000 years old. Women by their intrinsic insight first observed that plants come up from seeds. Men concentrated on hunting and gathering (Paleolithic and Neolithic periods) during that time. Women were the pioneers for cultivating useful plants from the wild flora. They dug out edible roots and rhizomes and buried the small ones for subsequent harvests. They used animal meat as main food and their skin for clothing.

Shifting Cultivation

A primitive form of agriculture in which people working with the crudest of tools, cut down a part of the forest, burnt the underneath growth and started new garden sites. After few years, when these plots lost their fertility or became heavily infested with weeds or soil-borne pests, they shifted to a new site. In India, shifting cultivation existed in different states, with different names as *jhum* cultivation in Assam, *podu* in Andhra Pradesh and Orissa, *kumari* in Western Ghats, *walra* in south east Rajasthan, *penda bewar* in Madhya Pradesh and *slash and burn* in Bihar.

Subsidiary Farming

Rudimentary system of settled farming, which includes cultivation, gathering and hunting. People in groups started settling down near a stream or river as permanent village sites and started cultivating in the same land more continuously, however the tools, crops and cropping methods were primitive.

Subsistence Farming

Advanced form of primitive agriculture *i.e.*, agriculture is considered as a way of life based on the principle of “Grow it and eat it” instead of growing crops on a commercial basis. Hence, it is referred as raising the crops only for family needs.

Mixed Farming

It is the farming comprising of crop and animal components. Field crop-grass husbandry (same field was used both for cropping and later grazing) was common. It is a stage changing from food gathering to food growing.

Advanced Farming

Advanced farming practices includes selection of crops and varieties, seed selection, green manuring with legumes, crop rotation, use of animal and crop refuse as manures, irrigation, pasture management, rearing of milch animals, bullocks, sheep and goat for wool and meat, rearing of birds by stall feeding etc.

Scientific Agriculture (19th Century)

During 18th century, modern agriculture was started with crop sequence, organic recycling, introduction of exotic crops and animals, use of farm implements in agriculture etc. During 19th century, research and development (R&D) in fundamental and basic sciences were brought under applied aspects of agriculture. Agriculture took the shape of a teaching science. Laboratories, farms, research stations, research centres, institutes for research, teaching and extension (training and demonstration) were developed. Books, journals, popular and scientific articles, literatures were introduced. New media, and audio-visual aids were developed to disseminate new research findings and information to the rural masses.

Present Day Agriculture (21st Century)

Today agriculture is not merely production oriented but is becoming a business consisting of various enterprises like livestock (dairy), poultry, fishery, piggery, sericulture, apiary, plantation cropping etc.

According to World Bank projections, the world population could reach a stationary level of just under 10 billion by around the end of 21 century, compared with 6.2 billions during 2000 A.D. Significance of these projections is faster growth in population than in food requirements. Almost all the population increase (95%) takes place in the present day developing countries, which have low per capita consumption levels. Simple lesson from projection is that world

demand could increase by 50 per cent in the next 20 years, would more than double again in the first half of the next century.

Agronomy

The Agronomy is derived from Greek words “Agros” meaning field and “nomos” meaning to “manage”

Agronomy is a branch of agricultural science which deals with principles and practices of soil, water and crop management.

Agronomy deals with methods which provide favourable environment to the crop for higher productivity.

Importance of basic sciences for development of Agriculture science

Basic science is the study of basic principles and fundamentals of the respective subject.

Applied science is the study in which the basic principles and fundamentals of respective field.

Agricultural sciences are essentially applied sciences and are dependent on basic sciences of Botany, Physiology, Bio chemistry, ecology, zoology, chemistry, physics, mathematics, economics etc.

For example

1. Knowledge of Botany is helpful in plant breeding and plant genetics and is making possible for evolution of different varieties in crops suitable to particular agro-climatic condition.
2. The knowledge of zoology (basic science of entomology) is helping the farmer to identify the insect pests which are responsible for damage to agricultural produce.
3. Soil chemistry helps in understanding the plant nutrient status in the soil and the deficiency symptoms in plants.
4. physics helps in understanding the weather phenomena and soil conditions
5. Mathematics is helpful in agricultural research and experimentation through statistics and Agricultural economics.
6. Study of economics is helpful in estimating the costs and returns and existing conditions of farmers in villages for effecting the improvements.

Without basic science there can be no development in applied science. In the field of Agriculture basic and applied sciences are interrelated to each other.

Scope of Agronomy

Agronomy is a dynamic discipline with the advancement of knowledge and better understanding of plant and environment, agricultural practices are modified and new practices developed for high productivity, for example availability of chemical fertilizer has necessitated the generation of knowledge on the method, quantity and time of application of fertilizers. Similarly availability of herbicides for the control of weeds has led to development of knowledge about selectivity, time and method of application of herbicides. To overcome the problems different management practices are developed.

Population pressure is increasing but area under cultivation is static, therefore more number of crops have to be grown on the same piece of land to increase the yield. As a result, intensive cropping has come into practice.

New technology has to be developed to overcome the effect of moisture stress under dryland conditions. As new varieties of crops with high yield potential become available package of practices have to be developed to exploit their full potential.

Restoration of soil fertility, preparation of good seed bed, use of proper seed rates, correct dates of sowing for each improved variety, proper conservation and management of soil moisture and proper control of weeds are agronomic practices to make our limited land and water resources more productive.

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. Soil physical, chemical and biological properties have to be understood thoroughly to effect modification of soil environment. Similarly it is necessary to understand the physiology of crops to meet their requirements. Advances in economic analysis helped in production of crops economically.

Agronomist aims to obtain maximum production at minimum cost. He exploits the knowledge developed by basic and applied science for higher crop production. Whatever may be the research findings of other scientists. Agronomist has to test their suitability in the field and accept them finally and also judge the reactions of farming community. He is a key person with working knowledge of all agricultural disciplines and coordinator of different subject matter specialists.

Tillage

Tillage and tilth – Objectives of tillage – characteristics of ideal seed bed – effect of tillage on soil properties.

Tillage: Tillage is as old as Agriculture, Primitive man used to disturb the soil for placing seed. *Jethro Tull* is considered as '**Father of Tillage**' Who Written '**Horse hoeing Husbandry**' book.

After the harvest of crop the soil becomes hard and compact because of:

1. Beating action of rain drops.
2. Irrigation and subsequent drying
3. Movement of implements and labourers.

Tillage:

Tillage consists of breaking the hard compact surface of soil to a certain depth and other operations that are followed for plant growth.

It is the physical manipulation of soil with tools and implements to result in good tilth for better germination and subsequent growth of crops.

Objectives of Tillage:

11. To facilitate adequate soil aggregation for gaseous exchange in the seed and root zone.
12. Adequate seed-soil contact to permit water flow to seed and seedling roots.
13. A non crusted soil to permit seedling emergence.
14. To increase infiltration rate.
15. To produce a satisfactory seed bed for good germination and good crop growth.
16. A low density soil that permits root elongation and proliferation.
17. To create an environment that provides adequate light to the seedlings (weed free environment)
18. To create pest and pathogen free environment
19. To mix the applied manures and fertilizers with the soil.
20. To remove the hard pan, if any to increase the soil depth for water absorption.

Effects of Tillage on soil physical properties:

1. Soil Structure: Arrangements of soil particles with crumbly and granular nature is considered good. Best size of soil aggregate for good growth of crop is (1-5mm) smaller aggregates may clog soil pores and larger ones may have large pore space.

Tillage improves soil structure when done at optimum soil moisture level. Tilling a soil when it is too wet spoils the structure. Ploughing a dry soil is difficult and will not help in improving structure.

2. Soil texture: Relative proportion of different soil particles namely sand, silt and clay.

Coarse sand - 2.0 - 0.2mm.

Fine sand - 0.2 - 0.02mm.

Silt - 0.02 - 0.002mm.

Clay - <0.002mm.

Tillage has no effect on soil texture.

3. Pore space: When a field is ploughed the soil particles are loosely arranged 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 soil.

4. Bulk Density: (B.D) When the soil is loosened, the soil volume increase without any affect on weight. BD of Clay soils is low (1.05 m³ and that of sandy soils is high (1.25 – 1.30 m³) and Bulk density of tilled soil is less than that of untilled soil. Particle density is always more than BD.

5. Particle density: Particle density is not altered by tillage.

6. 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.

Tilth: It is the physical condition of soil resulting from tillage.

Characteristics of good tilth

1. A soil should be mellow, friable, crumbly and adequately aerated.

2. A soil in good tilth is porous. Capillary and non capillary pores are equal. This facilitates free movement of air and water.

i. Higher percent of larger aggregates (more than 5 mm in diameter) are necessary for irrigated agriculture, while higher percentage of smaller aggregates (1 to 2 mm diameter) are desirable for dry land agriculture.

ii. Tilth can be coarse or fine. For sandy soils fine kind of tilth is required and for heavy black soils rough cloddy conditions or coarse tilth is enough.

iii. With very fine tilth the surface gets caked up when it dries after a rain. because of this the soil is unable to absorb rain water and it results in runoff losses.

Types of tillage – preparatory tillage – factors affecting preparatory cultivation, after cultivation, puddling

Tillage operations are grouped into two types based on the time at which they are carried out.

3. Preparatory cultivation – carried before sowing of crops
 4. Primary tillage- ploughing
 5. Secondary tillage –harrowing
 6. Seed bed preparation
4. After cultivation – After sowing of the crop

Factors influencing preparatory tillage:

1. The previous crop grown: Stubble of previous crop influence the tillage (Redgram, cotton stubbles are very deep rooted and require deep tillage to remove them)

2. The crop to be grown: Crops like sorghum can be grown with rough tilth for very small seeded. Crops like tobacco, chilles etc fine tilth is required. Deep tillage is required for crops like tuber crops and sugarcane.

3. Types of soil: Clay soil can be ploughed only with in a narrow range of soil moisture and the power or drought required is high. Light textured soils can be ploughed under a wide range of soil moisture and require less drought.

4. Climate: Deep tillage is not permitted in shallow soils in low rainfall areas as it leads to rapid drying and loss of stored soil moisture. Deep cultivation is possible in high rainfall areas.

5. Type of farming: Intensive cropping requires intensive tillage.

Preparatory Cultivation:

- Primary tillage or ploughing:

Ploughing is the opening of compacted soil with the help of different ploughs. Ploughing is done mainly to open the hard soil. In addition, ploughing should ensure inversion of soil, uprooting of weeds and stubbles.

- Optimum time for ploughing

The correct time for ploughing depends on soil moisture. When soil is dry, it is difficult to open the soil. More energy is used and large sized clods will result.

When the soil is ploughed under wet condition, the soil sticks to the plough, the soil below 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 50 -75% of available soil moisture.

- Depth of ploughing:

Depth of ploughing mainly depends on the effective root zone depth of the crop. Generally crops with tap root require greater depth of ploughing while fibrous shallow rooted crops require shallow ploughing.

- Number of ploughings:

The number of ploughings necessary to obtain good tilth depends on the soil type, weed problem and crop residues on soil surface. In heavy soils more number of ploughings are necessary, the range is 3-5 ploughings. Light soils require 1-3 ploughings to obtain proper tilth of the soil. When weed growth and plant residues are higher, more number of ploughings are necessary.

- Selection of ploughs:

Depending on the purpose, soil condition and nature of weed problem, different ploughs are used.

Ploughs

Purpose

- | | |
|---------------------------------------|------------------------------|
| 5. Mould board plough (Tractor drawn) | Deep ploughing and inversion |
|---------------------------------------|------------------------------|

- | | |
|--------------------------------------|---|
| 6. Mould board plough (Animal drawn) | Incorporation of manures , fertilizers and plant residues |
| 7. Disc plough | Cutting and creeping or spreading grass and inversion |
| 8. Country plough | Multipurpose |

Types of primary tillage:

Depending on the purpose and necessity, different types of tillage are carried out. They are deep ploughing, sub soiling and year round tillage.

- Deep tillage (25-30 cm and in western countries 50cm in rainfed and 70 cm in irrigated)

Deep ploughing turns out large sized clods, which are backed by 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. Summer ploughing kills pests. Deep tillage for long duration crops is advantageous.

- Sub soiling:

Subsoiling is breaking the hardpan without inversion and with less disturbance of top soil.

- Year round tillage:

Tillage operations carried throughout the year are known as year round tillage.

Secondary tillage:

Lighter or finer operations performed on the soil after primary tillage is known as secondary tillage. In this harrowing is done to crush the clods and uproot the remaining weeds and stubbles. Field is made ready for sowing after ploughing by harrowing and planking. Generally, sowing operations are also included in secondary tillage.

Layout of seed bed and sowing:

After seed bed preparation, the field is laid out properly for irrigation and sowing or planting. After field preparation sowing is done with seed drills/ dropping behind country plough. The seeds are covered by running blade harrow to a shallow depth, followed by planking so as to level and impart necessary compaction.

After cultivation:

It includes intercultivation and various other special operations carried out in a standing crop. They include.

1. Thinning and Gap filling.

2. Rogueing in crops for seed purpose.
 3. Earthing up in crops, sugarcane, banana, and groundnut.
 4. Cropping in banana
 5. Desuckering oper in banana
 6. Wrapping and propping in sugarcane
 7. Nipping in castor
 8. Topping, Trimming and desuk in tobaccor basal leaves are removed
 9. Defoliation in cotton
 10. Hand pollination in sunflower.
- Fertilizer app in irrigation also comes under after cultivation.

- **Intercultivation:**

Intercultivation starts from very early stage of crop i.e., two to three weeks from sowing. Short duration crops require two-three intercultivation while long duration crop require 3-4 weeks.

Tillage operations done between the crop rows with the objectives of

- Destroying the weeds
- To form a soil mulch
- To prevent cracking of soil
- To prevent crust formation

Tillage implements:

Primary tillage implements- Wooden plough , Soil turning plough (MB plough, disc plough, reversible or one way plough), Special ploughs (subsoil plough, chisel plough, ridge plough, rotary plough /hoes, basin lister).

Secondary tillage implements (Tractor drawn cultivator, sweep cultivator, harrows, disc harrow, blade harrow and big blade harrow).

Implements for sowing (plough, seed drill, ferti-cum – seed drill) and mechanical seed drill) and inter cultivation (Different sizes of blade harrows of different sizes)

Concepts of tillage –Minimum tillage, Zero tillage, conservation tillage and their advantages and limitations.

Modern concepts of tillage:

- **Conventional tillage:**

In conventional tillage, the soil is opened with mould board plough for primary tillage. The soil mass is broken in to loose system of clods of mixed sizes. Subsequently a fine seedbed is prepared by secondary tillage in which crushing of clods, repacking, incorporation of plant residues, fertilizers, smoothing of soil surface etc. are done.

- **Minimum tillage:**

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

Tillage can be reduced two ways-by omitting operations which donot give much benefit when compared to the cost and by combining agricultural operations like seeding and fertilizer application.

Advantages:

- a) Improved soil condition due to decomposition of plant residues in situ,
- b) Higher infiltration caused by the vegetation present on the soil and channel formed by decomposition of dead roots,
- c) Less resistant to root growth due to improved structure
- d) Less soil compaction due to reduced movement of heavy tillage vehicles and less erosion compared to conventional tillage.

Dis advantages:

- e) Germination is lower with minimum tillage
- f) Nodulation is less in certain legume crops –peas and broad beans
- g) Sowing operations are difficult with ordinary equipment
- h) Continuous use of herbicides cause pollution problems and dominance of perennial problem weeds

Minimum tillage can be practiced by different methods

- a) Row zone tillage; after primary tillage with MB plough, secondary tillage operations like discing and harrowing are reduced. The secondary tillage is done in row zone only.
- b) Plough plant tillage; After the soil is ploughed, a special planter is used and is run over the field, the row zone is pulverized and seeds are sown.
- c) Wheel track planting: Ploughing is done as usual. Tractor is used for sowing and the wheels of the tractor pulverize the row zone.

● **Zero Tillage:**

Zero tillage is the extreme form of minimum tillage. Primary tillage is completely avoided and secondary tillage is restricted to seed bed preparation in the row zone only. It is also known as no till and is resorted where soils are subjected to wind and water erosion, trimming of tillage operations is too difficult and requirements of energy and labour for tillage are too high.

Before sowing, the vegetation present has to be destroyed for which broad spectrum, nonselective herbicides with relatively short residual effect (Paraquat, Glyphosate etc.) are used.

Advantages:

- 1) Soils are homogenous in structure with more no. of earth worms.
- 2) Organic matter content increased due to less mineralization.
- 3) Surface runoff is reduced due to presence of mulch. Several operations are performed by using only one implement. In these weeds are controlled by spraying of herbicides.

Disadvantages:

- 1) Higher nitrogen is too applied due to slower mineralization of org. matter.
- 2) Large population of perennial weeds appears.

3) Buildup of pests is more.

- **Stubble mulch tillage:** A new approach for keeping soil protected at all times whether by growing crop or by crop residues left on the surface during fallow periods. It is known as stubble mulch tillage or stubble mulch farming. It is year round system of managing plant residue with implements that undercut residue, loosen the soil and kill weeds.

it presents the practical problem as the residues left on the surface interfere with seedbed preparation & sowing operations. The traditional tillage and sowing equipment is not suitable under these conditions.

Modern methods of tillage are not practiced in Indian condition because:

- a) Left over residue is a valuable fodder and fuel.
- b) Limited use of heavy machinery & therefore problem of soil compaction is rare.

Puddling

Rice growth and yield are higher when grown under submerged conditions. Maintaining standing water throughout the crop period is not possible without puddling. Puddling is ploughing the land with standing water so as to create an impervious layer below the surface to reduce deep percolation losses of water to provide soft seedbed for planting rice.

Puddling operation consists of ploughing repeatedly in standing water until the soil becomes soft and muddy. Initially, 5cm to 10 cm of water is applied depending on the water status of the soil to bring it to saturation and above and the first ploughing is carried out.

After 3 to 4 days, another 5 cm of water is applied and later after 2 to 3 days second ploughing is carried out. By this operation, most of the clods are crushed and majority of the weeds are incorporated. Within 3 to 4 days, another 5 cm of water is given and third ploughing is done in both the directions. The third ploughing can be done either with a wetland plough or with a wetland puddler. Planking or leveling board is run to level the field. To know whether puddling is thorough or not, a handful of mud is taken into the hand and pressed. If it flows freely through fingers and if there are no hard lumps, puddling is considered to be thorough. Unlike in other tillage operations, puddling aims at destroying soil structure. The individual soil particles viz., sand, silt and clay are separated during puddling operation. The soil layer with high moisture below the plough sole is compacted due to the weight of the plough. The soil particles separated during puddling settle later. The sand particles reach the bottom, over which silt particles settle and finally clay particles fill the pores thus making impervious layer over the compacted soil.

Puddling is done with several implements depending on the availability of equipment and nature of the land. Soils with bulk density less than 1.0 are considered as problem soils as puddling with animal-drawn implements is difficult. The feet of the animals sink very deep during puddling. Under such a situation, puddling is done with spades by manual labour. Most of the farmers use wetland plough or worn out dryland plough or mouldboard plough. Wetland puddler consists of a series of blades attached to a beam at an angle. When it is worked, the soil is churned and puddling operation is completed quickly compared to the country plough. Generally green manure is applied to rice field which is incorporated by green manure trampler. Tractor drawn implements can be used for puddling by attaching cage wheels to prevent sinking.

Seeds and Sowing

Seed:

Seed is a unit of reproduction of a flowering plant capable of developing in to another such plant.

Seed is any material used for planting and propagation whether it is in the form of seed (grain) of food, fodder, fiber or vegetable crop or seedlings, tubers, bulbs, rhizomes, roots, cuttings, grafts or other vegetative propagated material.

Seed material:

3. Seeds –Grains used for sowing
4. Vegetative propegules –Stem cuttings, tubers and rhizomes
Stem cuttings --- Sugar cane, rose
Rooted slips --- Fodder crops
Tubers -Potato
Rhizomes—Turmeric

Characteristics of good seed:

7. Purity
Free from rogues (off types), other crop seeds, weed seeds and inert material.
8. Fully matured and well developed
9. Free from storage pests and seed borne diseases
10. Free from dormancy (dormancy problems are seen in ground nut, rice, sunflower)
11. Viable (Soybean loses viability quickly)
12. High percentage of germination (98-99%),germination percent of many grasses is 20-25%

Seed germination

The resumption of growth by embryo and development of a young seedling from the seed.

Germination is an activation of dormant embryo to give rise to radical (root development) and plumule (stem development).Germination is the awakening of the dormant embryo.

The process by which the dormant embryo wakes up and begins to grow is known as Germination.

Seedling Emergence means actually coming above and out of the soil surface by the seedling.

Changes during germination:

5. Swelling of seed due to imbibition of water by osmosis.
6. Initiation of physiological activities such as respiration & secretion of enzyme.
7. Digestion of stored food by enzymes.
8. Translocation & assimilation of soluble food.

Seed treatment:

The seeds are subjected to special treatment for different purposes. They are for convenience in sowing, enhancing germination, improvement of nutrition and control of pests. The seed treatment is mainly done for control of diseases and insect pests. Eg. Mancozeb, Carbendazim, Captan, Thioram etc.

Reasons for poor establishment

5. Use of poor quality seed with low germination percentage
6. Improper seed bed preparation
7. Low moisture, low temperature at the time of sowing
8. Salinity and alkalinity of soil.

Factors affecting the germination

External Factors

1. Moisture: It enables the resumption of physiological activities, swelling of seed due to absorption of moisture & causes bursting of seed coat & softening the tissue due to which embryo awakes & resumes its growth.

2. Temperature: A suitable temperature is necessary for proper germination. Germination does not take place beyond certain minimum & maximum temperature i.e. 0°C & above 50°C. Optimum temperature range for satisfactory germination of seed is 25 to 30°C.

3. Oxygen: It is essential during germination for respiration & other physiological activities.

4. Light: It is not considered as essential for germination & it takes place without light. The seedlings grow more vigorously during darkness rather in light. However, for survival of germinating seedling, light is quite essential.

5. Substratum: It is the medium used for germinating seeds.

Internal Factors

Food and auxins: An Embryo feed on the stored food material until young seedlings prepares its own food. Auxins are the growth promoters, hence quite essential during the germination.

Viability: All seeds remain viable for certain definite period of time and thereafter embryo becomes dead. It depends on maturity of seed, storage conditions & vigour of parents and type of species. Generally, it is for 3-5 years and they remain for more than 200 years also as in lotus.

Dormancy:

Is a period in an organism's life cycle when growth, development are temporarily stopped.

It is the failure of mature viable seed to germinate under favorable condition of moisture. Many seeds do not germinate immediately after their harvest, they require rest period for certain physiological activities.

Breaking Dormancy:

Scarification:

The process of breaking, scratching, mechanically altering or softening the seed coats to make them permeable to water and gases is known as scarification. Generally it is done by pounding.

Scarified seeds are susceptible to pathogenic organisms; hence, scarification is done at the time of sowing or few days before sowing.

Stratification:

Placing of seeds close together in layers in moist sand or peat to preserve them or to help them germinate. Seed layer altered with layers of moist sand or appropriate material to store at low temperature. E.g.: Mustard & Groundnut.

Hot water treatment:

Seeds are dropped in water of 75 to 100° C. The seed is soaked gradually cooling water for 12 to 24 hrs. Following this, the un swollen seeds are separated from the swollen ones and treated gain. The seeds are to be planted within a few days after hot water treatment.

Acid treatment:

Acid scarification is done usually with the concentrated sulphuric acid. Dry seeds are placed in containers (glass, earthen ware or wood but not plastic or metal) and concentrated sulphuric acid twice the volume of seed is added. The mixture of seed and acid are stirred continuously and periodically for uniform treatment for 10 minutes to six hours or more depending on seed coat of plant species. The treatment is completed when thickness of seed is reduced. At the end of the treatment period, the acid is poured off and seeds are washed to remove the acid. Seeds are placed in large quantity of water with a small amount of baking soda (sodium bicarbonate) to neutralize any adhering acid. The extra acid can be removed by washing the seeds in running water for 10 minutes. The acid treated seeds can be sown immediately or dried and stored for subsequent use.

Leaching:

The purpose of leaching is to remove germination inhibitors by soaking or placing them in frequent changes of water for 12 to 24 hrs.

Hormonal treatment:

Treating the seeds with gibberilic acid (GA₃) breaks the dormancy of seeds caused by physiological reasons. The concentration is 500ppm and duration of soaking is 12 hrs. Similarly cytokenins and ethylene are also used to break dormancy.

Rhizobium treatment

In case of legumes – specific Rhizobium cultures are available depending upon the crop. These are helpful in fixing atmospheric – N. use 125g. jaggery in 1 litre of water – boil – cool – add Rhizobium culture (500g) and then thoroughly mix with seed (for 1 hour) and shade dry before sowing (R.japonicum, R.melitotus. are some examples)

Extension of viability:

Simple hydration midway during storage followed by immediate drying back helps in extending seed viability. However, soaking and drying treatment does not extend storage life of harvest fresh seed.

Methods of sowing

3. Direct sowing
 - c) Broadcast sowing
 - d) Line sowing
 - iii) Drilling
 - iv) Dibbling
4. Transplanting

1. Broadcasting:

In broadcasting method, seeds are spread uniformly over well prepared land and are covered by ploughing or planking. It is the most primitive method of sowing. Seeds fall at shallow depth and emerge early if moisture is available and later with subsequent rains if moisture is not available. Seeds that fall deep in the soil may not germinate and even if they do germinate may emerge from the soil after considerable time.

Advantages:

- Quickest & cheapest method
- Skilled labour is not required.
- Implement is not required.

Disadvantages:

- Seed requirement is more
- Crop stand is not uniform.
- Spacing is not maintained within rows & lines.

2. Line sowing

Sowing in lines at definite spacing, depth and covered with soil and compacted. To overcome the problems of broadcast sowing, drilling the seeds in lines has come into practice. Drilling or line sowing results in uniform crop stand. Seed rate can be considerably reduced by drilling.

In this method, sowing implements are used for placing the seeds into the soil. Both animal drawn and power operated (seed drills) implements are available. Seeds are drilled continuously or at regular intervals in rows. In this method, depth of sowing can be maintained and fertilizer can also be applied simultaneously. Crops like Jowar, wheat Bajara, etc. are sown by this method.

Advantages:

- Seeds are placed at proper & uniform depths,
- Along the rows, intercultivation can be done,
- Uniform row to row spacing is maintained,

- Seed requirement is less than ‘broad casting’

Disadvantages:

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

3.Dibbling:

Dibbling is the process of placing seeds in holes made in seedbed and covering them. The equipment used for dibbling is called dibbler. This method is time consuming process and is not suitable for small seeds. This method is followed in crops like Groundnut, Castor, and Hybrid Cotton, etc. which are having bold size and high value.

Advantages:

- Spacing between rows & plants is maintained,
- Seeds can be dibbled at desired depth in the moisture zone,
- Optimum plant population can be maintained,
- Seed requirement is less than other method,

Disadvantages:

- Laborious & time consuming method,
- Only high value & bold seeds are sown,
- Require strict supervision.

4.Putting seeds behind the plough:

It is dropping of seeds behind the plough in the furrow with the help of manual labour by hand. This method is followed for crops like gram in some areas for better utilization of soil moisture.

Planting:

When individual seeds or seed material is placed in the soil by manual labour or by machine, it is called planting. Planting is done for crops like cotton, maize, potato, sugarcane etc.

Transplanting:

Seeds are sown in small area called nursery and all the care is taken to raise the seedlings. After seedlings grow to a certain stage, they are pulled out from nursery and transplanted in the main field. The advantages of transplanting are saving in irrigation water, good stand establishment and increase intensity of cropping

Types of Sowing

Dry sowing:

Dry sowing is adopted in black soils where sowing operation are difficult to carryout once rains commence. Field is prepared with summer rains and seeds are sown in dry soil around 7 to 10 days before the anticipated rains. The seeds germinate after the receipt of rains. By this method, rainfall is efficiently utilized.

Wet sowing:

Wet sowing is the most common method of sowing of crops. The minimum amount of rainfall necessary for taking up sowing is 20 mm. Two to three days after rain, sowing can be taken and continued for two to three days.

Time of sowing:

1. Sowing very early in the season may not be advantageous.
Eg: sowing rainfed groundnut early may result in failure of crop if there is prolonged dry spell from the 2nd week of June to 2nd week of July.
2. Delayed sowing invariably reduces yields
 - a. Eg: rainfed sorghum yields are reduced due to delay in sowing beyond June season – sorghum sown late is subjected to severe attack of shoot borer.
 - b. Eg: In rainfed groundnut sowing beyond July reduced the yields of all varieties at tirupathi.
3. Advancing sowing of Rabi sorghum. From November-September to October.
Increase the yields considerably as more moisture would be available for early sown crop.
4. Sowing the crop at optimum time.

Increases yields due to suitable environment at all the growth stages of the crop.

1. Optimum time of sowing for Kharif crop – June or July.
2. Optimum time for Rabi crop - last week of October to first week of November.
3. Summer crop - First fortnight of January.

Depth of Sowing:

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 uniformity in maturity.

The thumb rule is to sow seeds to a depth approximately 3-4 times their diameter.

The optimum depth of sowing for most of field crops ranges between 3-5 cm. Shallow depth of sowing of 3-5 cm is enough for small seeds like sesamum finger millet and pearl millet.

Very small seeds like tobacco are placed at a depth of ICM. Bold seeded crops like castor, groundnut, cotton, and maize etc. 6-7 cm.

Seed rate:

1. Tobacco - 30g per hectore
2. Mustard - 2-3 Kg/ha
3. Pulses - 10-12Kg/ha
4. Soybean - 80-100 Kg/ha
5. Groundnut - 100-120 Kg/ha
6. Forage grasses (rooted slips) - 2-3 tons/ha
7. Potato tubers - 5-7 tons/ha
8. Sugarcane (setts) - 7 tons/ha

Crop density and geometry

Crop density and geometry- Crop stand establishment, factors affecting optimum stand establishment.

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.

In crops grown on stored soil moisture under rainfed conditions, population should not be high to deplete most of the moisture before crop matures and not low to leave moisture is utilized.

Under conditions of sufficient soil moisture and nutrients, higher population is necessary to utilize other growth factors efficiently. Once soil moisture and nutrients are not limiting, yield of crop is limited by solar radiation. The level of plant population should be such that maximum solar radiation is intercepted.

Yield of individual plants and community:

The full yield potential of individual plant is achieved when sown at wider spacing. When sown densely, competition among plants is more for growth factors resulting in reduction in size and yield of the plant.

Competition – types of competition, plant population, intra and inter plant growth and yield, optimum plant density and planting pattern.

What is competition?

Competition is the struggle between individuals within a population for available resources, when the level of resources is below the combined need of the members of the population.

How does competition occur in plants?

Crop plants are not grown in isolation but in closely spaced populations. In the early phase of growth, individual plants are small and widely spaced and do not interfere with each other. At some point, as the plants grow, they start to interfere with their neighbours and competition begins. Two plants, no matter how close, do not compete with each other so long as the growth

resources are in excess of the needs of both. When the immediate supply of a single necessary factor falls below the combined demand of the two plants, competition begins.

Types of competition

1. Competition for nutrients: Nutrient uptake increase with increase plant population. Higher population under low fertility conditions leads to development of nutrient deficiency symptoms because of competition.

2. Competition for light: Competition for light may occur whenever one plant casts a shadow on another or within a plant when one leaf shades another leaf. In early plant growth stages, there will be little mutual shading and even at relatively low light intensities the plant will be able to photosynthesize with full efficiency. As the plants develop, mutual shading increase and light becomes a limiting factor.

3. Competition for water: The success of any plant in community for water depends on the rate and competitiveness with which it can make use of the soil water supply.

4. Intra-specific and inter-specific competition: In populations of similar genotypes, in the absence of weeds, the competition is intra-specific (within species), where different species of crops are grown, in mixtures and where weeds present, the competition is inter-specific (between species).

Plant population and growth

- High plant density brings out certain modifications in the growth of plants.
- Plant height increases with increase in plant population due to competition for light.
- Sometimes it may happen that moderate increase in plant population may not increase but decrease plant height due to competition for water and nutrients but not for light.
- Leaf orientation is also altered due to population pressure. The leaves are erect narrow and are arranged at longer vertical intervals under high plant densities. This is a desirable architecture.

Plant population and yield

- Decrease in yield of individual plant at high plant density is due to the reduction in the no. of ears or panicles.
- Ex: - Redgram produces about 20 pods per plant at 3.33 lakh plants/ha (30x10cm) while it produces more than 100 pods per plant at 50,000 plants/ha (80x25cm).
- Under very high population levels plant become barren, hence optimum plant population is necessary to obtain maximum yield.

Optimum plant population

Optimum plant population for any crop varies considerably due to environment under which it is grown. It is not possible to recommend a generalized plant population since the crop is grown in different seasons with different management practices.

E.g.:- Redgram plants sown as winter crop will have half the size of those grown in monsoon season. Optimum plant population is 55,000 plants/ha. For monsoon season crop of redgram and this is increased to 3.33 lakh plants/ha for winter crop; as low temperature retards the rate of growth, higher population is established for quicker ground cover.

In sorghum, when the climate is favourable during pre-anthesis period, the optimum population is two lakh plants/ha and when it is not congenial for growth during pre-anthesis, it is four lakh plants/ha.

Planting pattern

Planting pattern influences crop yield through its influence on light interception, rooting pattern and moisture extraction pattern. Different planting patterns are followed to suit different weed control practices and cropping systems.

Plant geometry refers to the shape of plant while crop geometry refers to the shape of space available for individual plants. Crop geometry is altered by changing inter and intra-row spacing.

Square planting

It is reasonable to expect that squares arrangement of plants will be more efficient in the utilization of light, water and nutrients available to the individuals than in a rectangular arrangement. In wheat, decreasing inter-row spacing below the standard 15-12 cm i.e., reducing rectangularity, generally increases yield slightly. In crops like Tobacco, intercultivation in both directions is possible in square planting and helps in effective control of weeds. However, square planting is not advantageous in all crops. Groundnut sown with a spacing of 30x10cm (3.33 lakh/ha) gave higher pod yield than with same amount of population in square planting. Pod yield is reduced either by increasing rectangularity or approaching towards square planting.

Rectangular planting

Sowing the crop with seed drill is the standard practice. Wider inter-row spacing and closer intra-row spacing is very common for most of the crops, thus attaining rectangularity. This rectangular arrangement is adopted mainly to facilitate intercultivation. Sometimes only inter-row spacing is maintained and intra-row spacing is not followed strictly and seeds are sown closely as solid rows.

Miscellaneous planting arrangements

Crops are sown with seed drills in two directions to accommodate more number of plants and mainly to reduce weed population. Crops like rice, finger millet are transplanted at the rate of 2-3 seedlings per hill. Transplanting is done either in rows or randomly. Skipping of every alternate row is skipped, and the population is adjusted by decreasing intra-row spacing, it is known as paired row planting. It is generally restored to introduce an intercrop.

Crop nutrition- essential plant nutrients-primary, secondary and micro nutrients _ Nutrient uptake –Nutrient use efficiency.

The term mineral nutrient is generally used to refer to an inorganic ion obtained from soil required for plant growth. The process of absorption, translocation and assimilation of nutrients by the plants is known as mineral nutrition.

Essential elements:

Plants need 16 elements for their growth and completion of life cycle.

They are: Carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, zinc, copper, boron, molybdenum and chlorine.

In addition four more elements – sodium, cobalt, vanadium and silicon are absorbed by some plants for special purpose.

Criteria of essentiality:

Plant analysis indicates that plant body contains 30 to 60 elements. The presence of several elements in plant does not mean that all these are essential for plants.

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

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

Amount of nutrients:

Depending on the quantity of nutrients present in the plants, they can be grouped in to three- basic nutrients, macro nutrients and micro nutrients.

Basic nutrients: Carbon, hydrogen and oxygen which constitute 96 percent of total dry weight of plants. Among them carbon and oxygen constitute 45% each.

Macro nutrients: The nutrients required in large quantities are known as macro nutrients. They are N,P,K, Ca, Mg and S. Among these NPK are called primary nutrients and Ca, Mg and S are known as secondary nutrients. The latter are known as secondary nutrients as they are inadvertently applied to the soils through NPK fertilizers which contain these nutrients.

Micro nutrients: The nutrients which are required in small quantities are known as micro nutrients or trace elements. They are Fe, Zn, Cu, B, M, Mn and Cl. These elements are very efficient and minute quantities produce optimum effects. On the other hand, even a slight deficiency or excess is harmful to the plant.

Functions of nutrients in the plant:

The basic nutrient C, H and O are constituents of carbohydrates and several biochemical compounds.

Nitrogen is a constituent of proteins, hormones, vitamins, alkaloids, chlorophyll etc. Plant growth is adversely affected due to deficiency of nitrogen as it is a constituent of enzymes, chlorophyll and proteins.

Phosphorus is a constituent of sugar phosphates, nucleotides, nucleic acids, co-enzymes and phospholipids.

Potassium is not a constituent of any organic compound. However, it is required as a co – factor for 40 or more enzymes. It controls movement of stomata and maintains electroneutrality of plant cells.

Calcium is a constituent of cell wall as calcium pectate. It is required in hydrolysis of ATP and phospholipids.

Magnesium is a constituent of chlorophyll and is required in several enzymes involved in phosphate transfer.

Sulphur is a constituent of several amino acids and fatty acids.

As a constituent of various enzymes, iron plays the part of a vital catalyst in the plant. Consequently, it is a key element in various redox reaction of respiration,, photosynthesis and reduction of nitrates and sulphates.

Manganese is a constituent of several cation activated enzymes and essential for the formation of chlorophyll, reduction of nitrates and for respiration.

Copper and Zinc are involved in cation activated enzymes.

Boron helps in carbohydrate transport. It is necessary for germination of pollen, formation of flowers and fruits and for the absorption of cations.

Molybdenum is required for the assimilation of nitrates as well as for the fixation of atmospheric nitrogen.

Chlorine is involved in reaction reaction relating to oxygen evolution.

Soil fertility and productivity

Soil fertility and productivity –Soil organic matter and its maintenance.

Soil fertility: The inherent capacity of the soil to supply plant nutrients in adequate quantities and in suitable proportions is termed as soil fertility.

Soil productivity: Soil productivity refers to the capacity of a soil to produce crops

A productive soil must be fertile, but a fertile soil may not be productive.

Soil productivity is influenced by:

1. Soil fertility
2. Physical condition of the soil (depth, structure, texture)
3. Activity of soil micro organisms
4. Soil moisture
5. Inhibitory factors like acidity, alkalinity, salinity, water logging etc.

Nutrients are lost from the soil in the following ways

6. Removal by crop : Rice crop removes 90-100kgN, 20-25 kg P and 130-150 kg K per ha.
7. Removal by weeds
8. Leaching losses (more in sandy soils)
9. Loss through erosion
10. Loss in gaseous form (N-by denitrification and Volatilization)

Hence, it is necessary to add nutrients periodically to the soil.

Soil fertility	Soil productivity
5. It is considered as an Index of available nutrients to plants	It is a broader term used to indicate yield of crops
6. It is one of the factors for crop production. The other factors are water supply, slope of the land, depth of water table etc.	It is the interaction of all the factors that determine the magnitude of yield.
7. It can be analysed in the laboratory	It can be assessed in the field under particular climatic conditions
8. It is the potential status of the soil	It is the resultant of various factors influencing soil management to produce crops

Soil fertility can be maintained by

- c) Cultural practices:
Fallowing, Crop rotation, Mixed cropping
- d) By addition of materials
 7. Organic manures (bulky and concentrated)
 8. Inorganic fertilizers
 9. Bio fertilizers
 10. Soil amendments –lime, gypsum, paddy husk, ground nut shells etc.
 11. Green manuring or green leaf manuring
 12. Crop residues (Stubbles etc.)

Soil organic matter:

Any material of plant or animal origin found in the soil is known as organic matter.

Organic matter that is well decomposed and digested by many kinds of soil micro organisms and converted in to fairly stable amorphous, brown to black material in termed as humus.

Uses of organic matter:

9. Helps in aggregation of soil particles and improves the structure, permeability and water holding capacity and aeration.
10. It serves as a reservoir of plant nutrients.
11. Organic acids and CO₂ produced during decomposition helps to dissolve minerals like P,K and make them more available.
12. It helps in maintaining soil pH.
13. Leaching of certain cations ;like K,Ca, Mg, NH₄ is prevented because of its higher CEC.

14. It is the source of micro organisms, earth worms and other living things.
15. Helps to maintain soil temperature
16. Alkalinity is reduced

The rate of decomposition of organic matter is dependent on the activity of soil micro organisms, which in turn is dependent on

Soil moisture content, temperature, and aeration and C:N ration of the original material added.

Manures and fertilizers

Manures

Manures are plant and animal wastes that are used as sources of plant nutrients. They release nutrients after their decomposition.

Types of Manures

Bulky organic manures

FYM, Compost, Green manure

Concentrated

Oil seed *cakes*

Advantages of Bulky organic manures

1. They supply plant nutrients including micronutrients,
2. They improve soil physical properties like structure, water holding capacity etc.,
3. They increase the availability of nutrients,
4. Carbon dioxide released during decomposition acts as a CO₂ fertilizer, and
5. Plant parasitic nematodes and fungi are controlled to some extent by altering the balance of Micro organisms in the soil.

Farmyard Manure (FYM)

The decomposed mixture of dung and urine of farm animals along with litter and left over material from roughages or fodder fed to the cattle.

The FYM contains 0.5% N, 0.2% P₂O₅ and 0.5% K₂O and Urine contains 1.0% N and 1.35% K₂O. The N present in urine is mostly in the form of urea which is subjected to volatilization losses.

Sheep and Goat Manure

The dropping of sheep and goats contain higher nutrients than farm yard manure and compost. On an average, the manure contains 3% N, 1% P₂O₅ and 2% K₂O. It is applied to the field in two ways. The sweeping of sheep or goat sheds are placed in pits for decomposition and it is applied later to the field. The nutrients present in the urine are wasted in this method. The second method is sheep penning, wherein sheep and goats are allowed to stay overnight in the field and urine and fecal matter is added to the soil which is incorporated to a shallow depth by running blade harrow or cultivator.

Poultry Manure

The excreta of birds ferments very quickly. If left exposed, 50% of its nitrogen is lost within 30 days. The average nutrient content is 3.03% N, 2.63% P₂O₅ and 1.4% K₂O.

Night Soil

It is nothing but human excreta, both solid and liquid. It is richer in N, P and K than FYM and compost. On an average, night soil contains 5.5 % N, 4.0 % P₂O₅ and 2.0 % K₂O.

Sewage and sludge

In the modern system of sanitation adopted in cities and towns, home waste material is flushed out with water. The black muddy solid portion of the drain is called sludge and the liquid is called sewage. Both the components are separated and are given a preliminary fermentation and oxidation treatments to reduce bacterial contamination and offensive smell.

Concentrated organic manures

Concentrated organic manures have higher nutrient content than bulky organic manure. The important concentrated organic manures are oilcakes, blood meal, fish manure etc. These are also known as organic nitrogen fertilizer. Before their organic nitrogen is used by the crops, it is converted through bacterial action into readily usable ammonical nitrogen and nitrate nitrogen. These organic fertilizers are, therefore, relatively slow acting, but they supply available nitrogen for a longer period.

Oil-cakes

After oil is extracted from oilseeds, the remaining solid portion is dried as cake which can be used as manure.

The oil-cakes are of two types:

Edible oil-cakes which can be safely fed to livestock *e.g.* Groundnut cake, coconut cake etc., and

Non-edible oil-cakes which are not fit for feeding livestock *e.g.* Castor cake, neem cake, mahua cake etc. The nutrient range from 2 to 8 % in N, 1 to 3% in P₂O₅ and 1 to 2 % in K₂O.

Other Concentrated Organic Manures

Blood-meal when dried and powdered can be used as manure. The meat of dead animals is dried and converted into meat-meal which is a good source of nitrogen. Nutrient content of animal based concentrated organic manures range from 1 to 10% in N, 2-25% in P₂O₅ and 1 to 15% in K₂O.

Green manuring

It is a practice of ploughing in the green plant tissues grown in the field or adding green plants with tender twigs or leaves from outside and incorporating them into the soil for improving the physical structure as well as fertility of the soil. It can be defined as a practice of ploughing or turning into the soil, un decomposed green plant tissues for the purpose of improving the soil fertility.

The object of green manuring is to add an organic matter into the soil and thus, enrich it with 'N' which is most important and deficient nutrient.

Types of green manuring: There are two types of green manuring:

2. Green manuring in-situ: When green manure crops are grown in the field itself either as a pure crop or as intercrop with the main crop and buried in the same field, it is known as Green manuring In-situ. E.g.: Sannhemp, Dhaicha, Pillipesara, Shervi, Urd, Mung, Cowpea, Berseem, Senji, etc.

2. Green leaf manuring: It refers to turning into the soil green leaves and tender green twigs collected from shrubs and tress grown on bunds, waste lands and nearby forest area. E.g.: Glyricidia, wild Dhaicha, Karanj.

Stage of green manuring: A green manuring crop may be turned in at the flowering stage or just before the flowering. The majority of the G.M. crops require 6 to 8 weeks after sowing at which there is maximum green matter production and most succulent.

Advantages of green manuring:

- It adds organic matter to the soil and stimulates activity of soil micro-organisms.
- It improves the structure of the soil thereby improving the WHC, decreasing run-off and erosion caused by rain.
- The G.M. takes nutrients from lower layers of the soil and adds to the upper layer in which it is incorporated.
- It is a leguminous crop, it fixes 'N' from the atmosphere and adds to the soil for being used by succeeding crop. Generally, about 2/3 of the N is derived from the atmosphere and the rest from the soil.
- It increases the availability of certain plant nutrients like P₂O₅, Ca, Mg and Fe.

Disadvantages of green manuring:

- Under rain fed conditions, the germination and growth of succeeding crop may be affected due to depletion of moisture for the growth and decomposition of G.M.
- G.M. crop inclusive of decomposition period occupies the field least 75-80 days which means a loss of one crop.
- Incidence of pests and diseases may increases if the G.M. is not kept free from them.

Application of phosphatic fertilizers to G.M. crops (leguminous) helps to increase the yield, for rapid growth of Rhizobia and increase the 'P' availability to succeeding crop.

Stage of incorporation:

Best stage of incorporation is flowering stage. The plants used for green leafy manuring should be incorporated into soil before they mature or attain woody nature.

The success of green manuring depends on the correct time of trampling green matter into the soil and giving sufficient interval before sowing or planting the crop. After incorporation sufficient time is allowed for decomposition to take place and only after this, the main crop is sown or planted. Usually about six to eight weeks time is found to be sufficient for the decomposition.

Decomposition of green manure:

Mineralization of organic matter (OM)

3. Wide C:N ratio 50:1
4. Close C:N ratio 30:1 or 20:1

Composting

Composting is the natural process of 'rotting' or decomposition of organic matter by microorganisms under controlled conditions. Raw organic materials such as crop residues, animal wastes, food garbage, some municipal wastes and suitable industrial wastes, enhance their suitability for application to the soil as a fertilizing resource, after having undergone composting.

A mass of rotted organic matter made from waste is called compost.

The compost made from farm waste like sugarcane trash, paddy straw, weeds and other plants and other waste is called farm compost. The average nutrient contents of farm compost are 0.5 per cent N, 0.15 per cent P₂O₅ and 0.5 per cent K₂O. The nutrient value of farm compost can be increased by application of superphosphate or rock phosphate at 10 to 15 kg/t of raw material at the initial stage of filling the compost pit.

Composting is essentially a microbiological decomposition of organic residues collected from rural area (rural compost) or urban area (urban compost).

Vermicompost

Vermicompost is the use of earthworms for composting organic residues. Earthworms can consume practically all kinds of organic matter. Earthworms have the capacity to eat as much matter as their own weight and produce the same amount of manure per day in the form of castings.

Castings or excreta of earthworms are rich in nutrients and bacterial and actinomycetes population

The potential benefits include:

- Reduction of noxious qualities of a wide variety of organic waste, elimination of smell, reduction of harmful microorganisms
- Production of marketable organic fertilizer
- Production of aqua life, birds and animal food or even human food by drying earthworms
- Additional benefit to the farmers
- Increases soil fertility and bacterial activity in the soil

- Increases micro grains in the soil and enhances water absorption capacity
- Helps the plant root get air easily
- Increases plant resistance to pests, fungus and other deceases

Vermiwash

- Liquid fertilizer collected over passage of water through a column of worms in action useful as foliar spray
- Collection of excretory products and mucus secretion of earthworms along with micro nutrients from solid organic molecules.

Fertilizer

Fertilizer is any material of natural or synthetic origin added to the soil to supply one or more plant nutrients.

Classification of fertilizers

Fertilizers

1. Straight fertilizers: Straight fertilizers are those which supply only one primary plant nutrient, namely nitrogen or phosphorus or potassium. eg. Urea, ammonium sulphate, potassium chloride and potassium sulphate.

2. Complex fertilizers: Complex fertilizers contain two or three primary plant nutrients of which two primary nutrients are in chemical combination. These fertilizers are usually produced in granular form. eg. Diammonium phosphate, nitrophosphates and ammonium phosphate.

3. Mixed fertilizers: are physical mixtures of straight fertilizers. They contain two or three primary plant nutrients. Mixed fertilizers are made by thoroughly mixing the ingredients either mechanically or manually.

Fertilizers can also be classified based on physical form:

3. Solid
4. Liquid fertilizers

Solid fertilizers are in several forms *viz.*

7. Powder (single superphosphate),
8. Crystals (ammonium sulphate),
9. Pills (urea, Di-ammonium phosphate, superphosphate),
10. Granules (Holland granules),
11. Super granules (urea super granules) and
12. Briquettes (urea briquettes).

Liquid fertilizers:

3. Liquid form fertilizers are applied with irrigation water or for direct application.
4. Ease of handling, less labour requirement and possibility of mixing with herbicides has made the liquid fertilizers more acceptable to farmers.

Fertilizer

Nitrogenous fertilizer			
Ammonical	Nitrate	Ammonical and Nitrate	Amide fertilizer
Ammonium Sulphate Ammonium chloride Anhydrous ammonia	Sodium Nitrate Calcium Nitrate Potassium Nitrate	Ammonium Nitrate Calcium Ammonium Nitrate Ammonium Sulphate Nitrate	Urea Calcium Cyanamide

Nitrogenous fertilizers

4. Nitrogenous fertilizers take the foremost place among fertilizers since the deficiency of nitrogen in the soil is the foremost and crops respond to nitrogen better than to other nutrients.
5. More than 80 per cent of the fertilizers used in this country are made up of nitrogenous fertilizers, particularly urea.
6. It is extremely efficient in increasing the production of crops and the possibilities of its economic production are unlimited

The nitrogenous fertilizers can be further classified as given below:

2. Ammonical fertilizers

1. Ammonical fertilizers contain the nutrient nitrogen in the form of ammonium or ammonia.
2. Ammonical fertilizers are readily soluble in water and therefore readily available to crops.
3. Except rice, all crops absorb nitrogen in nitrate form. These fertilizers are resistant to leaching loss, as the ammonium ions get readily absorbed on the colloidal complex of the soil.

Example:

b) *Ammonium sulphate* [(NH₄)₂ SO₄]

It is a white salt completely soluble in water containing 20.6 per cent of nitrogen and 24.0 per cent of sulphur.

b) *Ammonium chloride* (NH₄Cl)

It is a white salt contains 26.0 per cent of nitrogen..

c) *Anhydrous ammonia* (NH₄)

It is a colour less and pungent gas containing 82.0 per cent nitrogen.

D. Nitrate Fertilizers

Nitrate fertilizers contain the nitrogen in the form of NO₃

a) *Sodium nitrate* (NaNO₃)

Sodium nitrate is a white salt containing about 15.6 per cent of nitrogen.

b) *Calcium nitrate* [Ca(NO₃)₂]

It is a white crystalline hygroscopic solid soluble in water containing 15.5 per cent nitrogen and 19.5 per cent calcium.

c) *Potassium nitrate* (KNO₃)

The purified salt contains 13.0 per cent nitrogen and 36.4 per cent potassium.

E. Ammonical and nitrate fertilizers

These fertilizers contain nitrogen in both ammonium and nitrate forms. The nitrates are useful for rapid utilization by crops and the ammonical is gradually available.

a) *Ammonium nitrate* (NH_4NO_3)

It is white, water soluble and hygroscopic crystalline salt containing 35 per cent nitrogen half as nitrate nitrogen and half in the ammonium form.

b) *Calcium ammonium nitrate* (CAN)

Calcium ammonium nitrate is a fine free-flowing, light brown or grey granular fertilizer, containing 26 per cent of nitrogen.

c) *Ammonium sulphate nitrate* [$(\text{NH}_4)_2\text{SO}_4 \text{NH}_4\text{NO}_3$]

It contains 26 per cent nitrogen, three fourths of it in the ammoniacal form and the rest (6.5 per cent) as nitrate nitrogen.

F. Amide fertilizers

Amide fertilizers are readily soluble in water and easily decomposable in the soil.

a) *Urea* [$\text{CO}(\text{NH}_2)_2$]

It is the most concentrated solid nitrogenous fertilizer, containing 46 per cent nitrogen.

b) *Calcium cyanamide* (CaCN_2)

Calcium cyanamide or nitrolime contains 20.6 per cent of nitrogen.

2. Phosphatic fertilizers

Phosphatic fertilizers are chemical substances that contain the nutrient phosphorus in absorbable form (Phosphate anions) or that yield after conversion in the soil.

a) *Super phosphate* [$\text{Ca}(\text{H}_2\text{PO}_4)_2$]

This is the most important phosphatic fertilizer in use and it contains 16 Per cent P_2O_5 in available form.

b) *Triple super phosphate:*

The concentrated super phosphate is called as *Triple super phosphate* and it contains 46 per cent P_2O_5 .

3. Potassic fertilizers

Potassic fertilizers are chemical substances containing potassium in absorbed form (K^+). There are two potassium fertilizers viz., muriate of potash (KCl) and sulphate of potash (K_2SO_4). They are water soluble and so are readily available to plants.

a) *Potassium chloride* (KCl)

Potassium chloride or muriate of potash is a white or red, crystal containing 60.0 per cent K_2O .

b) *Potassium sulphate* (K_2SO_4)

Potassium sulphate or sulphate of potash is a white salt and contains 48 per cent K_2O .

Bio fertilizers

Bio fertilizers are defined as preparations containing living cells or latent cells of efficient strains of microorganisms that help crop plants' uptake of nutrients by their interactions in the rhizosphere when applied through seed or soil. They accelerate certain microbial processes in the soil which augment the extent of availability of nutrients in a form easily assimilated by plants.

Use of bio fertilizers is one of the important components of integrated nutrient management, as they are cost effective and renewable source of plant nutrients to supplement the chemical fertilizers for sustainable agriculture. Several microorganisms and their association with crop plants are being exploited in the production of bio fertilizers. They can be grouped in different ways based on their nature and function.

S. No.	Groups	Examples
N₂ fixing Bio fertilizers		
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>
P Solubilizing Bio fertilizers		
1.	Bacteria	<i>Bacillus megaterium var. phosphaticum, Bacillus subtilis, Bacillus circulans, Pseudomonas striata</i>
2.	Fungi	<i>Penicillium sp, Aspergillus awamori</i>
P Mobilizing Bio fertilizers		
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>
Bio fertilizers for Micro nutrients		
1.	Silicate and Zinc solubilizers	<i>Bacillus sp.</i>
Plant Growth Promoting Rhizobacteria		
1.	Pseudomonas	<i>Pseudomonas fluorescens</i>

Rhizobium

Rhizobium is a soil habitat bacterium, which can able to colonize the legume roots and fixes the atmospheric nitrogen symbiotically. They are the most efficient biofertilizers as per the quantity of nitrogen fixed concerned. They have seven genera and highly specific to form nodule in legumes, referred as cross inoculation group.

Azotobacter

Of the several species of *Azotobacter*, *A. chroococcum* happens to be the dominant inhabitant in arable soils capable of fixing N₂ (2-15 mg N₂ fixed /g of carbon source) in culture media.

Azospirillum

Azospirillum lipoferum and *A. brasilense* (*Spirillum lipoferum* in earlier literature) are primary inhabitants of soil, the rhizosphere and intercellular spaces of root cortex of

graminaceous plants. They perform the associative symbiotic relation with the graminaceous plants.

Cyanobacteria

Both free-living as well as symbiotic cyanobacteria (blue green algae) have been harnessed in rice cultivation in India. A composite culture of BGA having heterocystous *Nostoc*, *Anabaena*, *Aulosira* etc. is given as primary inoculum in trays, polythene lined pots and later mass multiplied in the field for application as soil based flakes to the rice growing field at the rate of 10 kg/ha. The final product is not free from extraneous contaminants and not very often monitored for checking the presence of desired algal flora.

Azolla

Azolla is a free-floating water fern that floats in water and fixes atmospheric nitrogen in association with nitrogen fixing blue green alga *Anabaena azollae*. Azolla is used as biofertilizer

for wetland rice and it is known to contribute 40-60 kg N/ha per rice crop.

Phosphate solubilizing microorganisms(PSM)

Several soil bacteria and fungi, notably species of *Pseudomonas*, *Bacillus*, *Penicillium*, *Aspergillus* etc. secrete organic acids and lower the pH in their vicinity to bring about dissolution of bound phosphates in soil.

AM fungi

The transfer of nutrients mainly phosphorus and also zinc and sulphur from the soil *milieu* to the cells of the root cortex is mediated by intracellular obligate fungal endo symbionts of the genera *Glomus*, *Gigaspora*, *Acaulospora*, *Sclerocysts* and *Endogone* which possess vesicles for storage of nutrients and arbuscles for funneling these nutrients into the root system.

Silicate solubilizing bacteria (SSB)

Microorganisms are capable of degrading silicates and aluminum silicates. During the metabolism of microbes several organic acids are produced and these have a dual role in silicate weathering.

Plant Growth Promoting Rhizobacteria (PGPR)

The group of bacteria that colonize roots or rhizosphere soil and beneficial to crops are referred to as plant growth promoting rhizobacteria (PGPR).

Liquid Biofertilizers

Biofertilizers are such as *Rhizobium*, *Azospirillum* and Phosphobacteria provide nitrogen and phosphorous nutrients to crop plants through nitrogen fixation and phosphorous solubilization processes. These Biofertilizers could be effectively utilized for rice, pulses, millets, cotton, sugarcane, vegetable and other horticulture crops.

Liquid Bio-fertilizer application methodology

There are three ways of using Liquid Bio-fertilizers

4. Seed treatment
5. Root dipping
6. Soil application

Nutrient Use Efficiency (NUE)

Nutrient use efficiency (NUE) may be defined as yield per unit input. Nutrient use efficiency is the fraction of nutrients removed from the field with the crop harvest. In agriculture this is usually related to the input of manures and fertilizer. The nutrients most commonly limiting plant growth are N, P, K and S. NUE depends on the ability to efficiently take up the nutrient from the soil, but also on transport, storage, mobilization, usage within the plant, and even on the environment.

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

Irrigation –Importance of irrigation –Objectives of irrigation,-Methods of irrigation and water use efficiency

Water Resources

About 97 per cent of water in this world is the oceans and this is not useful for irrigation. Of the total quantity of water only 2.6 per cent is fresh water. Only small fraction of water resources of the earth that are present in the ground, lakes, rivers and atmosphere can be harvested for irrigation of crops and domestic purposes.

Water resources of the world

Particulars	Amount of water (KM³)	Percentage of total
Oceans	1,348,000000	97.39
Polar ice, glaciers	27,820,000	2.01
Ground water and soil moisture	8,062,000	0.58
Lakes and rivers	225,000	0.02
Atmospheric water	13,000	0.0001
Total	1,384,120,000	100.000

Water resources of India

The average annual rainfall of India is 1194 mm. When considered over the geographical area of 328 m ha, this rainfall amounts to 392 million hectare meters (million ha m). This may be rounded off to 400 million ha m by including the contribution of snow fall. Out of 400 million ha m of rainfall, 75% of it is received during south-west monsoon period (June to Sep) and rest in remaining 8 months. A major portion of the water (215 million ha m) soaks into the soil while 70 million ha m is lost as evapo- transpiration and surface flow is 115 million ha m (Rain fall 105 million ha m and snow fall 10 million ha m). Of the 215 million ha m of infiltration soil moisture is 165 million ha m and ground water 50 million ha m.

Irrigation

Irrigation may be defined as the artificial application of water to the soil for the purpose of crop production in supplement to rainfall and ground water contribution.

Importance of water to plants

1. Plants contain 90% water which gives turgidity and keeps them erect
2. Water is an essential part of protoplasm
3. It regulates the temperature of the plant system
4. It is essential to meet the transpiration requirements
5. It serves as a medium for dissolving the nutrients present in the soil
6. It is an important ingredient in photosynthesis

Objective of irrigation:

The main objectives of irrigation supply are to:

7. Ensure enough moisture essential for plant growth.
8. Provide crop insurance against short duration drought.
9. Cool the soil and atmosphere to provide a suitable surrounding
10. Wash out or dilute harmful salts and chemicals in the soil
11. Reduce hazards of soil piping.
12. Soften the tillage pan

Advantages of irrigation

1. For proper nourishment of crops certain amount of water is required. If rainfall is insufficient there will be deficiency in fulfillment of water requirement. Irrigation tries to remove this deficiency caused due to inadequate rainfall. Thus, irrigation comes to rescue in dry years.
2. Irrigation improves the yield of crops and makes people prosperous. The living standards of the people are thereby improved.
3. Irrigation also adds to the wealth of the country in two ways. Firstly as bumper crops are produced due to irrigation it makes country self-sufficient in food requirements. Secondly as the irrigation water is taxed when it is supplied to the cultivators, it adds to the revenue.
4. Irrigation makes it possible to grow cash crops which give good returns to the cultivators than the ordinary crops they might have grown in absence of irrigation. Fruit gardens, sugarcane, potato, tobacco etc., are the cash crops.
5. Sometimes large irrigation channels can be used as a means of communication.
6. Along the banks of large irrigation channels plantation can be successfully done which not only helps introducing social forestry but also improves environmental status of the region.
7. New irrigation works are started at the time of famines to provide employment to a large number of populations. These works are called famine works or relief works.

8. When watering facility is provided to a barren land, the value of this land gets appreciated.

Crop water requirement

Crop water requirement is the quantity of water regardless of source, needed for normal crop growth and yield in a period of time at a place and may be supplied by precipitation or by irrigation or by both.

Water is needed mainly to meet the demands of evaporation (E), transpiration (T) and metabolic needs of the plants, all together is known as consumptive use (CU). Since water used in the metabolic activities of plant is negligible, being only less than one percent of quantity of water passing through the plant, evaporation (E) and transpiration (T), i.e. ET is directly considered as equal to consumptive use (CU). In addition to ET, water requirement (WR) includes losses during the application of irrigation water to field (percolation, seepage, and run off) and water required for special operation such as land preparation, transplanting, leaching etc.

$WR = CU + \text{application losses} + \text{water needed for special operations.}$

Water requirement (WR) is therefore, demand and the supply would consist of contribution from irrigation, effective rainfall and soil profile contribution including that from shallow water tables (S)

$$WR = IR + ER + S$$

Under field conditions, it is difficult to determine evaporation and transpiration separately. They are estimated together as evapotranspiration (ET). IR is the irrigation requirement.

Water Use Efficiency (WUE):

Water use efficiency is defined as yield of marketable crop produced per unit of water used in evapotranspiration.

$$WUE = Y / ET \text{ (kg/ha/mm)}$$

Where,

WUE = Water use efficiency (kg/ha/mm of water)

Y = marketable yield (kg/ha)

ET= Evapotranspiration (mm)

If yield is proportional to ET, water use efficiency has to be constant but it is not so. Actually, Y and ET are influenced independently by crop management and environment. Yield is more influenced by crop management practices, while ET is mainly dependent on climate and soil moisture. Fertilization and other cultural practices for high yield usually increase in water use accompanying fertilization is often negligible. Crop production can be increased by judicious irrigation without markedly increasing ET. Under optimum water supply, ET is not dependent on kind of plant canopy provided the soil is adequately covered with crop.

Factors effecting water use efficiency:

1. Nature of plant
2. Climatic conditions

3. Soil moisture content
4. Fertilizers
5. Plant population etc.

Criteria of irrigation scheduling

An ideal irrigation schedule must indicate when to apply irrigation water and how much quantity of water to be applied; several approaches for scheduling irrigation have been used by scientist and farmers. These are as under

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 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.

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.

3) Critical stage approach

In each crop, there are some growth stages at which moisture stress leads to irrevocable yield loss. These stages are known as critical periods or moisture sensitive periods. If irrigation water is available in sufficient quantities, irrigation is scheduled whenever soil moisture is depleted to critical moisture level say 25 or 50 percent of available soil moisture. 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 crops

Sr. No.	Crop	Moisture Sensitive Stages
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1	Rice	Panicle Initiation, Flowering
2	Wheat	Crown Root Initiation, Jointing, Milking
3	Sorghum	Seedling, Flowering
4	Maize	Silking, Tasseling
5	Bajara	Flowering, Panicle Initiation
6	Nachani	Panicle Initiation, Flowering
7	Ground Nut	Rapid Flowering, Pegging, Early Pod Formation
8	Red Gram	Flowering & Pod Formation
9	Green Gram	Flowering & Pod Formation
10	Black Gram	Flowering & Pod Formation
11	Sugarcane	Formative Stage
12	Sesame	Blooming stage to Maturity
13	Sunflower	Two weeks before & after flowering
14	Safflower	From rosette to flowering
15	Soybean	Blooming & seed formation
16	Cotton	Flowering & Ball Formation
17	Tobacco	Transplanting to Full Bloom

Remote Sensing

In project areas, where a single crop is growing in large area, irrigation scheduling can be done with the help of remote sensing data. Reflectance of solar radiation by the plants with sufficient amount of water is different from that of stressed plants. This principle can be used for scheduling irrigation.

Methods of irrigation

1. Irrigation Methods are mainly classified into :

1. Surface Irrigation or Gravity Irrigation
2. Subsurface Irrigation or Sub-irrigation
3. Sprinkler or overhead irrigation
4. Drip or Trickle irrigation

Surface irrigation

- Irrigation water flows across the field to the point of infiltration
- Primarily used for field crops and orchards
- Water is applied to the soil surface and the water flows by gravity either through furrows, strips or basins.
- Water is applied from a channel located at the upper reach of the field.
- Loss of water by conveyance and deep percolation is high and the efficiency of irrigation is only 40-50% at field level in surface method of irrigation.
- Properly constructed water distribution systems to give sufficient control of water to the fields and effective land preparation to permit uniform distribution of water over the field are very important.

Water is applied to the field in either the controlled or uncontrolled manner.

- Controlled: Water is applied from the head ditch and guided by corrugations, furrows, borders, or ridges.
- Uncontrolled: Wild flooding.
- Surface irrigation is entirely practised where water is abundant.
- Low initial cost of development is later offset by high labour cost of applying water.
- Deep percolation, runoff and drainage problems

1. Furrow irrigation 2. Border irrigation 3. Basin irrigation

Furrow irrigation - in which the water poured on the field is directed to flow through narrow channels dug between the rows of crops, instead of distributing the water throughout the whole field evenly.

The furrows must all have equal dimensions, in order to guarantee that the water is distributed evenly. Like flood irrigation, furrow irrigation is rather cheap in areas where water is inexpensive.

In furrow irrigation, only a part of the land surface (the furrow) is wetted thus minimizing evaporation loss. Irrigation can be by corrugation using small irrigation streams. Furrow irrigation is adapted for irrigating on various slopes except on steep ones because of erosion and bank overflow.

Border Irrigation System

In border irrigation, controlled surface flooding is practised whereby the field is divided up into strips by parallel ridges or dykes and each strip is irrigated separately by introducing water upstream and it progressively covers the entire strip..

Basin method of irrigation is adopted mainly in orchards.

- Usually round basins are made for small trees and square basin for large trees.
- These basins allow more water to be impounded as the root zones of orchard plants are usually very deep.
- Each basin is flooded and water is allowed to infiltrate into the soil.
- Basin irrigation is suitable for many field crops. Rice grows best when its roots are submerged in water and so basin irrigation is the best method to use for this crop. Other crops which are suited to basin irrigation include: Pastures, e.g. alfalfa, clover; Citrus, banana; Crops which are broadcast, such as cereals, and to some extent row crops such as tobacco.

Sprinkler irrigation

- It is a method of applying irrigation water which is similar to natural rainfall. □ Water is distributed through a system of pipes usually by pumping.
- Water under pressure is carried and sprayed into the air above the crop through a system of: □ Overhead perforated pipes, nozzle lines, or through nozzles fitted to riser pipes attached to a system of pipes laid on the ground.
- Nozzles of fixed type or rotating under the pressure of water are set at suitable intervals in the distribution pipes. Sprayed water wets both the crop and the soil and, hence, has a refreshing effect. Water is applied at a rate less than the intake rate of soil so that there is no runoff.
- Measured quantity of water is applied to meet the soil water depletion.

- Sprinkler irrigation is suited for most row, field and tree crops and water can be sprayed over or under the crop canopy.
- Large sprinklers are not recommended for irrigation of delicate crops such as lettuce because the large water drops may damage the crop. Suitable slopes
- Sprinkler irrigation is adaptable to any farmable slope, whether uniform or undulating.
- Lateral pipes supplying water to the sprinklers should always be laid out along land contour.
- This will minimize the pressure changes at the sprinklers and provide a uniform irrigation.
- Sprinklers are best suited to sandy soils with high infiltration rates although they are adaptable to most soils.
- Application rate from the sprinklers (in mm/hour) is always chosen to be less than the basic infiltration rate of the soil - so that surface ponding and runoff can be avoided.
- Sprinklers are not suitable for soils which easily form a crust.

Drip or trickle irrigation

In this irrigation system:

- Water is applied directly to the crop ie. entire field is not wetted
- Water is conserved
- Weeds are controlled because only the places getting water can grow weeds.
- There is a low pressure system.
- There is a slow rate of water application somewhat matching the consumptive use. Application rate can be as low as 1 - 12 l/hr.
- There is reduced evaporation, only potential transpiration is considered.
- There is no need for a drainage system.

Drip irrigation / trickle irrigation - involves dripping water onto the soil at very low rates (2-20 litres/hour) -from a system of small diameter plastic pipes fitted with outlets called emitters or drippers. Water is applied close to plants so that only part of the soil in which the roots grow is wetted. With drip irrigation water, applications are more frequent (usually every 1-3 days). This provides a very favourable high moisture level in the soil in which plants can flourish.

Time of irrigation

Crops draw water from the moisture stored in the soil. When the moisture present in the soil is low, then the plant requirements are not met with. When the soil is supplied with moisture in excess the supply of air is reduced that limits the plants growth. In between, there is a range of moisture content that is called as optimum soil moisture range for plant growth.

The upper limit of the optimum soil moisture range is the field capacity (-0.01 to -0.03 Mpa) and the lower limit is just above the wilting point (-1.5 Mpa). The objective of irrigation is to store the moisture in the soil between these limits. Immediately after irrigation, all the macro and micropores will be filled with water. All the water present in macropores will drain to subsoil within 48 hours and moisture in micropores will be available to plants. As the soil dries due to loss of water by evaporation and transpiration, the plant wilts during day time to conserve moisture and become normal at night. When the same condition continues, the plant

will wilt without dieing. This condition is called as wilting coefficient. The irrigation is given whenever plants require water. This is decided by the crop and soil appearance.

Water logging

The problem associated with excessive irrigation on poorly drained soils is called water logging. This occurs in poorly drained soils where water can't penetrate deeply. For example, there may be an impermeable clay layer below the soil. It also occurs on areas that are poorly drained topographically. What happens is that the irrigation water (and/or seepage from canals) eventually raises the water table in the ground, the upper level of the groundwater from beneath.

The raised water table results in the soils becoming waterlogged. When soils are water logged, air spaces in the soil are filled with water, and plant roots essentially suffocate -- lack oxygen. Waterlogging also damages soil structure.

Drainage

Drainage is the artificial removal of water in excess of the quantity required for the crop. Drainage includes removal of excess water of both surface and subsurface in the root zone of crops. Irrigation and drainage go together and are not mutually exclusive. Irrigation aims at supplying optimum quantities of water throughout the crop period, whereas, drainage aims at removing excess quantity of water in a short time. Often, both may be required together to assure sustained and high level production of crops.

Role of drainage

8. Draining the land provides conditions favorable for crop production.
9. The greatest benefit of drainage relates to aeration. Good drainage facilitates the ready diffusion of oxygen to the root zone and escape of carbon dioxide from the root zone into the atmosphere. Several harmful gases also escape from the root zone into the atmosphere.
10. The activity of aerobic organisms which influence the availability of nutrients such as nitrogen and sulphur to plants depends on soil aeration and hence, drainage improves aerobic organisms.
11. Toxicity in acid soils due to excess iron and manganese is decreased by drainage (due to presence of oxygen in the root zone).
12. Drainage permits roots to grow deeper and spread wider thereby increasing the volume of soil from which nutrients can be extracted.
13. The removal of excess water helps in drying of the soil quickly and optimum soil temperature permits timeliness of field operations.
14. The provision of a good drainage system permits the removal of excess salts in the soil or irrigation water and prevents their build up in the upper soil layers.

Weed –definition – importance –Harmful and beneficial effects of weeds – Aquatic weeds

Weed

Definitions are

1. A weed is plant growing where it is not desired.
2. A weed is a plant growing out of its place.
3. Any plant not sown in the field by the farmer is out of place and is called weed.
4. Any plant or vegetation excluding fungi interfering with the objectives or requirement of people called weed.

Weeds are unwanted or undesirable plants compete with crops for water, soil nutrients, light and space (ie CO₂) and thus reduce crop yields.

Harmful effects

Of the total annual loss of agricultural produce from various pests in India, **weeds account for 45%**, insects 30%, diseases **20%** and 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 effect the growth of the crop and the weed

The following are the harmful effects of weeds on various activities of human beings, crops, livestock and related aspects.

Weed menace in/ to:

1. Agriculture
2. Animal husbandry
3. Human health
4. Aquatic ecosystems
5. Forest and pasture land
6. Weeds as alternate hosts to crop pests and diseases
7. Weeds reduce land value.
8. Weeds limits choice of crops

Beneficial effects

For making ropes and thatch boards. (*Typha* and *Saccharum* sp)

Adding flavor to coffee powder (*Cichorium intybus* roots)

Leafy vegetable (*Amaranthus viridis*, *Chenopodium album* and *Portulaca* sp.)

Exhibits nematocidal properties (*Crotalaria*, *Parthenium*, *Calotropis* and *Eichornia*)

Animal fodder (Hariyali grass (*Cynodon dactylon*) and *Cenchrus ciliaris*, *Dichanthium annulatum* *Eclipta alba*)

Protein supplement (china and Japan consume *Chlorella pyrenoides* (algae))

Alternate host for predators and parasites of insect pests which feed on the weeds.
Green manures (*Tephrosia purpurea* and *Croton sparsiflora*), adds Organic matter
Weeds check wind, water and soil erosion:
Reclamation of alkali Soils
Paper pulp, bio-gas and manufacture of edible proteins.
Ornamental and Hedge Plants
Aquatic weeds are useful in Paper, pulp and fiber industry.

Religious purpose. Ex. Hariali, Aghada, Maka etc.
Medicinal properties and used to cure :
snake bite (*Leucas aspera*),
gastric troubles (*Calotropis procera*),
skin disorders (*Argemone mexicana*),
jaundice (*Phyllanthus nirur*) and
Striga orobanchioides to control diabetes.

Aquatic weeds

Aquatic weeds are unwanted plants, growing in or near aquatic bodies such as canals, ponds, lakes, rivers, reservoirs etc.

Important Aquatic weeds of India

Over 140 species of aquatic weeds have been reported in India, but the most important and problematic ones are

Eichhornea crassipes (water hyacinth)
Salvinia molesta (water fern),
Salvinia natans (Water fern) ,
Hydrilla verticillata (hydrilla),
Valisneria spiralis (tape grass or eel weed),
Typha angustata (cat tail),
pistia stratiotes (water lettuce) and
algal weeds like *Chara* sp. *Nitella* sp. and bloom-forming blue-green algae

Kinds of problems caused by Aquatic weeds

Increase the loss of water by evapo-transpiration
Reduce the flow-rate of water in canals, channels drains, rivers etc.,
Hinder pisce culture
Interfere with hydro-electric projects and irrigation schemes
Interfere with movement of boats, for transport, recreation and fishing.
Create problem for lowland paddy cultivation
Provide habitat for the development of disease-causing insects
Cause silting of reservoirs lakes etc.
Aquatic weeds reducing the value of lakes, tanks, reservoirs streams etc.

Classification of weeds- Based on morphology, life cycle, habitat, origin, association and special features with examples.

Weeds can be grouped for the convenience of planning, interpreting and recording control measures against them. Weeds belonging to any group of these classes have specific mode of propagation, dispersal and persistence.

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 30000 species is grouped as weeds. Out of these 18,000 sps can cause damage to the crops.

Classification of weeds

Weeds are classified based on :

1. morphology
2. life cycle
3. habitat
4. origin
5. association
6. nature of stem
7. soil types
8. Special classification

1. Classification based on morphology/ cotyledon characters

Morphological characters of plant are closely related to herbicidal absorption, retention, and translocation. The weeds belonging to the same group are likely to have same kind of response to specific herbicides or cultural or mechanical methods.

This is the most widely used classification by the weed scientists. So, weeds are generally divided into three groups

- 1) Grasses
- 2) Sedges
- 3) Broad leaved weeds

Based on cotyledon characters they are classified into

Monocots
Eg Grasses or narrow leaved weeds

Dicots
Eg: *Amaranthus spp.*
Chenopodium album

Note : Cyperaceae and typhaceae are not grasses even though they are narrow leaved

Grasses
Eg, *Digitaria, Cynadon*

Sedges
Cyprus, Scirpus

2. Classification based on habitat / situation

Depending upon the place of their occurrence they are classified into terrestrial and aquatic weeds.

Terrestrial weeds are again classified into

1. Crop land weeds: weeds in field. Eg. *Echinochloa* in rice.
2. Non-crop land weeds: weeds in waste lands Eg. *Tribulus terrestris*, *Xanthium strumarium*.
3. Grass land weeds: Eg. *Vernonia* and *Rumex* spp.
4. Weeds of lawns & public parks Eg *Lippia nodiflora* and *Eleusine indica*.
4. Orchard or garden weeds Eg. *Euphorbia geniculata*, *Imperata Cylindrica* , *Acalypha indica*.
5. Weeds of plantation crops Eg. *Eupatorium* spp. *Makania micrantha*
6. Parasitic weeds Eg. *Loranthus*.
7. Road side weeds Eg. *Euphorbia* , *Lantana camera* , *Hyptis* and *Prosopis juliflora*

Aquatic weeds; They are classified into

- 1) Sub merged weeds Eg *Hydrilla Verticillata*, *Utricularia stellaris*.
- 2) Emerged weeds Eg *Typha Spp* *Nelambium speciosum*.
- 3) Floating weeds Eg *Eichhornia crassipes*, *Pistia stratiotes* .

3. Classification based on origin

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*, *Sorghum halepense*, *Cynodon dactylon* and *Echinochloa colonum*

Introduced or Exotic weeds or Alein: These are the weeds introduced from other countries. These weeds are normally troublesome and control becomes difficult. Eg. *Parthenium hysterophorus*, *Acanthospermum hispidum*, *Eichhornia crassipes*, *Argemone mexicana*, *Lantana camara* and *Croton bonplandianus*

When man aids in its introduction such Weeds are called as anthrophytes.

Alein/ Introduced weeds

Native weeds

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.**

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.

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

- 1 **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

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 and 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.

Classification based on nature of stem

Depending upon development of bark tissue on their stems and branches, weeds are classified into *woody, semi-woody and herbaceous weeds*.

Woody weeds: Weeds include shrubs and under shrubs and are collectively called brush weeds. *Lantana camera*, *Prosopis juliflora* (mesquite) *Zizyphus rotundifolia* (wild plum) are examples for brush weeds.

Semi-woody weeds: *Croton sparsiflorus* is semi woody weed.

Herbaceous weeds: Weeds have green, succulent stems are of most common occurrence around us. Eg. *Amaranthus viridis* and *Chenopodium album*.

Based on soil pH

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

Acidophile weeds habitat acid soils eg. *Rumex acetosella*, *Pteridium spp*

Basophile weeds dominate Saline and alkaline soil eg. *Taraxacum stricta*. *Salsola spp* dominate saline soils where as *Cressa erecta*, *Sporobolus diander* are dominant in alkaline soils.

Neutrophile – Weeds of neutral soils eg. *Acalypha indica* , *Spergula arvensis* will grow luxuriantly on low pH soils.

Classification based on life cycle / ontogeny

Based on life span (ontogeny), weeds are classified as annual, biennial and perennial weeds.

Annuals again they are classified into a) Kharif season annual b) Rabi season annual c) Summer season annual and d) Multi season annual

Summer and kharif annuals: *Trianthema sp.* (carpet weed)

Digera arvensis (digera)

Setaria glauca (yellow fox tail)

Winter annuals: *Chenopodium album* (Lamb's-quarters)

Vicia spp (vetches)

Avena fatua (wild oat)
Phalaris minor (little seed canary grass)

Multi-season annual (All seasons)
Echinochloa colonum
Eclipta alba
Eleusine indica
Phyllanthus niruri

Simple annuals when ever they are cut from ground level, they can't regrow again. Where as *Parthenium*, *lantana* and *pluchea spp* appears like perennial, when cut at ground level. It will again re grow from crown buds.

Biennial weeds: Complete their life cycle within two years/ two seasons, 1st year vegetative growth – Rosette stage. 2nd year produced inflorescence called bolting. They may propagate either by seeds or vegetative parts or by both.

Eg. *Daucus carota* , *Cirsium vulgare* , *Cichorium intybus* , *Taraxacum stricta*, *Alternanthera echinita* but *Cichorium intybus* bolts every year

Perennial weeds

Grow more than two years. Reproduce vegetatively from under ground and specialized organs. First time they come to flowering in 2nd year and there after flowering every year.

Difficult

perennial weeds also known as pernicious weeds. Eg. *Cynodon dactylon* (Bermudagrass) and *Agropyron repens* (quackgrass)are **shallow rooted perennials** where as *Cyperus rotandus* . (Purple nut sedge) *Sorghum halepense*(Johnsongrass) are **deep rooted Perennials**

Simple perennials: These reproduce solely by seeds but when roots or crown are cut, the cut pieces may produce new plant Eg. *Ipomea carnea* and *Lantana camera*

Balbous perennial: These propagate by bulbs or bulblets as well as by seeds. Eg. Wild onion and wild garlic (*Allium vineale*).

Creeping perennials: These propagate by means of rhizomes, stolons, spreading roots as well as seeds. Eg. *Convovulus arvensis* (deer's foot), *Apropyron repens* (quack grass) and *Sorghum halepense* (Jhonson grass)

Special classification

Besides the various classes of weeds, a few others deserve special attention due to their specificity. They are **a. Poisonous weeds b. Parasitic weeds and c. Aquatic weeds**

Poisonous weeds: The poisonous weeds cause ailment on livestock resulting in death and cause great loss.

Parasitic weeds: The parasite weeds are either total or partial which means, the weeds that depend completely on the host plant are termed as total parasites while the weeds that

partially depend on host plant for minerals and capable of preparing its food from the green leaves are called as partial parasites.

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. They are further grouped into four categories as submersed, emerged, marginal and floating weeds.

Classification of Aquatic weeds

They are classified as under

Emerged weeds (Surface weeds)

Emerged weeds, which have roots in the bottom soil but the leaves and flowers emerge to water surface .

Examples: *Nelumbo lutea* (lotus) *Nymphaeo odorata* (water lily) *Trapa natans* (water chestnut).and *Nymphoides* (Floating heart.)

Submersed weeds

Submerged weeds are those that remain below water surface .Most of the vegetative growth of these weeds take place beneath the water surface.

They are further differentiated into:

Rooted submersed --These weeds have roots, Examples: *Hydrilla verticillata* (hydrilla) *Valisneria spiralis* (tape grass or eel weed). *Potamogeton spp.* (pond weed).

Suspended submersed ---These weeds have no roots. *Ceratophyllum demersum* (coon tail) and *Hydrilla verticillata*, *Ceratophyllum demersum*

Floating Weeds ---Which remain free floating with their leaves above surface and roots within water. Their leaves floating on the water surface either singly or in rosettes. They have true roots and leaves.

Free floating : *Eichornia*, *Pistia*, *Salvinia*

Rooted floating : *Nymphaea*

Classification based on climate

Temperate and Tropical weeds

Eg. Annuals Perennials

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, troublesome and 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*, *Cynadon dactylon*, *Circium 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.

Based on ecological affinities

Weeds of dry lands: These are usually hardy plants with deep root system. They are adapted to withstand drought on account of mucilaginous nature of the stem and hairiness.

Eg. *Tribulus terrestris*, *Convolvulus arvensis*.

Weeds of wetlands: They are tender annuals with semi-aquatic habit. They can thrive well under waterlogged and in partially dry condition. Propagation is chiefly by seed. Eg. *Ammania baccifera*, *Eclipta alba*

Weeds of irrigated uplands (Garden lands): They are intermediate between dry land and wet land weeds with respect to their water requirement. They neither withstand waterlogged situation nor the extreme drought. Eg. *Trianthema portulacastrum* & *Corchorus trilocularis* and *Digera arvensis*

Based on edaphic factors

Some of the weed species are closely associated with a particular type of soil though not in a strict sense. Some times the same species may also occur in other soil types.

Black cotton soils: The weed species are mainly associated with dry conditions. Eg. *Aristolochia bracteata* and *Hibiscus vitifolius*

Red soils: The weeds predominantly occur in the irrigated uplands. Eg. *Commelina benghalensis* and *Leucas urticaefolia*

Light sandy or loamy soils: weeds such as *Mollugo oppositifolia*, *Oldenladia Umbellata* and *Leucas aspera* occur in soils having good drainage.

Laterite soils: Some of the weeds are specific to laterite soils. Eg. *Bidens pilosa*, *Lantana camara* and *Spergula arvensis*.

Crop-weed competition

Competition is struggle between two organisms for a limited resource that is essential for growth. Water, nutrient, light and space are the major factors for which usually competition occurs. Competition between crop plants and weeds is most severe when they have similar vegetative habit and common demand for available growth factors.

Principles of crop weed competition are

1. Competition for nutrients
2. Competition for moisture
3. Competition for light
4. Competition for CO₂

Plants require nutrients, water, light and CO₂ for growth. Light and CO₂ are used by leaves. Competition for those growth factors is, therefore, above the ground. The competition for nutrients and water is below the ground as these are absorbed by roots. At early stage of crop and weeds, leaf area index and root density are low and each plant is able to get its requirement as though every one of them is growing in isolation. In majority of crops, the period of non-interference between crop and weed is very short. Even at low population of weeds, competition is set in at three leaf stage of weeds.

Competition for nutrients

The nutrient concentration in weeds far exceeds the associated crop. The rate of nutrient uptake by weed is greater than the crop plants. It is common experience that crops infested with weeds show N deficiency. Certain weeds not only cause depletion of soil nitrogen by their absorption, but also induce nitrification. One case study shows that the associated weed of maize crop viz. *Amaranthus*, *Portulaca* and *Digitaria* contains higher concentration of nutrients than maize.

Chemical composition of maize and associated weeds

Plant	Nutrient content (%)				
	N	P	K	Ca	Mg
Maize	1.20	0.21	1.19	0.16	0.15
Amaranthus	2.61	0.40	3.86	1.63	0.44
Portulaca	2.39	0.30	7.31	1.51	0.64

Competition for light

Generally, weeds grow faster and shade the crop plants, if not checked. Even in case of shorter weeds, the lower leaves of crops are shaded by them. Weeds deplete photosynthetically active radiation resulting in reduction in photosynthesis and shortening the life of lower leaves. Due to shading, crop plants may have thin, pale green leaves with reduced number of vascular bundles and meristem cells.

Competition for water

The amount of water required to produce a unit amount of dry matter is known as transpiration ratio. The transpiration ratio of weeds is higher as compared to plants. The transpiration ratio of *Cynodon dactylon* is around 813 compared to 450 for pearl millet and 430 for sorghum. This indicates that more water is required to grow one tonne of weed than one tonne of crop.

Competition for CO₂

Competition for CO₂ may occur when the weed infestation is high. Since most of the weeds are C₄ plants, they can deplete CO₂ to a very low level compared to crops. When CO₂ content is increased artificially from 350 ppm to 700 ppm, the competitive ability of C₃ crop like soybean increased to its associated C₄ weed namely *Sorghum halepense*.

Allelopathic Effect

Most of the plants excrete certain chemicals into soil which inhibit germination and growth of other plants in their vicinity and this phenomenon is called allelopathy. The degree of allelopathic effect depends on plant species. The important weed species that show allelopathic effect are *Sorghum halepense*, *Lantana camara*, *Cyperus rotundus*, *Euphorbia maculate* etc.

Critical period of crop-weed competition

The period at which maximum crop weed competition occurs called **critical period**.

It is the shortest time span in the ontogeny of crop when weeding results in highest economic returns.

Factors affecting weed-crop interference or critical period of crop weed competition:

1. Period of weed growth.
2. Weeds / crop density.
3. Plant species effects. a) Weed species b) Crop species and Varieties.
4. Soil and climatic influence. a) Soil fertility b) Soil moisture status c) Soil reaction: d) Climatic influences.
5. Cropping practices. a) Time and method of planting crops b) Method of planting of Crops c) Crop density and rectangularity.

In general for most of the annual crops **first 20-30 days weed free period is very important

Critical period of crop-weed competition

It is the shortest time span in the ontogeny of crop when weeding results in highest economic returns.

Critical period of crop-weed competition in some crops 1.	Rice	:	Up to 6 WAT
	Transplanted	:	Up to 6 WAS
	Direct sowing		
2.	Wheat and Ragi	:	Up to 5 WAS
3.	Maize	:	2 to 6 WAS
4.	Bajra	:	Up to 4 WAS
5.	Jowar and Sesame	:	2-5 WAS
6.	Sugarcane	:	12 to 14 WAS
7.	Sunflower	:	2 to 4 WAS
8.	Groundnut	:	4 to 7 WAS
9.	Green gram and Black gram	:	4 to 6 WAS
10.	Red gram	:	Up to 7 WAS
11.	Horse gram	:	3 to 6 WAS
12.	Cotton	:	6 to 9 WAS
13.	Castor	:	3 to 9 WAS
14.	Tobacco	:	Up to 9 WAT

Concepts of weed management

Weed management is the application of certain principles and suitable methods that will improve the vigor and uniform stand of the crop. At the same time ignore or discourage the invasion and growth of weeds.

Importance of Weed Management:

The total annual loss of agricultural produce various due various parts in India is as below

- 1) Weeds: 45%
- 2) Insects: 30%
- 3) Diseases: 20%
- 4) Other pests (Rats, wild animals)

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.

Methods of Weed Control

I) Preventive Measures:

II) Control/ Curative Measures:

- 1) Mechanical methods
- 2) Cropping or cultural methods
- 3) Biological methods
- 4) Chemical methods

Principles of Weed Management are

1. Prevention

It encompasses all measures taken to prevent the introduction and/or establishment and spread of weeds.

Important weed prevention practices are

1. Use clean crop seeds/ weed free crop seed
2. Avoid feeding of screenings, grain or hay containing weed seeds to live stock without destroying their viability by grinding, cooking and ensiling.
3. Use well rotten\decomposed organic manure. Avoid reaching of weed seeds into the compost pit
4. Prevent movement of weeds with other farm resources
5. Keep non crop area clean
6. Use vigilance

7. Follow legal & quarantine measures

2. Eradication

It is the complete elimination or destruction of all live plant parts and seeds of a weed infestation from an area. Practically, it is not feasible to eradicate the weeds as it is long term and very expensive method.

3. Control

It is the process of limiting any given weed infestation to the extent that it permits economic crop production.

Weed control includes

Cultural.

Biological.

Chemical.

Cultural Methods:

Mechanical or Physical Methods of Weed Control

This includes the use of hand tools, implements and machinery operated either with the help of man power, or machine power for control of weeds. These are the costly and time consuming methods. However, these methods cause minimum damage to the environment.

i) Hand Pulling or Hand Weeding

Pulling the weeds by hand or hand weeding with the help of weeding hook is the oldest and most effective methods for control of weeds. Weeds can be easily uprooted after a good soaking irrigation or rain. Weeding should be done before flowering stage of weeds for avoiding seedling and further spread of weeds. Because as per the old saying. One year's seeding is seven years weeding. This is costly and time consuming method.

ii) Tillage

It is one of the practical method of destroying weeds of all categories.

a) Deep Ploughing

Weeds are buried deep in the soil and also exposed to heat of the sun by deep ploughing. Many annual and perennial weeds can be controlled by deep ploughing and exposing the field to heat of the sun.

b) Discing

Helpful for cutting and burying of weeds. Harrowing with blade harrow is very effective for destroying newly germinated weeds before sowing of the crop.

c) Inter-culturing

Inter-culturing with different types of hoes or mechanical weeder is useful to control weeds in between rows of the crop.

iii) Mowing and Sickling

This method is used lands, pastures, gardens and roadsides. The implement mower is use for cutting weeds. It does not destroy the weeds completely but prevents seed production by cutting growing parts. Cutting above ground parts of weed with sickle is called sickling and it prevents seed information.

iv) Flooding

It helps in controlling weeds like kans. (*Saccharum spontaneum*) which grows luxuriantly in heavy ill drained soils during rainy seasons. The fields are embanked with tall bunds to impound water. The weeds get submerged under water and are smothered.

v) Burning

This method is adopted to destroy weeds in non-cropped areas like waste lands road sides, railway lines, bunds etc. The flame throwers and steam boxes are used for burning weeds in advanced countries. The flame should be so adjusted that it causes only wilting but not charring of weeds. Heat kills the living cells by coagulating the protoplasm and inactivating enzymes.

vi) Digging

This method is useful for controlling perennial weeds like nut grass, hariali etc. Digging is very useful for removing the underground propagation parts of weeds from the deeper layer of soil digging , hand collection and destruction of underground parts of weeds is adopted when noxious weeds are observed in the patches in the field. It is not economical on large areas as it is costly and time consuming method.

Cheeling

An implement called cheel (spade like implement with very long handle) with which weeds & soil can be raked up. Generally practiced in tea plantations.

Mulching

Principle is exclusion of sunlight from environment. Polythene Sheets, natural materials like paddy husk, ground nut shells, saw dust etc. are used as mulching material.. The thickness should be enough to cut off light (i.e. 10-15 cm).The efficiency of polythene sheet is more (more polythene) if it is applied in continuous sheet rather than in particle form. It is effective against annual weeds and perennial weeds like *cynodon dactylon* and *sorghum halopense*. Mulching is used in high value crops like coffee tea plantations by using guatemala grass (*Tripsacum laxum*) and citronella grass (*Cymbopogon spp*)

Mulching Inter cultivation with blade harrow

Flooding

Flood kills weeds by excluding oxygen from their environment. Flooding is a worldwide crop husbandry method of controlling weeds in rice fields. Hand cultivator

Cropping or Cultural Methods of Weed Control

Use of cropping methods alone is not effective for control of weeds. However, these methods are useful for minimizing the weed population and crop weed competition to some extent. These methods need suitable combination of mechanical and chemical methods for effective control of weeds.

i) Crop Rotation

Many weed problems exist with us because of practicing monoculture i.e growing of same crop year after year in the same field. Monoculture leads to increase the infestation of certain crop associated weeds.

Crops	Weeds
Rice	<i>Echinochloa spp</i>
Wheat	<i>Phalaris minor</i> and <i>Chenopodium album</i>
Sorghum	<i>Striga spp</i>
Maize , Pearl millet and Sugarcane	<i>Striga spp</i>
Tobacco	<i>Orobanche spp</i>

The proper crop rotations or inclusion of pulse crops in rotation is helpful for control of crop associated and parasitic weeds. E .g Striga on Jawar or Orobanche crops like groundnut, soybean, cotton etc. in the crop rotation.

ii) Smothering

A quick growing dense crop can successfully compete with weeds. Fast growing and fast shading crop is called smother crop. Sweet potatoes, Lucerne, soybean, sun hemp, etc are good smother crops. These crops cover the field within short period due to higher plant density, fast growth and canopy coverage suppress weeds by fast shading effect and also make the underground parts of weed feeble. The smother crops are sown at close spacing with high plant population to suppress weeds.

iii) Solarization

In this method the soil temperature is further increased by 5 to 10⁰ C by covering a pre-soaking fallow field with transparent plastic sheet. In some regions the technique raised the soil temperature to as high as 56⁰ C which was sufficient to kill vegetative propagation. This technique followed for four weeks or longer period which reduced weed seed viability by 80 % or more. Israel has so far made maximum use of this technique as a part of integrated weed management. However, this is costly technique.

iv) Proper Crop Stand and Narrow Spacing

Weed crop competition is more in gap and lower plant population. Therefore, practice like use of good quality seed, proper method of sowing, optimum seed rate, spacing and time of sowing and plant protection measures against insect pests and diseases are very important to obtain proper and uniform stand of crop, capable of offering initial competition to young weeds. Higher plant density and narrow spacing is useful to minimize weed crop competition than the lower plant density and wider spacing.

v) Intercropping

Many a time intercropping with crops like soybean , cowpea, red gram, green gram , groundnut etc. helps in suppression of secondary growth of weeds *e.g* Intercropping of soybean or cow pea in sorghum or pearl millet is helpful to suppress secondary growth of weeds as the inter row space is covered by intercrop at latter stage of crop growth. In this method at initial stage of crop growth it is necessary to control the weeds by mechanical or chemical methods.

Biological Control of Weeds

The use of living organism (Bio-agents) such as insects, disease organisms, herbivorous fish, snails and even competitive plants to limit weed infestation is called biological control of weeds. It is also known as the classical biological weed control.

Herbicides, classification, selectivity, resistance, allelopathy

Herbicides are chemicals capable of killing or inhibiting the growth of plants. Today we have 150 herbicides in common use for selective and non selective control in different areas.

In Agriculturally developed countries, herbicides form over 45% of the total pesticides used. In India, share of herbicides is only 8% of the total pesticides consumed.

Advantages of herbicide usage in agriculture

1. Herbicides are useful in areas where incessant rainfall may hinder the physical weeding during monsoonal season
2. Herbicide usage reduce the competition for labour during early stages of crop growth
3. They control germinating weeds and there by make the crop weed free and more competitive during early stages
4. They are useful to control weeds which mimic crop plants.
5. They kill the weeds in situ with out dissemination of vegetative propagules..
6. Herbicide sprays easily reach the weeds growing in obstructed situation ,under fruit trees and on undulating areas

Disadvantages

1. Contaminate the environment.
2. Skill is needed in the use herbicides
3. In sequence cropping, the herbicide used for first crop may affect the 2nd crop (see that they don't damage the 2nd crop). Here selectivity is a major problem.

Classification of herbicides.

I. Classification based on chemical nature

Herbicides are primarily grouped into **inorganic** and **organic herbicides**. **Inorganic herbicides** do not contain carbon atoms in their molecules. **They were the first chemicals used for weed control**. Arsenic acid, arsonous acid, sulphuric acid are acid type of inorganic herbicides. Where as sodium arsenate, sodium chlorate, copper sulphate etc are inorganic salts

Organic herbicides: These herbicides contain carbon atoms in their molecules. They may be oils or non oils. Eg. diesel oil, xylene type of aromatic oils. Majority of present day herbicides are non oils.

There are about 150 herbicides are available. They differ each other like behavior in soil, plants, mode of action etc. based on this chemical nature; the herbicides are grouped into 31 classes.

II. Classification based on methods of application of herbicides

Methods of application of herbicides are decided largely by their modes of action and selectivity. Important methods of application of herbicides to crop and non-crop lands are given, as follows

Soil-Active and Foliage-Active Herbicides

Soil-Active Herbicide

A soil-active herbicide is one that is applied primarily to the soil rather than to the vegetation. Inside the soil it kills weeds as they germinate or inhibits sprouting of their rhizomes, stolons, and tubers. Therefore, in crop fields a soil-active herbicide eliminates early weed-crop competition for the period of 4 to 8 weeks, depending upon the herbicide and its rate used. The soil-active herbicides are applied at the times of planting of crops, and to the weed free inter-rows of established crops to obtain extended period of weed control. **Eg simazine, alachlor, trifluralin, and EPTC.** On non-crop lands, the soil-active herbicides used are soil sterilants and fumigants

Surface Application

Soil active herbicides are applied uniformly on the surface of the soil either by spraying or by broadcasting, where they may be either left undisturbed or incorporated into the soil physically. Eg many **substituted triazines, urea, and anilide** herbicides. There are other soil-applied herbicides which must be incorporated into the soil to prevent their rapid volatilization and/or photodecomposition losses. Eg EPTC and fluchloralin, trifluralin and nitralin

Sub-Surface Layering

It is the application of an herbicide in a concentrated band, about 7-10 cm below the soil surface.

Band Application

The band application of a herbicide constitutes its application to a restricted band along the crop rows, leaving an untreated band in the inter-rows. The band application of herbicides is primarily a cost saving device since it reduces the quantity of herbicide in the ratio of the treated band width to the crop row width.

Soil Fumigation:

Herbicides used for fumigation are called as fumigants. Depending upon the nature of the soil fumigant, it can be applied either (1) by soil injection (chloropicrin) (2) by releasing it under sealed, plastic covers (methyl bromide) or (3) by direct soil surface application (Metham).

Herbigation

Application of herbicides with irrigation water both by surface and sprinkler systems. In India farmers apply fluchloralin for chillies and tomato, while in western countries application of EPTC with sprinkler irrigation water is very common in lucerne.

**Methods of Application of Foliage-Active Herbicides **

\A Foliage-active herbicide is applied to weeds after their emergence from the soil. They are absorbed by the plant foliage and these are translocated to the other plant parts. Eg 2,4,5-T, paraquat, diquat, MCPB, amitrole, and herbicidal oils are common examples of foliage-active herbicides. There may be some herbicides that are both soil-active and foliage-active, for example, 2,4-D, picloram, and atrazine.

Blanket Application:

Blanket (or over-the-top) it is uniform application of herbicides to standing crops with disregard to the location of the crop plants.

Only highly selective herbicides are applied by this method, e.g. 2,4-D in wheat. rice , MCPB in pea, 2,4-DB in Lucerne, and picloram in sugarcane cf. surface application of herbicide

Directed Spraying:

It is the application of herbicide to weeds, which are growing in the inter-rows of crop avoiding the crop foliage as much as possible. One important pre-requisite of directed spraying is that farmer must get his row crops well grown over the weeds at the time of treatment. Orchards and plantations are good venues of directed herbicide sprays. Usually, the directed spraying is adopted with herbicides that are partially selective to the treated crops.

Spot treatment:

Spot treatment is the application of herbicides to small patches of weeds, leaving the weed-free gaps untreated. This is used for treating patches of noxious, perennial weeds in certain crop fields with potent herbicides. Spot treatment is of value also in the non-crop areas to prevent wastage of herbicide in the weed-free spaces.

Methods of treating brush and trees

Brush weeds and unwanted trees are treated with herbicides by different methods,. Foliage treatment is the most common method of treating brush.

- i) ***Foliage treatment*** : when the brush leaves are fully expanded, growing actively. Ground sprayers can cover up to 2.5 m high brush
- ii) ***Basal bark treatment***: A better method of dealing with tall brushes Basal 30 cm of stem bark is peeled off then spraying is done to the point of liberal run-off
- iii) ***Cut stump treatment*** : It comprises sawing of the tree above the ground followed by liberal application of the herbicide on the cut surface

Other ways by which the concentrated herbicides are applied to unwanted trees are, frill, notch, and injection methods. The frills and notches are made with sharp tools into the sapwood at convenient stem height and filled with herbicides. The herbicide injections are made into holes made in the tree trunk. Usually, one herbicide injection per 2.5 cm stem thickness is adequate. The frill, notch, and injection methods are adopted on thick stem trees which are 8 cm or more in diameter.

III. Classification based on time of application of herbicides

Pre-plant treatment

An herbicide treatment made any time before the crop is planted is called a preplant treatment. There are two types of preplant treatment, namely (a) preplant desiccation and (b) preplant incorporation treatment. In the former method herbicides are applied to destroy the standing vegetation as an aid to seedbed preparation. Field preparation is done after the application. eg: Paraquat, Glyphosate. In the preplant incorporation method (PPI), on the other hand, herbicides are mixed with the soil in weed-free seed-beds to obtain residual control of weeds during the crop season. eg Fluchloralin, Pendimethalin, Trichloralin and Alachlor

Pre emergence treatment

Application of herbicides soon after planting of a crop is called pre emergence treatment. But sometimes, a pre emergence treatment is further specified as pre emergence to weeds, when it may be applied to standing, weed free crop rows, benthocarb, atrazine in maize, diuron in cotton pendimethalin, butachlor (pre-emergence selective herbicide)

Post emergence treatment

Post emergence treatment is the application of herbicide after the emergence of both the crops and the weeds. But when the weeds grow before the crop plants have emerged through the soil, and these are knocked with an herbicide, the treatment is called **early post emergence treatment**.

Herbicides used for the early post emergence treatment are usually non-residual types, e.g. paraquat and diquat.

Propanil in Rice at 25 DAT 2,4-D at 30 DAT of Paddy. Isoproturon both pre and post emergence in wheat

Herbicide selectivity:

It is the phenomenon where in a chemical kills the target plant species in a mixed plant population without harming or affecting the other plants. It is considered to be the greatest single factor that helped in the success of chemical weed control. Selectivity enables control of target weed species inspite of the presence of other plants.

Herbicide Persistence:

The length of the time that a herbicide remains active in the soil is called persistence or soil residual life. The quantity of herbicide that remains in soil after its mission is accomplished is referred as residue. The term residue infers the continued presence of herbicide in the soil in very small quantities even though it may not be present in herbicidal quantities or available plant absorption.

Allelopathy

The phenomenon of one plant having a detrimental effect on another through the production and release of toxic chemicals has been termed 'allelopathy'. These chemicals are called allelochemicals. *Parthenium* daughter plants exhibiting teletoxy to its parent plants is known as autotoxy. Allelopathic chemicals – are largely derivatives of benzoic acids, cinnamic acids, phenolic acids, coumarins, hydroquinones, benzoquinones,

The word allelopathy is derived from Greek – allelo, meaning each other and patho, an expression of sufferance of disease. These chemicals inhibit the seed germination of small grains with *Cyperus rotundus* extracts. Growth of wheat plants by *avena fatua* and *Phalaris minor* extracts. Reduction of germination of cabbage and egg plant by *Amaranthus retroflexus*. Inhibition of the growth of many agronomic plants by *Parthenium spp* extracts.

Allelopathic control of certain weeds using Botanicals

Carrot gross powder found to detrimental to other aquatic weeds. The presence of **marigold** (*Tagetes erecta*) plants exerted adverse allelopathic effect on *parthenium* spp growth. The **eucalyptus** tree leaf **leachates** have been shown to suppress the growth of nut sedge and bermuda grass.

1) Allelopathic effects of weeds on crop plants.

Root exudates of Canada thistle (*Cirsium sp.*) injured oat plants in the field. Root exudates of Euphorbia injured flax. But these compounds are identified as parahydroxy benzoic acid.

Leaves and inflorescence of *Parthenium sp.* affect the germination and seedling growth of maize and sorghum.

Quack grass produced toxins through root, leaves and seeds interfered with uptake of nutrients by corn.

Seeds of wild oat affect germination and early seedling growth of wheat.

2) Effect of weed on another weed

Thatch grass (*Imperata cylindrica*) inhibited the emergence and growth of an annual broad leaf weed (*Borreria hispida*).

In case of *parthenium*, daughter plants have allelopathic effect on parent plant. This is called **autotoxy**

3) Effect of crop on weed

Root exudates of wheat, oats and peas suppressed *Chenopodium album*. It increased catalase and peroxidase activity of weeds and inhibited their growth.

4) Stimulatory effect

Root exudates of corn promoted the germination of *orbanchae minor*.

Herbicide resistance:

Herbicide resistance is the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide that would normally be lethal to the wild type .

In a plant resistance may occur naturally due to selection or it may be induced through such technique as genetic engineering.

Most cases of herbicide resistance in weeds involve a single mutation or modification in some function so that the weed is resistant or cross resistant.

Effect of different weather parameters on crop growth and development

Crop growth and development

Growth is defined as an increase in the number, size, and volume of cells. Development is the emergence of specialized, morphologically different body parts.

Plant growth substances

Plant growth substances are biochemical produced in plants (endogenous) or synthetic substances applied to plants externally (exogenous) which cause modifications in plant growth and development.

Plant growth substances are biochemical produced in plants are known as phytohormones.

Plant growth substances are mainly grouped into growth promoters (which enhance plant growth) and growth retardants (which reduce plant growth).

There are five major groups of endogenous growth substances present in plants viz. auxins, cytokinins, gibberellins, abscisic acid and ethylene. Auxins, cytokinins and gibberellins are growth promoters while abscisic acid and ethylene are growth retardants.

Factors affecting crop growth and development

Internal or external

Internal or Genetic Factors

Genetic makeup decided the crop growth and its production. Crops vary in the genetic makeup which included desirable and 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.

External or Environmental Factors

Edaphic or Soil factors

Soil is a thin layer of the earth's crust which serves as a natural medium for the growth of plants.

Water

- Major component of the plant body (90%).
- Act as solvent for dissolving the nutrients and nutrient carrier.
- Maintains/regulates the temperature of plant and soil as well
- Maintains the turgidity of plant cells.
- Essential for absorption of nutrients and metabolic process of the plants.

1) **Biotic factors**

Biotic factors include plant, symbiosis and animals.

Plant

The soil and water are two variables which either has to be suitably adjusted for the plant to grow or the plant should be so bred and 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 and water condition e.g. drought resistant, disease resistant, more nutrients absorbing capacity etc.

Symbiosis

There are the some organisms which have mutual relationship with each other and with the prevailing environment of the place. This biological inter relationship among the organisms is termed as symbiosis. The symbiotic relationship between legumes and Rhizobia which results in 'N' fixation is of great significance to crop production.

Soil organisms

The soil organisms include 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 and algae.

Soil fauna is of two types: **i)** Macro flora e.g. earthworm, moles, ants, and **ii)** Micro fauna e.g. protozoa, nematodes. All these organisms contribute decomposition, when using the OM for their living. Among these insects, nematodes cause considerable damage as crop pests.

Beneficial organisms: Insects like bees, wasp, moths, butterflies, beetles help in pollination of crops. Burrowing by earthworm facilitates aeration and drainage and the ingestion of OM and mineral matter results in a constant mixing of these materials in the soil & tends to make better plant growth.

Small animals

Like rabbits, squirrels, rats cause extensive damage to field and garden crops.

2) Anthropic or Management

Finally, man must so manage the soil-water-plant complex to produce efficiently food and fodder and for that purpose a number of management practices and methods have been evolved. The soil, water, plant and management are four factors which govern successful crop production.

3) Climate

Another factor that influences the growth, development, and production of crop is the climate which is out of control by the man but management is possible. More than 50% of variation in yield of crops is solar radiation, temperature and rainfall. Relative humidity and 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. Relative 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 and back to the sea again what is known as the hydrologic cycle. Continuous circulation of water between hydrosphere, atmosphere and lithosphere called as hydrologic cycle. Precipitation includes rainfall, snow or hail, Fog drip and dew also contribute to moisture. The yearly precipitation, both in total amount and seasonal distribution greatly affects the choice of cultivated crops of a place.

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 - 40°C. Every plant community has its own minimum, optimum and 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 and heaving and heat injury.

3. Relative humidity

Water which is present in the atmosphere in the form of invisible water vapor, termed as humidity, 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 and bacteria which affect seriously the crop.

4. Solar radiation

Solar energy provides two essential needs of plants:

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

5. Wind velocity

It affects growth mechanically (damage to crop) and physiologically (evaporation and transpiration). Hot dry winds may adversely affect photosynthesis and 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.

Crop Ideotype

The crop Ideotype consists of several morphological and physiological traits which contribute for enhanced or higher yield than currently prevalent crop cultivars. Ideal plant types or model plants in crops like wheat, rice, and maize are briefly described below:

Wheat

The term ideotype was coined by Donald in 1968 working on wheat. He proposed ideotype of wheat with following main features.

1. A short strong stem. It imparts lodging resistance and reduces the losses due to lodging.
2. Erect leaves. Such leaves provide better arrangement for proper light distribution resulting in high photosynthesis or CO₂ fixation.
3. Few small leaves. Leaves are the important sites of photosynthesis, respiration, and transpiration. Few and small reduce water loss due to transpiration.
4. Larger ear. It will produce more grains per ear.
5. Presence of awns. Awns contribute towards photosynthesis.
6. A single culm.

Rice

The concept of plant type was introduced in rice breeding by Jennings in 1964, through the term ideotype was coined by Donald in 1968. He suggested that the rice an ideal or model plant type consists of 1) Semi dwarf stature. 2) High tillering capacity, and 3) Short, erect, thick and highly angled leaves (Jennings, 1964, Beachell and Jennings, 1965). Jennings also included morphological traits in his model. Now emphasis is also given to physiological traits in the development of rice ideotype.

Maize

In 1975, Mock and Pearce proposed ideal plant type of maize. In Maize, higher yields were obtained from the plants consisting of 1) Low tillers, 2) Large cobs, and 3) Angled leaves for good light interception. Planting of such type at closer spacing's resulted in higher yields.

Crop rotation, cropping systems (monocropping, intercropping, multistoried cropping, sole cropping, sole cropping and sequence cropping, relay cropping and mixed cropping)

Cropping pattern: - It means the proportion of area under various crops, at a point of time in a unit area. It indicates the yearly sequence and spatial arrangement of crops and fallow in an area.

Cropping System: It is an order in which the crops are cultivated on a piece of land over a fixed period.

Monocropping: or Monoculture refers to growing of only one crop on a piece of land year after year.
Ex: Rice – Rice

Disadvantage in Monocropping

- Improper use of moisture and nutrients from the soil
- Control of crop associated pests and weeds become a problem.

Crop rotation: It is a process of growing different crops in succession on a piece of land in a specific period of time with an object to get maximum profit from least investment without impairing soil fertility.

Principles of crop rotation:

1. The crops with tap roots should be followed by those which have a fibrous root system
2. The leguminous crops should be grown after non leguminous crops.
3. More exhaustive crops should be followed by less exhaustive crop.
4. Selection of crops should be demand based.
5. Selection of crops should be problem based.
6. The crops of the same family should not be grown in succession because they act like alternate host for insects, pests and disease pathogens.
7. An ideal crop rotation is one which provides maximum employment to the family and farm labour, the machines and equipments are efficiently used then all the agriculture operations are done simultaneously.

Multiple cropping

Growing two or more crops on the same piece of land in one agriculture year is known as '*Multiple cropping*'.

It is the intensification of cropping in time and space dimensions i.e., more number of crops with in a year and more number of crops on the same piece of land. It includes intercropping, mixed cropping and sequence cropping.

Inter Cropping: It is growing two or more crops simultaneously on the same piece of land with a definite row pattern.

Ex: Setaria + Redgram in 5:1 ratio; Groundnut + Redgram in 7:1 ratio

(a). Additive series and (b). Replacement series

Mixed cropping

It is the process of growing two or more crops together in the same piece of land. This system of cropping is generally practiced in areas where climatic hazards such as flood, drought, frost etc. are frequent and common.

Sequence cropping

It can be defined as growing of two or more crops in sequence on same piece of land in a farming year.

Depending on number of crops grown in an year. It is called double, triple and quadruple cropping involving two, three and four crops respectively.

Relay cropping: It is analogous to a relay race where crop hands over land to next crop in quick succession.

Ex: Maize – Early Potato – Wheat – Mungo

Overlapping system of cropping:

In this, the succeeding crop is sown in standing proceeding crop thus in this system before harvesting one crop the seeds of next crop are sown.

Ex: Maize potato onion bendi in North India.

Ratoon cropping: It refers to raising a crop with re growth coming out of roots or stalks after harvest of the crop. Ex: Sugarcane.

Multi Storied System: Growing of plants of different heights in same field at the same time is termed as multi storied cropping. Ex: Coconut – Pepper - banana – Pineapple.

Difference between intercropping and mixed cropping

S. No	Intercropping	Mixed cropping
1	The main objective is to utilize the space left between two rows of main crop especially during early growth period of main crop.	Main objective is to get at least one crop under any climatic hazards (flood, drought or frost) conditions.
2	More emphasis is given to the main crop and subsidiary crops are not grown at the cost of main crop thus there is no	All crops are given equal care and there is no main or subsidiary crop. Almost all the crops compete with one another.

	competition between main and subsidiary crop.	
3	Subsidiary crops are of short duration and they are harvested much earlier than main crop	The crops are almost of same duration.
4	Both the crops are sown in rows. The sowing time may be the same or the main crop is sown earlier than subsidiary crop.	Crops may be broad casted and sowing time for all the crops is the same.

Adaptation and distribution of crops

Distribution of commercial crop production throughout the world is governed by many factors, with the main ones being climate, soils, topography, insect pressure, plant disease and economic conditions. Crop adaptation is determined primarily by genotype-environment interaction, the suitability of a crop to a particular region depending largely on the climatic features of the region in relation to the requirements for normal growth and development of the crop.

Adaptation

Adaptation of crop plants depends on many factors, and is best considered in relation to a set of conditions (environmental, edaphic (soil) and biotic) rather than to a single factor alone. In many situations, one factor (e.g. water availability) may dominate the prevailing conditions and the nature of the plant's response then largely reflects its adaptation to the existing level of that factor. More typically, adaptation is expressed as a response to a combination of factors (e.g. temperature and day length) and the nature of the response then reflects the plant's adaptation to the factors in combination. Success of a plant in a particular environment rarely depends on possession of a single adaptive character. Rather, fitness or adaptation to an environment depends on possession of an optimum combination of characters that minimizes the deleterious effects and maximizes the advantageous effects.

Adaptation was described by Wilsie (1962) thus: 'an adaptation may be defined as any feature of an organism which has survival value under the existing conditions of its habitat. Such a feature or features may allow the plant to make fuller use of the nutrients, water, temperature or light, available, or may give protection against adverse factors such as temperature extremes, water stress, disease or insect pressures'.

Acclimation

In contrast to adaptation, acclimation (or hardening) is the non-heritable modification of plant characters caused by exposure to new environmental conditions such as warmer or drier weather. It results from temporary modifications to the plant phenotype caused by the changing environment. Generally, plants subjected to several cycles of mild water or low temperature stress suffer less injury from subsequent drought or very low temperature exposure than plants which have not been previously stressed.

Main principles of crop adaptation and distribution

- Adaptation of a crop species is reflected in its responses to the combined environmental, edaphic and biotic features of its growing environment.

- Adaptation reflects the heritable features of a plant that enable it to survive, reproduce, or both, in a given environment.
- Acclimation reflects the non-heritable modifications to the plant phenotype caused by exposure to environmental stresses that enable it to tolerate further and more severe stress.
- Growth is an increase in plant biomass over time, and is determined by the level of availability of all factors necessary for normal plant metabolism and function.
- Development is the progression of a plant through the successive stages of its normal life cycle.
- Economic performance in grain crops is dependent on the successful completion of all development phases from establishment to harvest maturity.
- Development in most modern crop cultivars is dependent more on temperature than day length and is accelerated by high temperatures, resulting in a shortened life cycle.
- The outcomes of competition reflect the relative adaptation of competing plants in optimizing their capture or use of essential factors for growth that are in limited supply.
- Competitive ability in modern crop cultivars is a function of area, activity and distribution in space and time of absorptive surfaces (roots for water and nutrients; leaves for light and CO₂) in crowded, productive situations.
- Water supply and temperature, sometimes aided by the buildup of pests and diseases, determine the maximum length of the growing season, the range of crops that can be grown, their optimum duration and likely yield.
- Adaptation to temperature is a major factor governing the natural distribution of plants and is a principal determinant in the selection of crop species for any location.

Factors affecting crop adaptation and distribution

Day length

The physiological response of plants to the relative lengths of the diurnal cycles of light (day length) and dark periods is called photoperiodism. The most fundamental aspect of this response is the transition from vegetative to reproductive phase in photoperiod sensitive plants, which includes most modern day crop species. Depending on their adaptation, photoperiod sensitive species are induced to progress from vegetative to reproductive phase when subjected to certain critical day lengths. Most species of tropical or sub-tropical adaptation are classified as **Short Day (SD) plants, long day plants (LD), Intermediate day plants and Day Neutral plants.**

1. (a) Short Day (SD) plants	Photoperiod less than 10 hours
(b) Strict Short Day	Flowering does not occur if the day length is above or below a critical value as the case may be.
(c) Short Long Day (SLD)	Short day plants requiring an induction period of long days.
2. (a) Long- Day (LD)	Plant required photoperiod over 14 hours
(b) Facultative	Effects of photoperiod's additive. Long day plants will flower in a subsequently unfavourable photoperiod.

(c) Long Short Day (LSD)	Long day plants requiring short day induction.
3. Intermediate- Day	Photoperiod of 12-14 hours with inhibition of reproduction either below or above these levels
4. Day Neutral (DN) plants	Not affected by variations in day length.

Day length variation at any location depends on its latitude. Day length increases with increasing latitude in summer, from 12 hours at the Equator to 24 at the Pole. In winter, it decreases with increasing latitude, from 12 hours at the Equator to zero at the Pole. Hence higher latitude locations experience greater day length variation through the year than those in the Equatorial zone - day length at the Equator itself remains constant at 12 hours throughout the year.

Temperature

Thermoperiodism

Some temperate crop species, particularly the cereals (wheat, oats, barley, rye) and brassicas (canola, rape) have both 'winter' and 'spring' types. Winter types require a period of exposure to very low temperatures (0-2°C) before they can respond to increasing spring day length.

Heat units

The lengths of the vegetative and reproductive phases in DN species are temperature dependent, being shorter when conditions are warm to hot and longer when it is cold.

To complete each phase or stage of development requires the accumulation of a certain total number of 'heat units' – the warmer the environment, the more rapidly the units are accumulated and the plant progresses to the next developmental phase or stage. The standard heat unit expression is degree days (°D), which are calculated for each day as the average temperature minus the base temperature for the species or cultivar. For example, a day with an average temperature of 16°C would count as 14°D for wheat and 6°D for maize. Total (°D) for any period is calculated as the sum of daily (°D) for all days in the period.

Competition

The concept of competition is fundamental to an understanding of adaptation, particularly with crop plants that are grown in moderate to high density monocultures. Here, competition for one or more factors almost always limits growth and yield in rain fed production systems.

Factors for which plants compete

The main factors are:

- Water
- Nutrients
- Light (solar radiation)
- Gases (carbon dioxide [CO₂] and oxygen [O₂])

Photosynthetic Pathway as an Adaptive Mechanism

A plant species that is capable of maximizing photosynthesis, within the constraints of the available resources in its physical environment, will have a significant competitive advantage over other species present in the community. The process of photosynthesis depends on the

intake of CO₂ through open stomata in the leaves. Most plants initially incorporate CO₂ into 3-carbon (3C) molecules, and these species are known as C₃ plants. In the second major group, C₄ plants, CO₂ is initially incorporated into 4-carbon (4C) molecules. The third group is Crassulacean Acid Metabolism (CAM) plants, in which leaf stomata are open at night to fix large amount of CO₂ and during day time stomata are closed.

Crop management technologies in problematic areas

Soil problems do not develop overnight, nor are they solved quickly. It can take years for salt to accumulate enough to reduce crop growth and/or water infiltration. Reclamation can take just as long. Before undertaking a reclamation program, a plan should be developed with a knowledgeable consultant. Understanding the implications and costs of a plan is important. In some situations, it is not economical or even possible to reclaim problematic soils. Management of problematic soils requires agronomic practices along with other reclamations methods. For instance, reclamation of problematic soils may begin with the provision of effective drainage and good quality irrigation water to lower the levels of soluble salts. Some salt affected soils can be reclaimed by adding Gypsum (CaSO₄), followed by leaching out of the sodium. Problematic soils are classified as:

(1) Salt affected soils (Saline soils, Sodic soils, and Saline-sodic soils)

(2) Acid soils

(3) Acid-Sulphate soils

(4) Calcareous soil

(5) Sandy soil

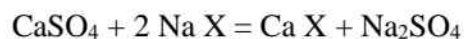
(6) Clayey soil.

Management of Saline and Non- saline alkali soil

Chemical Method:

Some chemicals are added to the soil as an integral part of the reclamation program adopted to improve the saline and alkali soils. These are known as chemical amendments. The principal purpose of the amendments is to furnish soluble calcium to replace exchangeable Na or to neutralize alkaline salts with acid. The various chemicals suitable for different soil conditions are:-

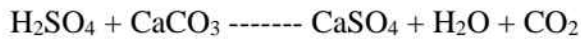
Gypsum: Gypsum a natural sulphate of calcium is found in large deposit in various parts of Rajasthan. It reacts with exchangeable Na with getting converted into sodium sulphate. Sodium sulphate is from the soil to reduce pH. The addition of gypsum improves the physical conditions of soil. Soils become flocculated and drainage improves.



Sulphur: Sulphur is a very effective chemical amendment to replaces exchangeable Na. Theoretically, one atom of sulphur replaces four Na ions by calcium. But under field conditions approximately, three exchangeable Na ions per atom of sulphur are replaced from the soil colloids.

Iron sulphate: Iron sulphate is sometimes used as a chemical amendment for improving alkali soil. Iron sulphate forms sulphuric acid, which is converted into calcium sulphate.

Calcium sulphate, thus formed replaces exchangeable sodium as indicated by following equations.



Lime stone: Ground limestone is applied to the soil having pH at 7.0 to 7.5. Since Calcium carbonate become insoluble as the pH increases, it is not effective on soils having pH more than 7.5. Following the reaction takes place:



When lime stone is applied to the soil, it gets dissolved in the soil solution. The Calcium of the lime stone reacts as with the spoil complex and replaces Na and Na combines with carbonate and form sodium carbonate which is leached down by flooding.

Mechanical method:

Flooding and leaching down of the soluble salts. The leaching can be done by ponding the water on the land and allowing it stand there for a week. Most of the soluble salts would leach down and below the root zone. After a week standing water is allowed to escape, such 2 to 3 times treatments given to reclaim highly saline soils. Sometime gypsum is also added to flood water when the soluble salts are low in Ca to check the development of alkalinity.

Scraping of the surface soil when the soluble salts accumulate on the soil surface, scraping helps to remove salts. This is a temporary cure and salinity again develops on such soils.

Cultural method

- Providing proper drainage if the soil is not free draining artificial drains are opened or tile drains laid underground to help wash out the salts.
- Few of salt free irrigation water good quality of irrigation should be given.
- Proper use of irrigation water, it is known that as the amount of water in the soil decrease the concentration of the salts in the soil solution of the salts in the soil solution is increasing thus moisture should be kept at optimum field capacity.

Use of acidic fertilizes: In saline soil acid fertilizers such as ammonium sulphate should be used

Use of organic manures: When sufficient amount of manures is added the water holding capacity of soil increased and as a result the conductivity of the soil solution decreases.

Ploughing and levelling of the land: Ploughing increasing the infiltration and percolation rate. Therefore salts leached down to the lower levels.

Returning of water evaporation: Mulching with crop residues or plastic sheet helps in decrease evaporation.

Growing of the salt tolerance crops:

Table: Tolerance of some crops to saline conditions

Sensitive (0-4 dS/m)	Moderately tolerant (4-6 dS/m)	Tolerant (6-8 dS/m)	Highly tolerant (8-12 dS/m)
Bean, Clover, Onion, Potato, Almond	Maize, Sorghum, Soybean, Tomato	Oats, Sunflower, Wheat	Barley, Cotton, Olive

Sodic soil:

- By drainage
- Tillage and addition of soil amendments
- Crop tolerance and supplying calcium to improve water infiltration

Saline sodic soil: Saline sodic soil must be treated as sodic soil first. These soils require calcium to correct a sodium problem, followed by leaching to remove salts. Sodium must be made soluble in a saline-sodic soil before the soil is leached with clean irrigation water. If salts are leached with clean water while sodium is insoluble, the result may be a sodic soil. The resulting destruction of soil structure will prevent water infiltration. It is extremely important to know how much of a sodium problem exists before applying clean irrigation water to leach salts.

Management of acid soils

1. Growing acid tolerant crops:

- (a) High acid tolerant crops: Rice, potato, sweet potato, oat, castor, etc.
- (b) Moderate acid tolerant crops: Barley, wheat, maize, turnip, brinjal, etc.
- (c) Slightly acid tolerant crops: Tomato, carrot, red clover.

2. Use of basic fertilizers: NaNO_3 and basic slag, etc.

3. Soil and water management

4. Ameliorating the soil through the application of amendments: (a) Lime stone (CaCO_3), (b) Quick lime (CaO), (c) Hydrated (stake) lime [$\text{Ca}(\text{OH})_2$], (d) Dolomitic limestone [$\text{CaMg}(\text{CO}_3)_2$]

Management of acid sulphate soils:

- (a) Controlling water table
- (b) Keeping the area flooded
- (c) Liming and leaching

Management of calcareous soils:

Management and reclamation of calcareous soils are not difficult because the pH in such soil is not very high. Generally, there is no need of chemical amendments for reclamation of calcareous soil. The calcareous soils can be managed in the following ways:

1. **Tillage operation:** Light (Sandy) calcareous soil develops a large number of pore spaces due to flocculation. This type of soil has poor water holding capacity. Therefore, such types of soils are needed compaction by plank and roller to increase the water holding capacity.
2. **Application of organic manure:** When sufficient amount of farmyard manure composts and green manure is added, the amount of carbon dioxide and acid increase and as a result pH of soil decreases.
3. **Use of chemical fertilizers:** Availability of phosphorus is less in calcareous soil. To increase the availability of P, the phosphorus fertilizers should be used in the following manner
 1. Phosphatic fertilizers should be used near the root of the plant.
 2. Use of Phosphatic fertilizer in ball form also increases the availability of P.
 3. P may be used in split form.
4. **Use of micronutrients:** Addition of micronutrients like Zn, Fe and Cu would be helpful in increasing the yield.

Management of sandy soils:

- (a) Compaction
- (b) Deep tillage
- (c) Use of amendments
- (d) Sub- surface Barrier
- (e) Soil mulching
- (f) Methods of irrigation
- (g) Management of applied nutrients

Management clayey soils:

- (a) Drainage
- (b) Good crop stand
- (c) Mulching
- (d) Control run-off and soil erosion.

Management of waterlogged soils:

Water logged soils are managed in the following ways:

Drainage: drainage removes excess water from the root zone that is harmful for the plant growth. Land can be drained by surface drainage, sub-surface drainage and drainage good method.

Controlled irrigation: Excess use of water in the irrigation results in water logged area.

To check the seepage of canal: Due to seepage land becomes water logged.

Flood control measures: Construction of bund may check water flows river of the cultivated land.

Plantation of trees having a higher evaporation rate: Transpiration rate of certain trees like Eucalyptus, Acacia is very high. In transpiration process the underground water is consumed by trees, thus lowering the ground water table.

Selection of crops and their varieties: Certain crops like paddy, water nut, jute and Sesbenia can tolerate waterlogged conditions. In trice crop sub-merged varies from variety to variety. Generally lowland and deep water varieties can tolerate water logging, but upland varieties do not have this capacity.

Methods of sowing: In water logged areas, sowing should be done on bunds or ridges. In this method there is a scope of good aeration near the root zone.

Nutrient management: Low nitrogen fertility is an important constraint in the waterlogged soil. The predominant form of nitrogen in water logged soils is NH_4 .

Harvesting and threshing of crops

Harvest constitutes a major operation among agricultural activities. Considered for a long time as the last step in production, it must rather be approached as the first one in the postproduction system, because of its influence on subsequent processing and preservation of the products.

Harvesting methods differ according to the part of the plant to be used. As regards forage crops, the whole plant is cut, but for underground crops (eg, groundnuts, roots and tubers),

the crop is lifted while the soil sticking to it is removed. With cereals, the crop is first cut either as a whole or partially (ears), and then threshed and cleaned to separate the grain from the ears and straw.

Harvesting

Harvesting, an important field operation for any food grain crops, is the cutting process carried out when the crop attains physiological maturity such that a maximum recovery of quality product is obtained. Harvesting a crop at an appropriate stage of maturity minimizes the field loss, thereby, increasing the total yield of crop. Consequently, to draw maximum benefit from the crop, harvesting must be done at the right time. Farmers generally judge the maturity by visual observation of colour of leaf and panicle. Recent investigations have shown that the delayed harvesting at low grain moisture led to considerable increase in field losses and deterioration in the grain quality, resulting in reduction in milling outcome. Timely harvest, on the other hand, can prevent such a loss. It has been reported that in South India, a total of 22% field loss and 2% reduction in milling yield occurred because of improper and delayed harvesting of IR 8 variety of paddy. Exact harvest time for each crop is, therefore, crucially essential for maximum recovery.

Table: Critical Period of Harvesting and Range of Grain moisture content for different crops

Crop	Critical period of harvest (Days after flowering)	Grain moisture content (%)	Harvest duration (Days)
Rice	26-33	22-27	6-10
Wheat	27-31	14-20	4-7
Soybean	84-92	18.5-32.4	7-10
Chickpea (Short duration)	98-107	17.5-37	9-11
Chickpea (Long duration)	109-119	15.5-23.5	9-12
Jowar	104-106	21-24	3-6

Threshing

The prime objective of the threshing process is to detach the undamaged grain kernels from the plants. In some crops, it also involves the removal of kernels from the protective cover called husk or seed coat. Traditionally, threshing is performed by treading the grain under the hooves of animals, striking the grains with sticks, beating them over a log of bamboo grating or over a ladder. The machine used for the purpose of grain detachment and separation is called a thresher and was introduced in India about 1960.

Traditional threshing

Conventionally, harvested paddy and wheat crops are either dried in the field or on a cemented floor for 3-5 days to bring down the moisture content from 27-40% to 15-20% when threshing operations are carried out.

Pedal threshing

Threshers of different designs and capacities are being manufactured by various companies in all over the countries. This type of thresher is small in size, manually operated and very common in small and marginal paddy farm.

Power threshing

The prime functions of threshing units are to detach grain kernels from husk or pod, separate them from broken stalks, leftovers and chaffs, convey and deliver the undamaged and broken grain or seed, free from foreign materials, to a delivery outlet and bag the grain for safe storage.

Questions from the syllabus

1. Define agriculture and agronomy.
2. Briefly discuss about the scope of agronomy.
3. What is seed? What is micro propagation? Briefly discuss about the factors affecting seed germination.
4. What is seed viability? What is seed dormancy? What are the methods to break seed dormancy?
5. Briefly discuss about different class of seed.
6. What is seeds act? What is seed testing? What type of seed testing's required to determine the quality of seed?
7. What is seed treatment? What are the objectives of seed treatment?
8. Briefly discuss about different methods of sowing along with advantages and disadvantages.
9. What is tillage? What are the objectives of tillage?
10. Discuss on different types of tillage in brief.
11. Define modern concepts of tillage? What is minimum tillage and zero tillage?
12. Why modern concepts of tillage is important in today's scenario? What are the different types of minimum tillage?
13. What is conservation tillage? What is puddling? Why puddling is important for transplanted rice crop?
14. What is optimum plant population? What is the importance of plant population in agriculture?
15. Define crop geometry. Discuss on different types of crop geometry.
16. What do you mean by essential plant nutrient? Classify different essential plant nutrient? What are the functions of all essential plant nutrients?
17. What is manure? Briefly classify manures.
18. What is fertilizer? Briefly classify fertilizer.
19. What is green manure? What are the benefits of green manuring?
20. What is bio-fertilizer? What are the importance of bio- fertilizer? What are the methods of bio-fertilizer application?
21. Define azolla, BGA, PSM, VAM.
22. What is vermicompost? Briefly explain the production method of vermicompost.
23. Define compost? Discuss on different methods of compost preparation.
24. Define sewage and sludge, night soil, poultry manure, sheep and goat manure.
25. What is concentrated organic manure? Write the nutrient value of different concentrated organic manure (Both plant and animal origin)
26. Briefly discuss about water resources of India.
27. What is irrigation? What are the advantages of irrigation?
28. What is water use efficiency? What are the criteria for scheduling irrigation?
29. What do you mean by weed? What is the importance of weed?
30. What is weed management? Briefly discuss on different methods of weed control.
31. What is crop weed competition? What is allelopathy?

32. What is herbicide? Briefly classify herbicide.
33. What is herbicide selectivity? Why weeds are unwanted plants?
34. Briefly discuss on plant growth substances.
35. What are the factors affecting plant growth and development.
36. What is crop ideotype? What are the features of rice and wheat crop?
37. What are the proposed ideotype of maize?
38. What do you mean by crop rotation? What are the principles and advantages of crop rotation?
39. Define inter cropping and mixed cropping? What are the major differences between inter cropping and mixed cropping?
40. Define relay cropping, Sequence cropping. What are the objectives of mixed cropping?
41. What is crop adaptation? What are the principles of crop adaptation?
42. What are the factors affecting crop adaptation and distribution?
43. What are the management strategies for saline and Non- saline alkali soil?
44. How to manage waterlogged soil and acid soil?