B.Sc. Ag
I Sem

Fundamentals of Agronomy

Credit - 4(3+1)

As per ICAR
5TH Dean Syllabus

Agronomy – definition – meaning and scope. Agro-climatic zones of India and Tamil Nadu – Agro ecological zones of India

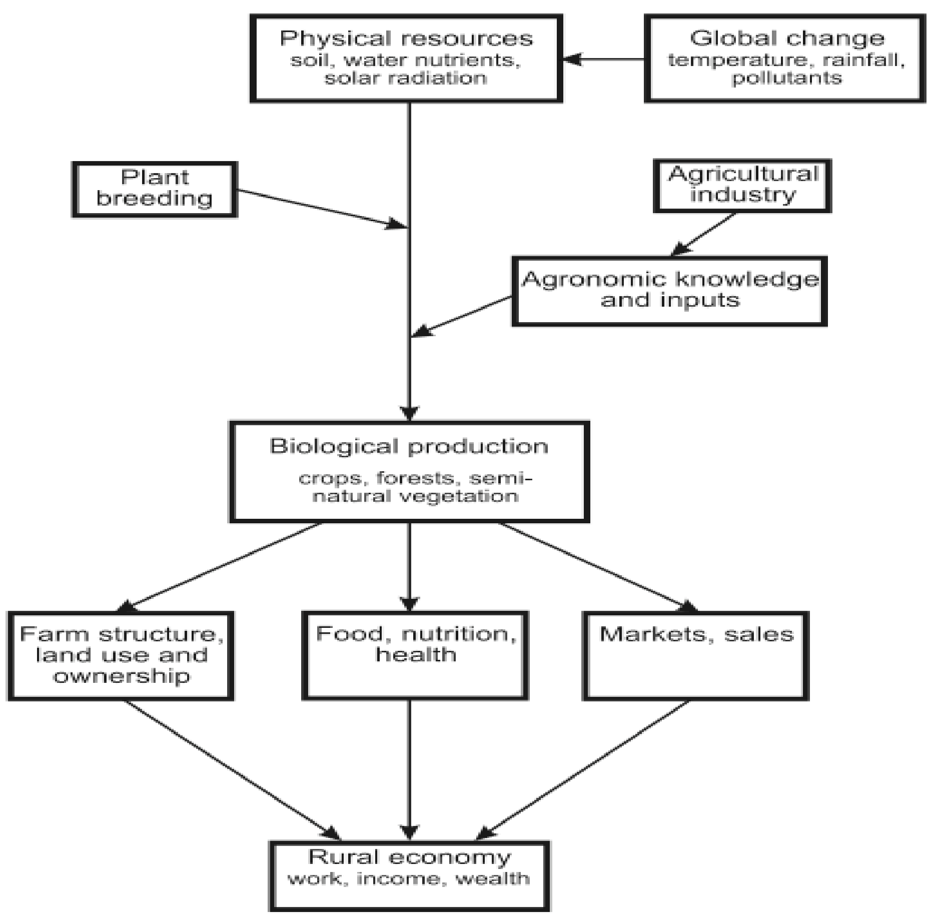
Agronomy is derived from a Greek word '**agros'** meaning 'field' and '**nomos'** meaning 'management'. Principles of agronomy deal with scientific facts in relations to environment in which crop are produced.

Definition of Agronomy

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

Boundaries and scale

Crop management, and its scientific study agronomy, are part of a system that comprises the physical elements of the climate, soil and land, the biological constituents of the vegetation and soil, the economic opportunities and constraints of markets, sales and profit, and the social circumstances and preferences of those who work the land.



Flow diagram of physical, biological, economic and social dimensions of agronomy

Scope of Agronomy

Agronomy is a dynamic discipline with the advancement of knowledge and better understanding of planet, environment and agriculture. Agronomy science becomes imperative in Agriculture in the following areas.

- Identification of proper season for cultivation of wide range of crops is needed which could be made possible only by Agronomy science.
- Proper methods of cultivation are needed to reduce the cost of cultivation and maximize the yield and economic returns.
- Availability and application of chemical fertilizers has necessitated the generation of knowledge to reduce the ill-effects due to excess application and yield losses due to the unscientific manner of application.
- Availability of herbicides for control of weeds has led to development for a vast knowledge about selectivity, time & method of its application.
- Water management practices play grater role in present day crisis of water demand and Agronomy science answer to the questions 'how much to apply?' and 'when to apply?'.
- Intensive cropping is the need of the day and proper time and space intensification not only increase the production but also reduces the environmental hazards.
- New technology to overcome the effect of moisture stress under dry land condition is explored by Agronomy and future agriculture is depends on dry land agriculture.
- Packages of practices to explore full potential of new varieties of crops are the most important aspects in crop production which could be made possible only by Agronomy science.
- Keeping farm implements in good shape and utilizing efficient manner to nullify the present day labour crisis is further broadening the scope of agronomy.
- Maintaining the ecological balance through efficient management of crops, livestock and their feedings in a rational manner is possible only by knowing agronomic principles.
- Care and disposal of farm and animal products like milk and eggs and proper maintenance of accounts of all transactions concerning farm business is governing principles of agronomy.

Relation of agronomy to other sciences

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

- The Soil Science helps the agronomist to thoroughly understand the soil physical, chemical and biological properties to effect modification of the soil environment.
- The Agricultural Chemistry help the agronomist to understand the chemical composition and changes involved in the production, protection, and use of crops and livestock.
- The crop physiology helps to understand the basic life process of crops to understand functioning of each parts of plant to determine their input requirement like nutrients etc.
- The plant ecology helps us to understand the associated environment in which the crops grown like the influence of weather (Temperature, Rainfall etc).
- The biochemistry shows the way in which biochemical process takes place in crops which helps to understand critical requirements to favourably activate this process.
- The economics paves the way for profit and loss analysis in farming.

Role of Agronomist

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

- Agronomist aims at obtaining maximum production at minimum cost by exploiting the knowledge of the basic and applied sciences for higher crop production.
- In a broader sense, agronomist is concerned with production of food and fibre to meet the needs of growing population.
- He develops efficient and economic field preparation method for sowing crops in different season. (Flat bed, Ridges and furrows)
- He is also involved to selection of suitable crop and varieties to suit or to match varied seasons and soils. Eg. Red soil - groundnut, Black soil - cotton, Sandy soil – tuberous crops, Saline soil – Finger millet (*Ragi*). In *Kharif* if water is sufficient go for rice and water is not sufficient go for maize, sorghum.
- Evolves efficient method of cultivation (whether broadcasting, nursery and transplantation or dibbling, etc.) provides better crop establishment and maintain required population
- He has to identify various types of nutrients required by crops including time and method of application (e.g. for long duration rice (150-60-60 kg NPK), short duration: 120:50:50 kg NPK/ha Application P&K basal and N in three splits)
- Agronomist must select a better weed management practice. Either through mechanical or physical (by human work) or chemical (herbicides or weedicides, e.g. 2-4-D) or cultural (by having wide space it may increase weed growth by using inter space crops). Weeds are controlled by integrated weed management method also
- Selection of proper irrigation method, irrigation scheduling i.e. irrigation timing and quantity based on the crops to be irrigated, whether to irrigate continuously or stop in between and how much water to be supplied are computed by agronomy science so as to achieve maximum water use efficiency.
- Crop planning (i.e.) suitable crop sequence are developed by agronomist (i.e.) what type of crop, cropping pattern, cropping sequence, etc. (Rice - Rice - Pulse)
- Agronomists are also develops the method of harvesting, time for harvesting, etc. (Appropriate time of harvest essential to prevent yield loss)
- Agronomist is responsible for every decision made in the farm management. (What type of crop to be produced? How much area to be allotted for each crop? How and when to market? How and When to take other management activities?) All the decisions should be taken at appropriate time to efficiently use resources available)

Agro-climatic zones

An agro-climatic zone is a land unit uniform in respect of climate and length of growing period (LGP) which is climatically suitable for a certain range of crops and cultivars (FAO, 1983).

Classification by Planning Commission

Planning Commission of India (1989) made an attempt to delineate the country into different agro climatic regions based on homogeneity in rainfall, temperature, topography, cropping and farming systems and water resources. India is divided into 15 agro-climatic regions.

1. Western Himalayan zone

This zone consists of three distinct sub-zones of Jammu and Kashmir, Himachal Pradesh and Uttar Pradesh hills. The region consists of skeletal soils of cold region, podsolic mountain meadow soils and hilly brown soils. Lands of the region have steep slopes in undulating terrain. Soils are generally silty loams and these are prone to erosion hazards.

2. Eastern Himalayan zone

Sikkim and Darjeeling hills, Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Tripura, Mizoram, Assam and Jalpaiguri and Coochibihar districts of West Bengal fall under this region, with high rainfall and high forest cover. Shifting cultivation is practiced in nearly one-third of the cultivated area and this has caused denudation and degradation of soils with the resultant heavy runoff, massive soil erosion and floods in lower reaches and basins.

3. Lower Gangetic Plains zone

This zone consists of West Bengal-lower Gangetic plain region. The soils are mostly alluvial and are prone to floods.

4. Middle Gangetic Plains zone

This zone consists of 12 districts of eastern Uttar Pradesh and 27 districts of Bihar plains. This zone has a geographical area of 16 million hectares and rainfall is high. About 39% of gross cropped area is irrigated and the cropping intensity is 142%.

5. Upper Gangetic Plains zone

This zone consists of 32 districts of Uttar Pradesh. Irrigation is through canals and tube wells. A good potential for exploitation of ground water exists.

6. Trans-Gangetic Plains zone

This zone consists of Punjab, Haryana, Union territories of Delhi and Chandigarh and Sriganganagar district of Rajasthan. The major characteristics of this area are: highest net sown area, highest irrigated area, high cropping intensity and high groundwater utilization.

7. Eastern Plateau and Hills zone

This zone consists of eastern part of Madhya Pradesh, southern part of West Bengal and most of inland Orissa. The soils are shallow and medium in depth and the topography is undulating with a slope of 1-10%. Irrigation is through tanks and tube wells.

8. Central Plateau and Hills zone

This zone comprises of 46 district of Madhya Pradesh, part of Uttar Pradesh and Rajasthan. The topography is highly variable nearly 1/3rd of the land is not available for cultivation. Irrigation and cropping intensity are low. 75% of the area is rainfed grown with low value cereal crops. There is an intensive need for alternate high value crops including horticultural crops.

9. Western Plateau and Hills zone

This zone comprises the major part of Maharastra, parts of Madhya Pradesh and one district of Rajasthan. The average rainfall of the zone is 904 mm. The net sown area is 65% and forests occupy 11%. The irrigated area is only 12.4% with canals being the main source.

10. Southern Plateau and Hills zone

This zone comprises 35 districts of Andhra Pradesh, Karnataka and Tamil Nadu which are typically semi-arid zones. Dryland farming is adopted in 81% of the area and the cropping intensity is 111 percent.

11. East Coast Plains and Hills zone

This zone comprises of east coast of Tamil Nadu, Andhra Pradesh and Orissa. Soils are mainly alluvial and coastal sands. Irrigation is through canals and tanks.

12. West Coast Plains and Ghats zone

This zone comprises west coast of Tamil Nadu, Kerala, Karnataka, Maharastra and Goa with a variety of crop patterns, rainfall and soil types.

13. Gujarat Plains and Hills zone

This zone consists of 19 districts of Gujarat. This zone is arid with low rainfall in most parts and only 32.5% of the area is irrigated largely through wells and tube wells.

14. Western Dry zone

This zone comprises nine districts of Rajasthan and is characterized by hot sandy desert, erratic rainfall, high evaporation, scanty vegetation. The ground water is deep and often brackish. Famine and drought are common features of the region.

15. Islands zone

This zone covers the island territories of Andaman and Nicobar and Lakshadeep which are typically equatorial with rainfall of 3000 mm spread over eight to nine months. It is largely a forest zone with undulated lands.

1	Western Himalayan Region	J&K, HP, UP, Utranchal
2	Eastern Himalayan Region	Assam Sikkim, West Bengal & North-Eastern states
3	Lower Gangetic Plains Region	West Bengal
4	Middle Gangetic Plains Region	UP, Bihar
5	Upper Gangetic Plains Region	UP
6	Trans-Gangetic Plains Region	Punjab, Haryana, Delhi & Rajasthan
7	Eastern Plateau and Hills Region	Maharastra, UP, Orissa & West Bengal
8	Central Plateau and Hills Region	MP, Rajasthan, UP
9	Western Plateau and Hills Region	Maharastra, MP & Rajasthan
10	Southern Plateau and Hills Region	AP, Karnataka, Tamil Nadu
11	East Coast Plains and Hills Region	Orissa, AP, TN,& Pondichery
12	West Coast Plains and Ghat Region	TN, Kerala, Goa, Karnataka, Maharastra

13	Gujarat Plains and Hills Region	Gujarat
14	Western Dry Region	Rajasthan
15	The Islands Region	Andman & Nicaobar, Lakshya Deep

Classification by ICAR

The State Agricultural Universities were advised to divide each state into sub-zones, under the National Agricultural Research Project (NARP) under ICAR. Based on the rainfall pattern, cropping pattern and administrative units, 127 agro-climatic zones are classified. The zones of each state are given below.

State	No. of zones	State	No. of zones
Andhra Pradesh	7	Madhya Pradesh	12
Assam	6	Rajasthan	9
Bihar	6	Maharashtra	9
Gujarat	8	North Eastern Hill region	6
Haryana	2	Orissa	9
Himachal Pradesh	4	Punjab	5
Jammu and Kashmir	4	Tamil Nadu	7
Karnataka	10	Uttar Pradesh	10
Kerala	8	West Bengal	6

The state of Tamil Nadu has been classified into seven distinct agro-climatic zones listed below.

1. North Eastern zone
2. North Western zone
3. Western zone
4. Cauvery Delta zone
5. Southern zone
6. High Rainfall zone
7. Hilly zone

1. North Eastern zone

This zone covers the districts of Thiruvallur, Vellore, Kanchipuram, Thiruvannamalai, Viluppuram, Cuddalore (excluding Chidambaram and Kattumannarkoil taluks), some parts of Perambalur including Ariyalur taluks and also Chennai. The mean annual rainfall of this region is 1054 mm received in 53 rainy days and is benefited by both the monsoons. The mean monthly maximum temperature ranges between 28.2 to 38.9 °C and the minimum ranges from 19.5 to 24.8°C.

2. North Western zone

This zone comprises of Dharmapuri and Krishnagiri district (excluding hilly areas), Salem, Namakkal district (excluding Tiruchengode taluk) and Perambalur taluk of Perambulur district. The climate prevailing in this region is dry and sub humid. This region has been identified as moderately drought prone area. The elevation varies from 330 to 1070 m above mean sea level. The mean annual rainfall of this region is appreciably lower than in North Eastern zone and is 825 mm received in 47 rainy days. The region is benefited by both south-west and north-east monsoon rains but unlike the NEZ, the former contributed more to the total rainfall. The mean monthly maximum temperature ranges between 30 to 37°C with minimum temperature ranging between 19 to 25.5°C. The annual PET of this region is 1727 mm compared to the annual precipitation of 825 mm.

3. Western zone

This zone comprises of Erode, Coimbatore, Dindigal, Theni districts, Tiruchengode taluk of Namakkal district, Karur taluk of Karur district and some western part of Madurai district. The mean annual rainfall is 718 mm in 45 rainy days. The monthly mean maximum temperature is 35°C in April and 30°C in January and November. The monthly mean minimum temperature is 19°C in January and 24°C in May.

4. Cauvery Delta zone

This zone comprises the Cauvery Delta area in Thanjavur, Thiruvarur, Nagapattinam districts and Musiri, Tiruchirapalli, Lalgudi, Thuraiyur and Kulithalai taluks of Tiruchirapalli district, Aranthangi taluk of Pudukottai district and Chidambaram and Kattumannarkoil taluks of Cuddalore district. The mean annual rainfall of the zone is 1078 mm out of which 40mm is received during winter, 69.2mm during summer, 295.4mm during South West Monsoon and 673.8mm during North East Monsoon.

5. Southern zone

This is the biggest among the seven zones of Tamil Nadu. It is typical zone surrounded by coastal areas on the East and mountains in the West. This zone comprises Sivagangai, Ramanathapuram, Virudunagar, Tuticorin and Tirunelveli districts and Natham and Dindigul taluks of Dindigul district, Melur, Tirumangalam, Madurai South and Madurai North taluks of Madurai district and Pudukkottai district excluding Aranthangi taluk. This zone lies on the Southern part of the State under rain shadow area. Because of this, the area is prone to drought very often. The climate is semi-arid tropics. The elevation varies from mean sea level to 300 m. The mean annual rainfall is 776 mm received in 43 rainy days. The monthly mean maximum temperature in this region ranges from 28.5°C in December to 38.5°C in June. The monthly mean minimum temperature varies from 21.0°C in January to 27.5°C in June.

6. High rainfall zone

This zone consists of Kanayakumari district. This district situated in the southern most part of the Peninsular India, with its high rainfall having a climate which is entirely different from the rest of the state. The climate is monsoon tropics and there is seasonal in shores flow of moist air. The elevation ranges from sea level to about 600 m. The mean annual rainfall of the district is 1469 mm received in 64 rainy days. There is not much fluctuation in the mean monthly air temperature. The monthly mean maximum temperature varies from 28.0°C in December to 33.5°C in May. The monthly mean minimum temperature varies from 22°C in December to 26.5°C in May.

7. High altitude and Hilly zone

This zone comprises the hilly regions, namely the Nilgiris, Shevroys, Elagiri-Javvadhu, Kollimalai, Patchaimalai, Anamalais, Palanis and Podhigaimalais. The rainfall varies from 850 mm in Kalrayan hills to about 4500 mm in Anamalai hills.

Agro-ecological zones of India

An ecological region is characterized by distinct ecological responses to macroclimate as expressed in vegetation and reflected in soils, fauna and aquatic systems. Therefore, an agro-ecological region is the land unit on the earth's surface carved out of agro-climatic region when superimposed on different landform and soil conditions that act as modifiers of climate and length of growing period (LGP).

National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) of the ICAR has delineated 20 agro-ecological regions (AERs) in the country using the FAO 1978 concept of superimposition of length of growing periods and bio-climate maps on soil physiographic map.

Arid ecosystem

1. Western Himalayas, cold eco-region, shallow soils, LGP <90 days.
2. Western plain Kachohh and parts of Kathiawar Peninsula, hot arid eco-region, desert and saline soils. LPG <90 days.
3. Deccan plateau, hot arid ecoregion, red and black soils. LGP <90 days.

Semiarid ecosystem

4. Northern plain and central high lands, hot semiarid eco-region, alluvial soils. LGP 90-150 days.
5. Central high lands, Gujarat plains, Kathiawar peninsula, hot semiarid eco-region, medium and deep black soils. LGP 90-150 days.
6. Deccan plateau, hot semiarid ecoregion. LGP 90-150 days.
7. Telangana, Eastern ghats, hot semiarid eco-region. LGP 90- 150 days.
8. Eastern ghats, Tamil Nadu uplands and Karanataka plateau, hot semiarid eco-region. LGP 90-150 days.

Subhumid Ecosystem

9. Northern plain, hot sub-humid (dry) eco-region, red and black soils. LGP 150-180 days.
10. Central highlands, hot sub-humid eco-region, black and red soils. LGP 150-180 (210) days.
11. Eastern plateau, hot sub-humid eco-region, red and yellow soils, (210) days. LGP 150-180 days.
12. Eastern plateau (Chotanagpur) and Eastern ghats hot sub-humid eco-region, red and lateritic soils. LGP 150-180 (210) days.
13. Eastern plain, hot sub-humid (moist) eco-region, alluvial soils. LGP 180-210 days.
14. Western Himalayas, warm sub-humid to humid eco-region with brown forest soils. LGP 180-210+ days.

Humid-Perhumid ecosystem

15. Bengal and Assam plain hot sub-humid (moist) to humid eco-region, alluvial soils. LGP 210+ days.
16. Eastern Himalayas, warm per-humid eco-region, brown and red hill soils. LGP 210 + days.
17. North eastern hills, warm per-humid eco-region, red and lateritic soils. LGP 210+ days.

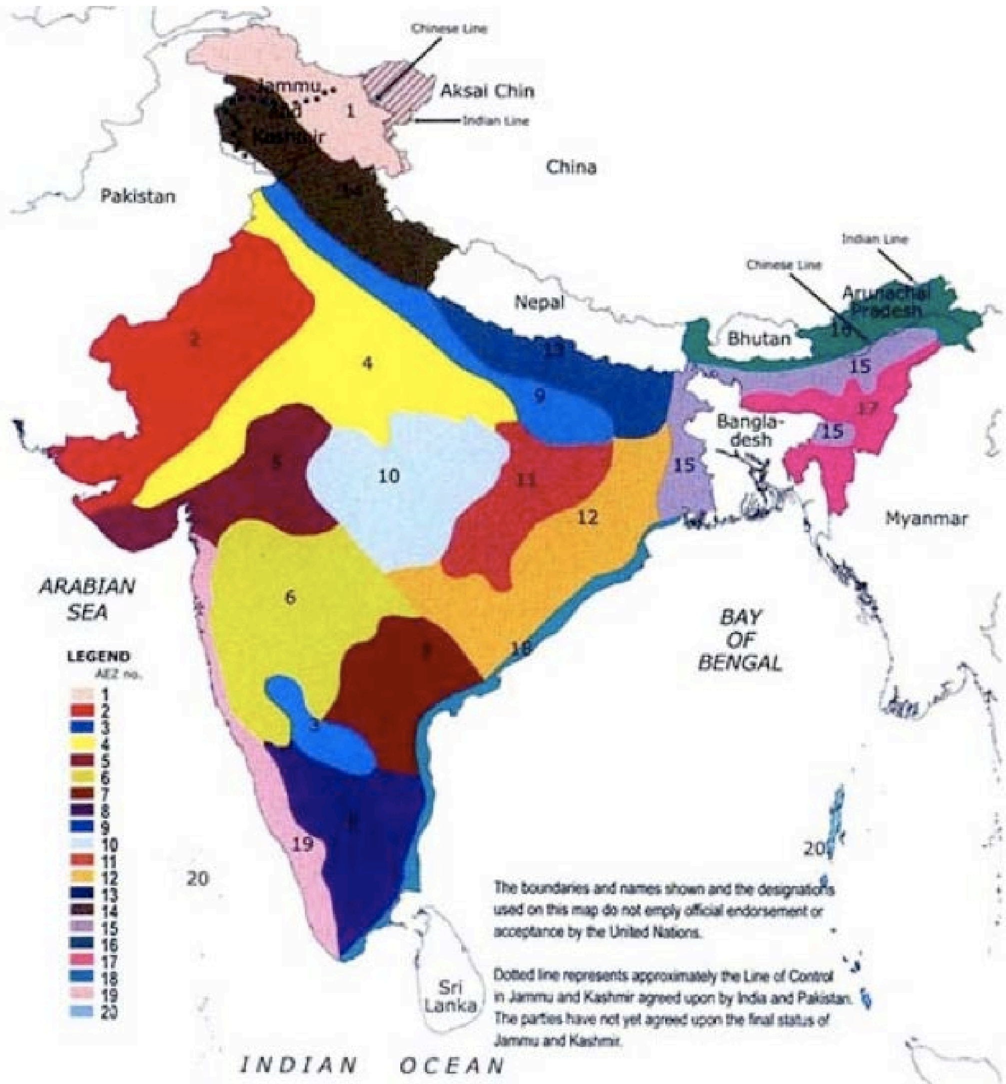
Coastal Ecosystem

18. Eastern coastal plain, hot sub-humid to semiarid eco-region, coastal alluvium. LGP 90-210 +days.
19. Western Ghats and coastal plain, hot humid-per-humid eco-region, red, lateritic and alluvium derived soils. LGP 210+ days.

Island Ecosystem

20. Andaman Nicobar and Lakshadeep, hot humid to per-humid eco-region, real loamy and sandy soils. LGP 210+ days.

The major advantage of LGP based criteria is that the LGP is the direct indicative of moisture availability of a given landform rather than the total rainfall. For example, both Ratnagiri in western Maharashtra and Nagpur in eastern Maharashtra have LGP 180-210 + days but the total annual rainfall of Ratnagiri is more than 2000 mm where as that of Nagpur is only 1100 mm. Therefore, agro-ecosystems approach allows crop planning based on length of growing period rather than the quantity of rainfall.



Chinese Line
Aksai Chin
Indian Line
Jammu and Kashmir
China
Pakistan
Nepal
Bhutan
Arunachal Pradesh
Indian Line
Chinese Line
Bangla-desh
Myanmar
ARABIAN SEA
BAY OF BENGAL
INDIAN OCEAN
Sri Lanka
LEGEND
AEZ no.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
The boundaries and names shown and the designations used on this map do not emply official endorsement or acceptance by the United Nations.
Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The parties have not yet agreed upon the final status of Jammu and Kashmir.

Crops and major soils - Classification – Economic and agricultural importance in India and Tamil Nadu

CROPS

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

Classification of crops

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

Classification types used in crops

1. Based on ontogeny (Life cycle)
2. Based on economic use (Agronomic)
3. Based on Botany (Scientific)
4. Based on seasons
5. Based on climate

1. Based on Ontogeny (Life cycle)

a) Annual crops:

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

b) Biennial crops:

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

c) Perennial crops:

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

2. Based economic use (Agronomic)

a) Cereals: Cereal derived from word 'Ceres' which denotes as 'Goddess' who was believed as the giver of grains by Romans. Cereals are the cultivated grasses grown for their edible starchy grains. Larger grains used as staple food – Rice, wheat, maize, barley, oats etc.

Cereal grain contains 60 to 70% of starch and is excellent energy rich foods for humans. In almost every country and region, cereals provide the staple food. In the world as a whole, only 5% of starchy staple food comes from root crops (mainly cassava, potato, and yams, depending on climate), whereas the rest is from cereal. Cereals are an excellent source of fat soluble vitamin E, which is an essential antioxidant. Whole cereal grains contain 20 to 30% of the daily requirements of the minerals such as selenium, calcium, zinc and copper.

b) Millets:

Millets are small grained cereals, staple food in drier regions of the developing countries are called 'millets'. They are also annual grasses of the group cereals. But' they are grown in lesser area or less important area whose productivity and economics are also less important. These are also staple food for people of poor countries. In India, pearl millet is a staple food in Rajasthan.

Millets are broadly classified in to two, 1) Major millets and 2) Minor millets.

Major millets

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

Minor millets

1. Foxtail millet / *Thenai* - *Setaria italica*
2. Little millet / *Samai* - *Panicum miliare*

3. Common millet / *Panivaraugu* - *Panicum miliaceum*
4. Barnyard millet / *Kudiraivali* - *Echinchloa colona* var *frumentaceae*
5. Kodo millet / *Varagu* - *Paspalum scrobiculatum*

c) Pulses:

Seeds of leguminous plants used as food (*Dhal)* rich in protein. Pod containing grain is the economic portion. Pulses are preferred for protein rich value & also economic important in cropping system. The wastes or stalk is called the 'haulm' or 'stover'. Haulm is used as green manure and has high value cattle feed. Green pods used as vegetables, e.g. cowpea, lablab. Seed coat of pulses are nutritious cattle feed.

1. Red gram - *Cajanus cajan*
2. Black gram - *Vigna mungo*
3. Green gram - *V. radiata*
4. Cowpea - *V. unguiculata*
5. Bengalgram - *Cicer arietinum*
6. Horsegram - *Macrotyloma uniflorum*
7. Lentil - *Lens esculentus*
8. Soybean - *Glycine max*
9. Peas or gardenpea - *Pisum sativum*
10. Garden bean - *Lablab purpureus*
11. Lathyrus/Kesari - *Lathyrus sativus*

d) Oil seeds: Those crops which are rich in fatty acid are cultivated for the production of vegetable oil. They are used either for edible or industrial or medicinal purposes.

1. Groundnut or peanut - *Arachis hypogeae*
2. Sesame or gingelly - *Sesamum indicum*
3. Sunflower - *Helianthus annuus*
4. Castor - *Ricinus communis*
5. Linseed or flax - *Linum usitatissimum*
6. Niger - *Guizotia abyssinia*
7. Safflower - *Carthamus tinctorius*
8. Rapeseed & Mustard
   Brown or Indian Mustard - *Brassica juncea*
9. Sarson - *Brassica sp.*

Groundnut:

Pod is economic portion in groundnut and contains 50% of oil content. Oil is edible or cooking oil and haulm is a used as cattle feed and also has manure value. The shell has fuel value; it is used for soil amendment. It is a bed material in the poultry forms. Oil cake is used as cattle feed and has manural value. Oil is used for production of *Vanaspathi* and soap making.

Sesame:

Sesame oil is cooking oil and economic parts are generally seeds (in the pod). Gingelly cake is used as a cattle feed, whereas capsule and stalk are used for composting / burning purpose.

Castor:

Seed (kernal) of castor contains oil and used as medicinal and industrial oil. Mainly aviation industries use this for lubrication purpose. Castor cake is concentrated organic manure. The shell and stalk is used for fuel purpose.

Mustard:

Mustard oil is edible oil and seeds are the economic portion. Oil cake is a good cattle feed.

Safflower and sunflower:

Oil is used for cooking purpose. Both of these oils contain more of unsaturated fatty acids and used for heart patients. Cake is used as cattle feed and also organic material and decorticated manure.

Niger:

Seed is the economic portion and used in soap making, paint, varnish & light lubricant. Crop is generally an industrial crop.

Linseed:

Oil extracted from seeds is used in preparation of paints and varnishes.

e. Sugar crops

Crops cultivated for sugar. Juice is extracted from stem of sugarcane used for jaggery or sugar. Number of by products like molasses, bagasse, pressmud etc. is obtained from sugar industry. Molasses used for alcohol and yeast formation and bagasse for paper making and fuel. Pressmud used for soil amendment; whereas, trash (green leaf + dry foliage) is used for cattle feed.

Sugar beet is another sugar crop where tubers are mainly used for extraction of sugar. Tubers and tops are used as a fodder for cattle feed.

1. Sugarcane - *Saccharum officinarum*
2. Sugar beet - *Beta vulgaris*

f) Fibre crops:

Plants are grown for obtaining fibre. Different kinds of fibre are, i) seed fibre – cotton; ii) Stem/ bast fibre – Jute, mesta; iii) leaf fibre – *Agave*, pineapple.

Cotton:

Important fibre crop of the world, used for garment purpose. Seed for cattle feed and oil is edible purpose. Epidermal hairs of seed coats is the economic portion. Lint (*Kapas*-seed) has industrial value (fibre) and stalk is of fuel nature.

Jute, *Sunnhemp*, mesta:

The fibre obtained from stems is used for gunny bags, ropes. Stem itself is used as fuel. Sunnhemp is used for both stem fibre and green manure crop.

g) Fodder / Forage: It refers to vegetative matter, fresh or preserved, utilized as feed for animals. It includes hay, silage, pasturage and fodder.

Ex. 1. Grasses - *Bajra napier* grass, guinea grass, fodder sorghum, fodder maize.

2. Legumes - Lucerne, *Desmanthus*, etc.

h) Spices and condiments: Crop plants or their products used for flavour, taste and add colour to the fresh or preserved food. Ex.– Ginger, garlic, fenugreek, cumin, turmeric, chillies, onion, coriander, anise and asafetida.

i) Medicinal plants: Crops used for preparation of medicines. Ex. Tobacco, mint. etc.

j) Beverages: Products of crops used for preparation of mild, agreeable and simulating drinking. Ex. Tea, coffee, cocoa (Plantation crops).

3. Scientific or botanical classification

Botanical or scientific names of plants which consist of genus and species and are universally accepted. Carolus Linnaeus, a Swedish botanist, was responsible for the binomial system of classification.

Group	Grass (Wheat)	Legume (Alfalfa)
Kingdom	Plant	Plant
Division	Spermatophyta	Spermatophyta
Sub-division	Angiospermae	Angiospermae
Class	Monocotyledonae	Dicotyledonae
Order	Graminales	Rosales
Family	Gramineae	Leguminosae

Tribe	Hordeae	-
Genus	*Triticum*	*Medicago*
Species	*aestivum*	*sativa*

4. Based on seasons

Crops are grouped under the seasons in which their major field duration falls.

a) Kharif crops: Crops grown during June-July to September–October which require a warm wet weather during their major period of growth and shorter day length for flowering.

Ex. Rice, maize, castor, groundnut.

b) Rabi crops: Crops grown during October–November to January-February, which require cold dry weather for their major growth period and longer day length for flowering.

Ex. Wheat, mustard, barley, oats, potato, bengal gram, berseem, cabbage and cauliflower.

c) Summer crops: Crops grown during February–March to May–June which require warm dry weather for growth and longer day length for flowering. Ex.Black gram, greengram, seasome, cowpea etc.

This classification is not a universal one. It only indicates the period when a particular crop is raised. Ex. *Kharif* rice, *kharif* maize, *rabi* maize, summer pulse etc.

5. Based on climatic condition

1) Tropical crop : Coconut, sugarcane
2) Sub-tropical crop : Rice, cotton
3) Temperate crop : Wheat, barley
4) Polar crop : All pines, pasture grasses

SOILS

Soil is defined as the thin layer of earth's crust made up of disintegrated and decomposed rocks, complex mineral compound, organic matter, water/air and living organism like bacteria, fungi, insects and worms and serves as the natural medium of growth of plants.

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

Classification based on soil taxonomy

Order : *Entisols* Suborder : Fluvents
Great Group : Torrifluvents Subgroup : Typic Torrifluvents
Family : Fine-loamy, mixed, superactive, calcareous, Typic Torrifluvents
Series : Jocity, Youngston.

Major soils of India

1. Alluvial soil (*Entisols, Inceptisols and Alfisol)*
2. Black soil (*Vertisol*)
3. Red soil (*Alfisol*)
4. Laterite soil (*Ultisol*)
5. Desert soil (*Aridisol*)
6. Forest soil and hill soil, peat and marshy soils
7. Problem soils (saline, alkali, acid)

1. Alluvial soil or Indo-Gangetic Alluvium

This is the most extensive soil found in India. Out of total area of India, 48.0 m.ha comes under river alluvium. These soils include deltaic alluvium, calcareous alluvium and coastal alluvium. Alluvial soils are formed by transportation in streams and rivers and are deposited in flood plains or along the coastal belts. Newly formed alluvium may not have distinct soil horizons while older alluvium may have soil horizons. They occur in the basins of Indus, Ganges, Brahmaputra, Godavari, Krishna, Cauvery and Tambiraparani deltas spread in U.P., Bihar, West Bengal, Gujarat, Punjab, Rajasthan, Andhra Predesh, Tamil Nadu.

Newer alluvium is called as *Khadar*, is sandy, light colour and less *Kankar* nodules. Older alluvium is called as *Bhangar*, full of clay, dark colour and more *Kankar* nodules. Alluvial soils of high altitude are acidic in nature and plains are neutral to alkaline. Alluvial soils of plains are medium in phosphorous content and high in potassium content. Generally, alluvial soils are rich in nutrients and are fertile and they support good crop growth with plenty of water. Many crops including vegetable are cultivated in river alluvium. Crops like rice, wheat, cotton, maize, sugarcane, vegetables, jute, oil seeds, millets, pulses and fruits are cultivated in these soil.

2. Black soil

Dark-grey in colour due to clay-humus complex. Area around 32.0 m.ha is under this soil. This soil is also called black cotton soil, mixing of soil along the entire column with *Montmorillonite* clay. Cotton grows very well with water available in soil. Black soil holds more moisture and available for a long time. Found in Maharashtra, Madhya Pradesh, South Orissa, South and Coastal Andhra Pradesh, North Karnataka and parts of Tamil Nadu. Black soil contains high proportion of clay (30-40%), so, the water holding capacity is high. Typical characteristics of this black soil are swelling (during wet period) and shrinkage (dry period). While dry, it forms very deep cracks of more than 30-45 cm. In Kovilpatti (Tamil Nadu) areas the cracks may extend to 2 to 3 m with a width of 1 to 6 cm. Field preparation takes longer time compared to other soil. Only after secondary tillage, the soil is suited for crop production. The soils are fine grained contain high proportion of Calcium and Magnesium carbonates. They are poor in N, medium in P and medium to high in K (Characteristic feature of typical Indian soil).

In Tamil Nadu Black soils have high pH (8.5 to 9) and are rich in lime (5-7%), have low permeability. The soils are with more cation exchange capacity (40-60 m.e./100 g). Crops grown in this soil are cotton, bengal gram, mustard, millets, pulses, oil seeds (sunflower, safflower) are commonly grown in this soil. Most of the soils come under rainfed areas.

3. Red soil

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

4. Laterites and Lateritic soil

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

5. Desert soil

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

6. Peaty and Organic soil

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

7. Problem soil

Saline soils: Contain excess amounts of neutral soluble salts dominated by chlorides and sulphates of Na, Ca and Mg affects plant growth. White encrustation of salts and hence called white alkali. These soils are characterized by, EC: $4 dSm^{-1}$ at 25°C, ESP: < 15; pH; < 8.5. This soil needs leaching and drainage before cropping for amelioration.

i) High salt tolerant: *Sesbania*, Rice, sugarcane, oats, berseem, lucerne, indian clover & barley.
ii) Medium salt tolerant: Castor, cotton, sorghum, pearl millet, maize, mustard & wheat.
iii) Low salt tolerant: Pulses, peas, *Sunnhemp*, gram, linseed and sesame.

Sodic / Alkali soils: High content of carbonates and bicarbonates of Na. Hence, they are with high exchangeable sodium percentage (ESP) with dark encrustation, hence called as black alkali. These soils are rich in $NaHCO_3$ and characterized by pH: > 8.5; EC : < $4 dSm^{-1}$; ESP : > 15. Use gypsum ($CaSO_4$, $2H_2O$) as amendment for reclamation of sodic alkali soils. Iron pyrites (FeS_2), bulky organic manures (especially green manure) and crop residues which produces weak organic acids.

i) Tolerant crops: Karnal / rhodes / para/ bermuda grass, rice and sugar beet.
ii) Semi–tolerant: Wheat, barley, oats, berseem and sugarcane.
iii) Sensitive: Cowpea, gram, groundnut, lentil, peas and maize.

Acid soils: These are low pH with high amounts of exchangeable H^+ and Al_3. Occur in regions with high rainfall. Significant amount of partly decomposed organic matter exist. Have low CEC and high base saturation. Liming and judicious use of fertilizers are the management measures suggested. Suitable crops: Acedophytes (like potato).

Comparison of three types of soils

Parameters	Saline soil	Saline alkali	Alkali soil
EC (dS/m)	>4	>4	<4
ESP (%)	<15	>15	>15
pH	<8.5	<8.5	>8.5

Soils of Tamil Nadu

Type of Soil	**Areas in Tamil Nadu**
Red loam (79.8 L. ha & 61.7%)	Parts of Kancheepuram, Cuddalore, Salem, Dharmapuri, Coimbatore, Tiruchirappalli, Thanjavur, Ramanathapuram, Madurai, Tirunelveli, Sivagangai, Thoothukudi, Virudhunagar, Dindigul and The Nilgiris Districts.
Laterite soil (3.8 L.ha & 2.9%)	Parts of The Nilgiris District
Black soil (15.0 L. ha & 11.6%)	Parts of Kancheepuram, Cuddalore, Vellore, Thiruvannamalai, Salem, Dharmapuri, Madurai, Ramanathapuram, Tirunelveli, Sivagangai, Thoothukudi, The Nilgiris, Virudhunagar and Dindigul Districts.
Sandy coastal alluvium (9.8 L. ha & 7.6%)	On the Coasts in the districts of Ramanathapuram, Thanjavur, Nagapattinam, Cuddalore, Kancheepuram and Kanyakumari
River alluvium (21.0 L. ha & 16.2%)	All river deltaic areas (Cauvery, Vaigai, Tambiraparani)

Source: Department of Economics and Statistics, Chennai

Tillage – Definition – objectives – types of tillage - modern concepts of tillage – main field preparation

Tillage

Tillage operations in various forms have been practiced from the very inception of growing plants. Primitive man used tools to disturb the soils for placing the seeds. The word tillage is derived from 'Anglo-Saxon' words *Tilian* and *Teolian*, meaning 'to plough and prepare soil for seed to sow, to cultivate and to raise crops'. **Jethrotull,** who is considered as father of tillage suggested that thorough ploughing is necessary so as to make the soil into fine particles.

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

Tilth is the physical condition of soil obtained out of tillage (or) it is the result of tillage. The tilth may be a coarse tilth, fine tilth or moderate tilth.

Objectives of tillage

The main objectives of tillage are,

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

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

Types of tillage: Tillage operations may be grouped into

1. On season tillage 2. Off-season tillage

<u>1. On-season tillage</u>

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

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

Types of preparatory tillage

a. Primary tillage
b. Secondary tillage

a. Primary tillage: The tillage operation that is done after the harvest of crop to bring the land under cultivation is known as primary tillage or ploughing. Ploughing is the opening of compact soil with the help of different ploughs. Country plough, mould board plough, bose plough, tractor and power tiller drawn implements are used for primary tillage.

b. Secondary tillage: The tillage operations that are performed on the soil after primary tillage to bring a good soil tilth are known as secondary tillage. Secondary tillage consists of lighter or finer operation which is done to clean the soil, break the clods and incorporate the manure and fertilizers. Harrowing and planking is done to serve those purposes.

Planking is done to crush the hard clods, level the soil surface and to compact the soil lightly. Harrows, cultivators, *Guntakas* and spade are used for secondary tillage.

c. Layout of seed bed:This is also one of the components of preparatory tillage. Leveling board, buck scrapers etc. are used for leveling and markers are used for layout of seedbed.

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

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

Special purpose tillage: Tillage operations intended to serve special purposes are said to be special purpose tillage. They are,

a. Sub-soiling: To break the hard pan beneath the plough layer, special tillage operation (chiseling) is performed to reduce compaction. Sub-soiling is essential and once in four to five years where heavy machineries are used for field operations, seeding, harvesting and transporting. Advantages of sub-soiling are, greater volume of soil may be obtained for cultivation of crops, excess water may percolate downward to recharge the permanent water table, reduce runoff and soil erosion and roots of crop plants can penetrate deeper to extract moisture from the water table.

b. Clean tillage: It refers to working of the soil of the entire field in such a way no living plant is left undisturbed. It is practiced to control weeds, soil borne pathogen and pests.

c. Blind tillage: It refers to tillage done after seeding or planting the crop (in a sterile soil) either at the pre-emergence stage of the crop plants or while they are in the early stages of growth so that crop plants (sugarcane, potato etc.) do not get damaged, but, extra plants and broad leaved weeds are uprooted.

d. Dry tillage: Dry tillage is practiced for crops that are sown or planted in dry land condition having sufficient moisture for germination of seeds. This is suitable for crops like broadcasted rice, jute, wheat, oilseed crops, pulses, potato and vegetable crops. Dry tillage is done in a soil having sufficient moisture (21-23%). The soil becomes more porous and soft due to dry tillage. Besides, the water holding capacity of the soil and aeration are increased. These conditions are more favourable for soil micro-organisms.

e. Wet tillage or puddling: The tillage operation that is done in a land with standing water is called wet tillage or puddling. Puddling operation consists of ploughing repeatedly in standing water until the soil becomes soft and muddy. Puddling creates an impervious layer below the surface to reduce deep percolation losses of water and to provide soft seed bed for planting rice. Puddling is done in both the directions for the incorporation of green manures and weeds. Wet tillage destroys the soil structure and the soil particles that are separated during puddling settle later. Wet tillage is the only means of land preparation for transplanting semi-aquatic crop plant such as rice. Planking after wet tillage makes the soil level and compact. Puddling hastens transplanting operation as well as establishment of seedlings. Wet land ploughs or worn out dry land ploughs are normally used for wet tillage.

Depth of ploughing

The desirable depth of ploughing is 12 to 20 cm for field crops. The ploughing depth varies with effective root zone of the crop. The depth of ploughing is 10-20 cm for shallow rooted crops and 15-30 cm for deep rooted crops.

Number of ploughing

Number of ploughing depends on soil conditions, time available for cultivation between two crops and type of cropping systems. Zero tillage is practiced in rice fallow pulses. Minimum number of ploughing is taken up at optimum moisture level to bring favourable tilth depending on need of the crop.

Time of ploughing

The optimum soil moisture content for tillage is 60% of field capacity.

Modern concepts in tillage:

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

1. Minimum tillage: It aims at reducing tillage operations to the minimum necessity for ensuring a good seed bed. The advantages of minimum tillage over conventional tillage are,

- The cost and time for field preparation is reduced by reducing the number of field operations.
- Soil compaction is comparatively less.
- Soil structure is not destroyed.
- Water loss through runoff and erosion is minimum.
- Water storage in the plough layer is increased.

Tillage can be reduced in 2 ways

1. By omitting operations which do not give much benefit when compared to the cost.
2. By combining agricultural operations like seeding and fertilizer application.

The minimum tillage systems can be grouped into the following categories,

1. Row zone tillage

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

2. Plough plant tillage

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

3. Wheel track tillage

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

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

2. Zero tillage (No tillage): In this, new crop is planted in the residues of the previous crop without any prior soil tillage or seed bed preparation and it is possible when all the weeds are controlled by the use of herbicides. Zero tillage is applicable for soils with a coarse textured surface horizon, good internal drainage, high biological activity of soil fauna, favourable initial soil structure and an adequate quantity of crop residue as mulch. These conditions are generally found in *Alfisols*, *Oxisols* and *Ultisols* in the humid and sub-humid tropics.

Till planting

Till planting is one method of practicing zero tillage. A wide sweep and trash bar clears a strip over the previous crop row and planter opens a narrow strip into which seeds are planted and covered. Here, herbicide functions are extended. Before sowing, the vegetation present has to be destroyed for which broad spectrum non selective herbicides like glyposate, paraquat and diquat are used.

Advantages

- Zero tilled soils are homogenous in structure with more number of earthworms.
- Organic matter content increases due to less mineralization.

- Surface run-off is reduced due to presence of mulch.

Disadvantages

- Higher amount of nitrogen has to be applied for mineralization of organic matter in zero tillage.
- Perennial weeds may be a problem.
- High number of volunteer plants and buildup of pests.

3. Stubble mulch tillage or stubble mulch farming

Soil is protected at all times either by growing a crop or by leaving the crop residues on the surface during fallow periods. Sweeps or blades are generally used to cut the soil up to 12 to 15 cm depth in the first operation after harvest and depth of cut is reduced during subsequent operations. When large amount of residues are present, a disc type implement is used for the first operation to incorporate some of the residues into the soil. This hastens the decomposition but still keeps enough residues on top soil.

Two methods for sowing crops in stubble mulch tillage are,

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

Disadvantages of stubble mulch farming

- The residues left on the surface interfere with seed bed preparation and sowing operations.
- The traditional tillage and sowing implements or equipments are not suitable under these conditions.

4. Conservation tillage: The major objective is to conserve soil and soil moisture. It is a system of tillage in which organic residues are not inverted into the soil such that they remain on surface as protective cover against erosion and evaporation losses of soil moisture. If stubble forms the protective cover on the surface, it is usually referred to as stubble mulch tillage. The residues left on soil surface interfere with seed bed preparation and sowing operations. It is a year round system of managing plant residue with implements that undercut residues, losses the soil and kills the weeds.

Advantages

- Energy conservation through reduced tillage operations.
- Improve the soil physical properties.
- Reduce the water runoff from fields.

<u>Main field preparation:</u>

Tillage operations are generally classified in to two, preparatory cultivation and after cultivation. The preparatory cultivation or tillage is operations that are done before the cultivation. This preparatory cultivation is generally called as main field preparation. The main field preparation involves three processes, viz., primary tillage, secondary tillage and lay-out for sowing. Some of the important primary tillage implements are country plough, mould board plough, disc plough, chisel plough etc. Cultivators and harrows are generally used for secondary tillage purpose. However, in practical means, the first two (primary and secondary tillages) may not have any key difference, since; both operations are mainly carried out with same implement. Country plough and cultivators are used for both the purposes. After thorough ploughing, the field modified in to suitable way for planting such as ridges and furrows or beds and channels or pit according to the need of the crops. Such field modifications are mandatory for better crop production.

Seeds - Seed rate - Sowing methods - Germination - Crop stand establishment - Planting geometry

SEEDS

Plant propagation is made in two ways, Sexual (by seeds) and asexual (by vegetative means). Biologically, seed is a ripe, fertilized ovule and a unit of reproduction of flowering plants.

SEED RATE

The required number of plants/unit area is decided by calculating the seed rate. The seed rate depends on spacing or plant population, test weight, germination percentage. The formula is as follows.

$$\text{Seed rate (kg/ha)} = \frac{\text{Plant population (per ha)} \times \text{No. of seeds/hill} \times \text{Test weight (g)} \times 100}{1000 \times 1000 \times \text{Germination percentage (\%)}}$$

SOWING METHODS

1. Broadcasting
2. Dibbling
3. Sowing behind the country plough (manual and mechanical drilling)
4. Seed drilling
5. Nursery transplanting

1. Broadcasting

Broadcasting is otherwise called as random sowing. Literally means 'scattering the seeds'. Broadcasting is done for many crops. Broadcasting is mostly followed for small sized to medium sized crops. This is the largest method of sowing followed in India, since; it is the easiest and cheapest and requires minimum labours. To have optimum plant population in unit area certain rules should be followed.

- Only a skilled person should broadcast the seeds for uniform scattering.
- The ploughed field should be in a perfect condition to trigger germination.

The seeds are broadcasted in a narrow strip and the sowing is completed strip by strip. To ensure a good and uniform population, it is better to broadcast on either direction. This is called criss-cross sowing. If the seed is too small, it is mixed with sand to make a bulky one and for easy handling. Ex. Seasame seeds are mixed with sand at 1:15 or 1:10 ratio and sown.

In certain cases the person sowing will be beating the seeds against the basket for uniform scattering. Ex. Sorghum, pearl millet.

After broadcasting, the seeds are covered gently either using a country plough with a very shallow ploughing or some wooden planks (boards / levelers) are used to cover the surface. In some cases, tree twigs or shrub branches are used. If the seeds are large, levelers collect the seeds and leave in the other side. Comb harrow is the best used one.

Disadvantages

- All the seeds broadcasted do not have contact with the soil. 100% germination is not possible.
- Enhanced seed rate is required.
- Seeds cannot be placed in desired depth. Desired depth ensures perfect anchorage. Lodging (falling down) is common in broadcasting.

2. Dibbling

This is actually line sowing. Inserting a seed through a hole at a desired depth and covering the hole. Dibbling is practiced on plain surface and ridges and furrows or beds and channels. This type of sowing is practiced only under suitable soil condition. Rice fallow cotton is dibbled on a plain surface. The seeds are dibbled at 2/3rd from top or 1/3rd at bottom of the ridge. Before sowing, furrows are opened and fertilizers are applied above which seeds are sown. The seeds do not have contact with the fertilizers. This is done for wider spaced crops and medium to large sized seeds. Ex. Sorghum, maize, sunflower, cotton are dibbled on ridges and furrows. Both beds and channels; and ridges and furrows come under line sowing. While earthing up, the plant occupies middle of the ridge. Earthing up is essential for proper anchorage of the root system.

Advantages of line sowing are, (i) uniform population, (ii) better germination, (iii) reduced seed rate.

Sl. No.	Dibbling (Line sowing)	Broadcasting (Random sowing)
1.	Costlier	Cheaper
2.	Takes considerable time	Quickest and time saving
3.	Fixed seed rate	Higher seed rate
4.	Mechanization is possible, e.g. weeding, harvesting	Not possible
5.	Uniform utilization of resources (land, water, light, nutrient, etc.)	Resource utilization is un-uniform

3. Sowing behind the plough

Sowing behind the plough is done by manual or mechanical means. Seeds are dropped in the furrows opened by the plough and the same is closed or covered when the next furrow is opened. The seeds are sown at uniform distance. Manual method is a laborious and time consuming process. Seeds like redgram, cowpea and groundnut are sown behind the country plough. Major sown crop is ground out. Seeds are sown by mechanical means by Gorus – seed drill. A seed drill has a plough share and hopper. Seeds are placed on hopper. Different types of seed drill are available, e.g., simple Goru – Guntakas.

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

4. Drill sowing (or) Drilling

Drilling is the practice of dropping seeds in a definite depth covered with soil and compacted. In this method, sowing implements are used for placing the seeds into the soil. Both animal drawn Gorus 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. It is possible to take up sowing of inter crops also. It requires more time, energy and cost, but maintains uniform population per unit area. Seeds are placed at uniform depth, covered and compacted.

5. Transplanting

This method of planting has two components, a. nursery and b. transplanting. In nursery, young seedlings are protected more effectively in a short period and in a smaller area. Management is easy and economical.

Advantages

- Can ensure optimum plant population
- Sowing of main field duration, i.e., management in the main field is reduced
- Crop intensification is possible under transplanting

Disadvantages

- Nursery raising is expensive
- Transplanting is another laborious and expensive method

Age of seedlings is 1/4th of the total duration of the crop. If the total duration is 16 weeks, four week period (1 month) is under nursery beds. Nursery age is not very rigid, e.g., thumb rule – 3 months crop – nursery duration 3 weeks, minimum 4 months – 4 weeks minimum period; 5 months

– 5 weeks. After the nursery period, seedlings are pulled out and transplanted. This is done on the main field after thorough field preparation or optimum tilth. The seedlings are dibbled in lines or in random. Closer spaced crops are mostly raised in random method even after nursery, Ex. rice and finger millet. For vegetables, desired spacing is required during transplanting. Transplanting shock is a period after transplanting, the seedlings show no growth. This is mostly due to the change in the environment between root and the soil. The newly planted seedlings should adjust with new environment. It is for a period of 5-7 days depending upon season, crop, variety, etc. At higher temperature, dehydration is possible and leaves dried out. Area required for nursery normally is $1/10^{th}$ of the total area.

GERMINATION

- Germination is a protrusion of radicle or seedling emergence.
- Germination results in the rupture of the seed coat and emergence of seedling from embryonic axis.

Factors affecting seed germination

1. Soil: Soil type, texture, structure and microorganisms greatly influence the seed germination.
2. Moisture: When the seeds do not get required moisture in the soil, the viability is lost. When the moisture is excess after germination, it will lead to rotting of the sprouts.
3. Temperature: When it is above and below the optimum temperature, the germination rate will be affected.
4. Light: The most effective wavelength for promoting germination is red (662 nm) and 730 nm inhibits germination.
5. Soil condition: a. Tilth is the most important soil factor influences on germination of seed. Small seeds require fine tilth whereas, moderate and larger seeds requires medium and coarse tilth soils, respectively.

   b. Depth of sowing: The seeds should be placed at optimum depth. When the seeds are placed at deeper layers they have to spend more energy for germination. When it is placed on soil surface, it will be taken away by birds/worked away. The thumb rule is to sow seeds to a depth of approximately 3 to 4 times diameter of the seed. The optimum depth of sowing for most of the field crops ranged between 3 and 5 cm depth. The seeds sown should be protected from rodents or birds before germination by employing labourers to scare the birds at least for three days after sowing.

CROP STAND ESTABLISHMENT

Good crop establishment is one of the most important features in better crop production. The better crop establishment is in turn expressed as optimum plant population in fields. Number of plants per unit area in the cropped field is called as plant population.

Optimum plant population

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

Importance of plant population

- Yield of any crop depends on final plant population.
- The plant population depends on germination percentage and survival rate in the field.
- Under rain fed conditions, high plant population will deplete the soil moisture before maturity, where as low plant population will leave the soil moisture unutilized.
- When soil moisture and nutrients are not limited high plant population is necessary to utilize the other growth factors like solar radiation efficiently.
- Under low plant population, individual plant yield will be more due to wide spacing.

- Under high plant population, individual plant yield will be low due to narrow spacing leading to competition between plants.
- Yield per plant decreases gradually as plant population per unit area is increased, but yield per unit area increases up to certain level of population. That level of plant population is called as optimum population.
- So, to get maximum yield per unit area, optimum plant population is necessary. So the optimum plant population for each crop should be identified.

Factors affecting plant population

A. Genetic Factors

1. Size of the plant

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

2. Elasticity of the plant

- Variation in size of the plant between minimum size of the plant that can produce some economic yield to the maximum size of the plant that can reach under unlimited space and resources is the elasticity of the plant.
- The optimum plant population range is high in indeterminate plants. Ex. Redgram – 55,000 to1,33,000 plants/ha.
- The elasticity is due to tillering and branching habit of the plants.
- For determinate plants like pearl millet, sorghum elasticity range is less.
- For indeterminate plants like cotton and Redgram, more branches will be produced by the crop.

3. Foraging area or soil cover

- Crop should cover the soil as early as possible so as to intercept maximum sunlight.
- Higher the intercepted radiation more will be the dry matter produced.
- Close spaced crops intercept more solar radiation than wide spaced crops.

4. Dry matter partitioning

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

5. Crop and variety

Depending on the crops and varieties, the plant population varies.

Rice :	Short duration	-	6,66,666 plants/ha (15 cm x 10 cm)
	Medium	-	5,00,000 plants/ha (20 cm x 10 cm)
	Long	-	3,33,000 plants/ha (20 cm x 15 cm)
Cotton :	Medium	-	55,555 plants/ha (60 cm x 30 cm)
	Long	-	44444 plants/ha (75 cm x 30 cm)
	Hybrids	-	18,518 plants/ha (120 cm x 45 cm)
Maize :	Varieties	-	83,333 plants/ha (60 x 20 cm)
	Hybrids	-	47,620 plants/ha (60 x 35 cm)

B. Environmental factors

1. Time of sowing

- The crop is subjected to various weather conditions when sown at different periods.

- Among weather factors, day length and temperature influence much on the plant population. As low temperature retards growth, high plant population is required to cover the soil.

2. Rainfall / irrigation

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

3. Fertilizer application

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

4. Seed rate

- Quantity of seed sown/unit area, viability and establishment rate decides the plant population. Under broadcasting the seed rate is higher when compared with line sowing/transplanting, Ex. Rice.

  Direct sowing - 100 kg/ha; Line sowing - 60 kg/ha; Transplanting - 40 kg/ha.

PLANT GEOMETRY

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

Different crop geometries are available for crop production

1) Random plant geometry

Random plant geometry results due to broadcasting method of sowing and no equal space is maintained. Resources are either under utilized or over exploited.

2) Square plant geometry

The plants are sown at equal distances on either side. Mostly perennial crops, tree crops follow square method of cultivation. Ex. Coconut – 7.5 x 7.5 m; banana – 1.8 x 1.8 m. But, due to scientific invention, the square geometry concept is expanded to close spaced field crops like rice too.

Advantages

Light is uniformly available, movement of wind is not blocked and mechanization can be possible.

3) Rectangular method of sowing

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

The different types exist in rectangular method are,

a) Solid row: Each row will have no proper spacing between the plants. This is followed only for annual crops which have tillering pattern. There is definite row arrangement but no column arrangement, Ex. Wheat.

b) Paired row arrangement: It is also a rectangular arrangement. It a crop requires 60 cm x 30 cm spacing and if paired row is to be adopted the spacing is altered to 90 cm instead of 60 cm in order to accommodate an intercrop. The base population is kept constant.

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

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

PLANTING GEOMETRY AND ITS EFFECT ON GROWTH AND YIELD

Methods of Sowing and Transplanting

1. Broadcasting
2. Dibbling
3. Sowi ng behind the country plough (manual and mechanical drilling)
4. Seed Drilling
5. Nursery transplanting

1) Broadcasting

Literally means scattering the seeds. Broadcasting is done for many crops. Broadcasting is mostly followed for small sized to medium sized crops. This is the largest method of sowing followed in India since it is the easiest and cheapest and requires minimum labours. To have optimum plant population in unit area certain rules should be followed.

i) Only a skilled person should broadcast the seeds for uniform scattering

ii) The ploughed field should be in a perfect condition to trigger germination

The seeds are broadcasted in a narrow strip and the sowing is completed strip by strip. To ensure a good and uniform population, it is better to broadcast on either direction. This is called criss-cross sowing. If the seed is too small, it is mixed with sand to make a bulky one and for easy handling. In certain cases the person sowing will be beating the seeds against the basket for uniform scattering. After broadcasting the seeds are covered gently either using a country plough with a very shallow ploughing or some wooden planks (boards / levelers) are used to cover the surface. In some cases tree twigs or shrub branches are used. If the seeds are large, levelers collect the seeds and leave in the other side. Comb harrow is the best used one.

Disadvantages

1) All the seeds broadcasted do not have contact with the soil. 100% germination is not possible.

2) Seed rate is not sufficient. Enhanced seed rate required

3) Seeds cannot be placed in desired depth. Desired depth ensures perfect anchorage. Lodging (falling down) is common in broadcasting

2) Dibbling

Line sowing: Inserting a seed through a hole at a desired depth and covering the hole. Dibbling on plain surface and ridges and furrows or beds and channels.This types of sowing is practiced only under suitable soil condition. Rice – fallow – cotton is dibbled on a plain surface. The seeds are dibbled at 2/3rd from top or 1/3rd at bottom. Before sowing furrows are opened and fertilizers are applied above which seeds are sown. The seeds do not have contact with the fertilizers. This is done for wider spaced crops and medium to large sized seeds, e.g., sorghum, maize, sunflower, cotton are dibbled on ridges and furrows. Both beds and channels and ridges and furrows come under line sowing. While earthing up the plant occupies middle of the ridge. Earthing up is essential for proper anchorage of the root system.

Advantages of ridges and furrows

(i) Uniform population

(ii) Better germination

(iii) Reduced seed rate.

3) Sowing behind the plough

Sowing behind the plough (line sowing) is done manually or mechanical means. Seeds are dropped in the furrows opened by the plough and the same is closed or covered when the next furrow is opened. The seeds are sown at uniform distance. Manual method is a laborious and time consuming process. Seeds like redgram, cowpea and groundnut are sown behind the country plough. Major sown crop is ground out. Seeds are sown by mechanical means by 'Gorus' – seed drill. A seed drill has a plough share and hopper. Seeds are placed on hopper. Different types of seed drill are available, e.g., simple Goru – Guntakas.

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

Sl. No.	**Line sowing**	**Random sowing**
1.	Costlier	Cheaper
2.	Takes considerable time	Quickest and time saving
3.	Fixed seed rate	Higher seed rate
4.	Mechanization is possible, e.g. weeding, harvesting	Not possible
5.	Uniform utilization of resources (land, water, light, nutrient, etc.)	Resource utilization ununiform

4. Drill Sowing (or) Drilling

Drilling is the practice of dropping seeds in a definite depth covered with soil and compacted. In this method, sowing implements are used for placing the seeds into the soil. Both animal drawn gorrus 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. It is possible to take up sowing of inter crops also. It requires more time, energy and cost, but maintains uniform population per unit area Seeds are placed at uniform depth, covered and compacted

5) Nursery Transplanting

In nursery, young seedlings are protected more effectively in a short period and in a smaller area. Management is essential.

Advantages

i) Can ensure optimum plant population

ii) Sowing of main field duration, i.e., management in the main field is reduced

iii) Crop intensification is possible under transplanting

Disadvantages

i) Nursery raising is expensive

ii) Transplanting is another laborious and expensive method

Age – $1/4^{th}$ of the total duration is on the nursery beds. If the total duration is 16 weeks, four week period (1 month) is under nursery beds. Nursery age is not very rigid, e.g., thumb rule – 3 months crop – nursery duration 3 weeks, minimum 4 months – 4 weeks minimum period; 5 months – 5 weeks. After the nursery period, seedlings are pulled out and transplanted. This is done on the main field after thorough field preparation or optimum tilth. The seedlings are dibbled in lines or in random. Closer spaced crops are mostly raised in random method even after nursery, e.g. rice, ragi. For vegetables, desired spacing is required during transplanting. Transplanting shock is a period after transplanting, the seedlings show no growth. This is mostly due to the change in the environment between root and the soil. The newly planted seedlings should adjust with new environment. It is for a period of 5 – 7 days depending upon season, crop, variety, etc. At higher temperature – dehydration – leaves dry out. Area: normally $1/10^{th}$ of the total area is required for nursery.

Plant Population or Plant Density

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

Optimum plant population

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

Crop Geometry

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

Importance of plant population / crop geometry

1. Yield of any crop depends on final plant population
2. The plant population depends on germination percentage and survival rate in the field
3. Under rain fed conditions, high plant population will deplete the soil moisture before maturity, where as low plant population will leave the soil moisture unutilized
4. When soil moisture and nutrients are not limited high plant population is necessary to utilize the other growth factors like solar radiation efficiently
5. Under low plant population individual plant yield will be more due to wide spacing.
6. Under high plant population individual plant yield will be low due to narrow spacing leading to competition between plants.
7. Yield per plant decreases gradually as plant population per unit area is increased, but yield per unit area increases upto certain level of population
8. That level of plant population is called as optimum population
9. So to get maximum yield per unit area, optimum plant population is necessary. So the optimum plant population for each crop should be identified.

Factors affecting plant population

Genetic Factors

1. Size of the plant 2. Elasticity of the plant 3.Foraging area or soil cover

4. Dry matter partitioning

Environmental factors

1. Time of sowing 2. Rainfall / Irrigation. 3.Fertilizer application

4. Seed rate

1. Size of the plant

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

2. Elasticity of the plant

1. Variation in size of the plant between minimum size of the plant that can produce some economic yield to the maximum size of the plant that can reach under unlimited space and resources is the elasticity of the plant.
2. The optimum plant population range is high in indeterminate plants

   Eg : Opt. population range for redgram is 55000-133, 000 plants/ha
3. The elasticity is due to tillering and branching habit of the plants
4. For determinate plants like bajra, sorghum elasticity range is less
5. For indeterminate plants like cotton and redgram more branches will be produced the crop

3. Foraging area or soil cover

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

4. Dry matter partitioning

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

5. Crop and variety

Rice :	Short duration	-	15 cm x 10 cm- 6,66,666 pl/ha
	Medium	-	20 cm x 10 cm-5,00,000 pl/ha
	Long	-	20 cm x 15 cm-3,33,000 pl/ha
Cotton :	Medium	-	60 cm x 30 cm
	Long	-	75 cm x 30 cm
	Hybrids	-	120 cm x 45 cm
Maize :	60 x 20 cm (varieties)		
	60 x 35 cm (hybrids)		

Environmental factors

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

2. Rainfall / irrigation

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

3. Fertilizer application

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

4. Seed rate

1. Quantity of seed sown/unit area, viability and establishment rate decides the plant population Under broadcasting the seed rate is higher when compared with line sowing/transplanting, e.g. for rice

   Direct sowing - 100 kg/ha

   Line sowing - 60 kg/ha

   Transplanting - 40 kg/ha

Different crop geometries are available for crop production

1) Broadcasting

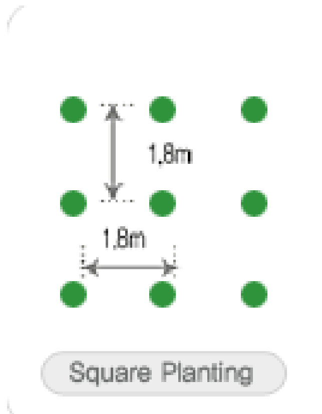
Results in random geometry, no equal space is maintained, resources are either under exploited or over exploited.

2) Square method or square geometry

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

Advantages

i) Light is uniformly available,
ii) Movement of wind is not blocked and
iii) Mechanization can be possible.



3) Rectangular method of sowing

There are rows and columns, the row spacing are wider than the spacing between plants. The different types exist in rectangular method

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

b) Paired row arrangement – It is also a rectangular arrangement. It a crop requires 60 cm x 300 m spacing and if paired row is to be adopted the spacing is altered to 90 cm instead of 60 cm in order to accommodate an intercrop. The base population is kept constant.

SPRING MAIZE INTER-CROP IN PAIRED ROW PLANTING

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

Conventional planting on the left, compared with plant1 – skip1 on the right

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

Cropping pattern and cropping system - Intensive cropping- Sustainable agriculture – IFS

CROPPING PATTERN AND CROPPING SYSTEM

Traditionally, increased food production has come from putting more land under cultivation. However, in large areas of the world, especially in Asia, all the land that can be economically cultivated is already in use. In future, most of the extra food needs must come from higher production from land already being farmed. A major share of this increase is likely to come from increasing the number of crops produced per year on a given land using improved crop cultivars. Such multiple cropping offers potential not only to increase food production but also land degradation.

In India, the concept of cropping systems is as old as agriculture. Farmers preferred mixed cropping, especially under dry land conditions, to minimise the risk of total crop failure. Even in Vedas, there is a mention of first and second crops, indicating the existence of sequential cropping.

A **system** is defined as a set of components that are interrelated and interact among themselves. A **cropping system** refers to a set of crop systems, making up the cropping activities of a farm system. Cropping system comprises all components required for the production of a particular crop and the interrelationships between them and environment (TAC, CGIAR, 1978). In other words, a cropping system usually refers to a combination of crops in time and space. Combination in time occurs when crops occupy different growing period and combinations in space occur when crops are inter planted. When annual crops are considered, a cropping system usually means the combination of crops within a given year (Willey *et al.*, 1989

Cropping pattern

The yearly sequence and spatial arrangement of crops or of crops and fallow on a given area.

Cropping system

The cropping patterns used on a farm and their interaction with farm resources, other farm enterprises, and available technology which determine their make up.

INTENSIVE CROPPING

Principles

The turn around period between one crop and another is minimised through modified land preparation. It is possible when the resources are available in plenty. Ex. Garden land cultivation. Cropping intensity is higher in intensive cropping system. Crop intensification technique includes intercropping, relay cropping, sequential cropping, ratoon cropping, etc. All such systems come under the general term multiple cropping.

Need for intensive cropping

- Cropping systems has to be evolved based on climate, soil and water availability for efficient use of available natural resources.
- The increase in population has put pressure on land to increase productivity per unit area, unit time and for unit resource used.
- This cropping system should provide enough food for the family, fodder for cattle and generate sufficient cash income for domestic and cultivation expenses.

Intensive cropping: Growing number of crops on the same piece of land during the given period of time.

Cropping intensity: Number of crops cultivated in a piece of land per annum is cropping intensity. In Punjab and Tamil Nadu, the cropping intensity is more than 100% (i.e. around 140-150%). In Rajasthan, the cropping intensity is less.

Multiple cropping: The intensification of cropping in time and space dimensions. Growing two or more crops on the same field in a year.

Forms of multiple cropping

Intercropping: Growing two or more crops simultaneously on the same field. Crop intensification is in both time and space dimensions. There is intercrop competition during all or part of crop growth.

(a) *Mixed intercropping:* Growing two or more crops simultaneously with no distinct row arrangement. Also referred to as mixed cropping. Ex: Sorghum, pearl millet and cowpea are mixed and broadcasted in rainfed conditions.

(b) *Row intercropping:* Growing two or more crops simultaneously where one or more crops are planted in rows. Often simply referred to as intercropping. Maize + greengram (1:1), Maize + blackgram (1:1), Groundnut + Rredgram (6:1)

(c) *Strip intercropping:* Growing two or more crops simultaneously in strips wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically. Ex. Groundnut + redgram (6:4) strip.

(d) *Relay intercropping:* Growing two or more crops simultaneously during the part of the life cycle of each. A second crop is planted after the first crop has reached its reproductive stage of growth, but, before it is ready for harvest. Often simply referred to as relay cropping. Rice- rice fallow pulse.

Advantages of intercropping

- Better use of growth resources including light, nutrients and water
- Suppression of weeds
- Yield stability; even if one crop fails due to unforeseen situations, another crop will yield and gives income
- Successful intercropping gives higher equivalent yields (yield of base crop + yield of intercrop), higher cropping intensity
- Reduced pest and disease incidences
- Improvement of soil health and agro-eco system

Sequential cropping: Growing two or more crops in sequence on the same field in a farming year. The succeeding crop is planted after the preceding crop has been harvested. Crop intensification is only in time dimension. There is no intercrop competition.

(a) *Double, triple and quadruple cropping:* Growing two, three and four crops, respectively, on the same land in a year in sequence.

Ex. Double cropping: Rice: cotton; Triple cropping: Rice: rice: pulses; Quadruple cropping: Tomato: ridge gourd: *Amaranthus* greens: baby corn

(b) *Ratoon cropping:* The cultivation of crop re-growth after harvest, although not necessarily for grain. Ex. Sugarcane: ratoon; Sorghum: ratoon (for fodder).

The various terms defined above bring out essentially two underlying principles, that of growing crops simultaneously in mixture, i.e., intercropping; and of growing individual crops in sequence, i.e., sequential cropping. The cropping system for a region or farm may comprise either or both of these two principles.

SUSTAINABLE AGRICULTURE

Definition:

A farming systems that are "capable of maintaining their productivity and usefulness to society indefinitely and must be resource-conserving, socially supportive, commercially competitive, and environmentally sound."

USDA (legal)

Sustainable agriculture means, an integrated system of plant and animal production practices having a site-specific application that will, over the long term:

- satisfy human food and fiber needs;
- enhance environmental quality and the natural resource based upon which the agricultural economy depends;
- make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;
- sustain the economic viability of farm operations;
- enhance the quality of life for farmers and society as a whole.

Advantages

- Production cost is low
- Over all risk of the farmer is reduced
- Pollution of water is avoided
- Very little or no pesticide residue is ensured
- Ensures both short and long term profitability

Disadvantages

- Since sustainable agriculture uses least quantum of inputs, naturally the output (yield) may also be less.

Major components of sustainable agricultural system

- Soil and water conservation to prevent degradation of soil productivity
- Efficient use of limited irrigation water without leading to problems of soil salinity, alkalinity and high ground water table
- Crop rotations that mitigate weed, disease and insect problems, increase soil productivity and minimise soil erosion
- Integrated nutrient management that reduces the need for chemical fertilizers improves the soil health and minimise environmental pollution by conjunctive use of organics, in-organics and bio-fertilizers.
- ‘Integrated pest management that reduces the need for agrochemicals by crop rotation, weather monitoring, use of resistant cultivar, planting time and biological pest control.
- Management system to control weed by preventive measures, tillage, timely inter cultivation and crop rotation to improve plant health.

INTEGRATED FARMING SYSTEM (IFS)

Integration of two or more appropriate combination of enterprises like crop, dairy, piggery, fishery, poultry, bee keeping etc., for each farm according to the availability of resources to sustain and satisfy the necessities of the farmer

Definition: A farming system is a collection of distinct functional units such as crop, livestock, processing, investments and marketing activities which interact because of the joint use of inputs they receive from the environment which have the common objective of satisfying the farmers’ (decision makers) aims. The definition of the borders of the options depends on circumstances; often it includes not only the farm (economic enterprise) but also the household (farm – household system)”

Possible enterprises

Wetland based farming system

- Crop + Fish + Poultry/poultry/pigeon

- Crop + Fish + Mushroom

Gardenland based farming system

- Crop + Dairy + Biogas
- Crop + Dairy + Biogas + Sericulture
- Crop + Dairy + Biogas + Mushroom + Sylvi-culture

Dry land based farming system

- Crop + Goat + Agroforestry
- Crop + Goat + Agroforestry + Horticulture

Benefits of IFS

- Higher Productivity
- Profitability
- Sustainability
- Balanced food
- Recycling reduces pollution
- Money round the year
- Employment generation
- Increase input efficiency
- Standard of living of the farmer increased
- Better utilisation of land, labour, time and resources

Role of manures and fertilizers in crop production – agronomic interventions for enhancing FUE - Inter cultivation - Thinning - Gap filling and other intercultural operations

MANURES

Manures are plant and animal wastes that are used as source of plant nutrients. They release nutrients after their decomposition. Manures can be grouped into bulky organic manures and concentrated organic manures.

a. Bulky organic manures - Farm Yard Manure (FYM), compost from organic waste, night soil, sludge, sewage, green manures.
b. Concentrated organic manures - oilcakes (edible, non-edible), blood meal, fishmeal and bone meal.

FERTILIZERS

Fertilizers are industrially manufactured chemical containing plant nutrients. Nutrient content is higher in fertilizers than organic manures and nutrients are released almost immediately. The fertilizers has three groups;

Straight fertilizers – supplies single nutrient Ex: Urea, Muriate of Potash

Complex fertilizers - supplies two or more nutrient Ex: 17:17:17 NPK complex

Mixed fertilizers- supplies two or more nutrient Ex: Groundnut mixture

ROLE OF MANURES AND FERTILIZERS

1. Organic manures bind the sandy soil and improve its water holding capacity.
2. Organic manures open the clayey soil and help in aeration for better root growth.
3. Organic manures add plant nutrients in small percentage and also add micronutrients, which are essential for plant growth.
4. Manures increases the microbial activity which helps in releasing plant nutrients to available form.
5. Organic manures should be incorporated before the sowing or planting because of slow release of nutrients.
6. Fertilizers play an important role in crop production as they supply large quantities of essential nutrient to crops
7. Fertilizers are manufactured in forms that are readily utilized by plants directly or after rapid transformation.
8. Fertilizers dose can be adjusted to suit the requirement as determined by soil testing.
9. Balanced application of nutrient based on crop requirement is possible by appropriate mixing of fertilizers.
10. Fertilizers applied as straight fertilizers (providing single nutrient) or complex and mixed fertilizers (supplies two or more nutrients) based on crop requirement.

AGRONOMIC INTERVENTIONS FOR ENHANCING FUE

The following are the agronomic measures to improve the Fertilizer use efficiency (FUE).

1. Using best fertilizer source
2. Using adequate rate & diagnostic techniques
3. Usage of balanced fertilization
4. Integrated nutrient management
5. Utilization of residual nutrients

1. Using best fertilizer source:

Identification of best source of fertilizer is pre-requisite for better crop production. Source of fertilizer depends on crop and variety, climatic and soil condition, availability of fertilizer, etc.

- Nitrogen: Ammoniacal or Nitrate
- Phosphorus: Water soluble or Citrate soluble
- Potassium: Muriate of potash
- Sulphur: Sulphate or Elemental S
- Multinutrient fertilizers: MAP, DAP, SSP, Nitrophosphates
- Multi-nutrient mixtures: Several combinations of NPK
- Fortified fertilizers: Neem-coated urea, Zincated urea, Boronated SSP, NPKS mix.

2. Using adequate rate & diagnostic techniques:

The fertilizer recommendation must be in adequate quantity so as to meet the demand of crop at any point of growth. The fertilizer supply is made by diagnosing its requirement by any of the following method.

- State recommended generalized fertilizer dose or blanket recommendation
- Soil-test based fertilizer recommendations
- Soil-test crop response based recommendation
- Plant analysis for diagnosing nutrient deficiencies
- Chlorophyll meter and Leaf colour charts, etc.

3. Balanced fertilization

Balanced fertilization includes adequate supply of all essential nutrients, proper method of application, right time of application and nutrient interrelationships.

a. Adequate supply of all essential nutrients: Due to more concentration and application on primary nutrients (NPK), soils developed deficiency symptoms for secondary and micro-nutrients. Hence, ignored elements must be added with the NPK (may be in minor quantity) to get higher yields in crops. Experimental results shown that about 20-25 kg of micro-nutrient application or two foliar sprays increases the yield of crops up to 20%.

b. Proper method: N and K can be applied as broadcasting and band placement. Water soluble P fertilizers are preferred to apply as band placement in neutral & alkaline soils. Citrate soluble P fertilizers are applied as broadcast method in acidic soils. Sulphate forms of S fertilizers are applied as broadcasting or band placement, whereas, elemental S and pyrite are applied as broadcasting method. Micronutrients are applied in minor quantity as foliar sprays and water soluble fertilizers are applied in fertigation.

c. Right time: (according to physiology of crop)

- Upland crops - 2 splits (seeding, 3-5 weeks after first dose)
- Flooded rice - 3 splits (Transplanting, 3 and 6 weeks after first dose)

d. Nutrient interrelationships:

Antagonistic nature of fertilizers is to be considered while applying into the soil. Some of the fertilizer application in excess, cause loss of yield and quality of crops. Ex. Application of excessive 120 kg P ha^{-1} created an imbalance and reduced the seed and oil yields in soybean compared to 80 kg P ha^{-1}.

4. Integrated nutrient management

Organic manures, crop residues, green manures, bio-fertilizers etc. are to be blended in right manner along with inorganic fertilizers to meet the crop demand. All the possible and available organic sources are to be utilized efficiently to reduce the usage of inorganic fertilizers.

5. Utilization of residual nutrients

Some of the strategies to utilize the crop residues in efficient manner are,

- Knowledge on climatic conditions & carry-over effects of residues.
- Blending rightly on cereal-legume rotations
- Mixing shallow-deep rooted crop rotations

INTER CULTIVATION

Cultivation practices taken up after sowing of crop is called inter-cultivation. It is otherwise called as after operation. There are three important after cultivation processes viz., Thinning and gap filling, weeding and hoeing and earthing up.

1. Thinning and Gap filling

The objective of thinning and gap filling process is to maintain optimum plant population. Thinning is the removal of excess plants leaving healthy seedlings. Gap filling is done to fill the gaps by sowing of seeds or transplanting of seedlings in gap where early sown seed had not germinated. It is a simultaneous process. Normally, these are practiced a week after sowing to a maximum of 15 days. In dryland agriculture, gap filling is done first. Seeds are dibbled after 7 days of sowing. Thinning is done after gap filling; in order to avoid drought. It is a management strategy to remove a portion of plant population to mitigate stress is referred to as mid season correction.

2. Weeding and Hoeing

Weeding is removal of unwanted plants. Weeding and hoeing is a simultaneous operation. Hoeing is disturbing the top soil by small hand tools and helps in aerating the soil.

3. Earthing up

It is a dislocation of soil from one side of a ridge and to be placed nearer the cropped side. It is carried out in wide spaced and deep rooted crops. It is done around 6-8 weeks after sowing / planting in sugarcane, tapioca, banana, etc.

4. Other inter cultivation practices

Harrowing

Stirring or scraping the surface soil in inter and intra row spacing of the crop using tools or implements.

Roguing

Removal of plants of a variety admixed with other variety of same crop. Ex. In IR 50 rice field, the other rice varieties are rogue. It is practiced in seed production to maintain purity.

Topping

Removal of terminal buds. It is done to stimulate auxillary growth. Practiced in cotton and tobacco.

Propping

Provision of support to the crop is called propping. Practiced in sugarcane commonly. It is done to prevent lodging of the crop. Cane stalks from adjacent rows are brought together and tied with their own trash and old leaves.

De-trashing

Removing of older leaves from the sugarcane crop.

De-suckering

Removal of axillary buds and branches which are considered non essential for crop production and which removes plant nutrients considerably are called suckers. Ex. Tobacco.

Organic / eco-friendly agriculture - Dry farming - Concepts and principles

Organic farming: Organic farming is a production system where all kinds of agricultural products are produced organically, including grains, meat, dairy, eggs, fibers such as cotton, flowers and processed food products.

Organic farming avoids or largely excludes the use of synthetic fertilizers, pesticides, growth regulators and livestock feed additives.

Need & scope of organic farming

- Increase in awareness and health consciousness
- Global consumers are increasingly looking for organic food, which is considered safe, and hazard free.
- The global prices of organic food are more lucrative and remunerative.
- The potential of organic farming is signified by the fact that the farm sector has abundant organic nutrient resources like livestock, water, crop residue, aquatic weeds, forest litter, urban, rural solid wastes and agro industries, bio-products.
- India offers tremendous scope for organic farming as it has local market potential for organic products

Principles (International Federation of Organic Agriculture Movements - IFOAM, 1972)

1. To produce food of high quality in sufficient quantity.
2. To interact in a constructive and life-enhancing way with natural systems and cycles.
3. To consider the wider social and ecological impact of the organic production and processing systems.
4. To encourage and enhance biological cycles within the farming system, involving micro-organisms, soil flora and fauna, plants and animals.
5. To maintain and increase the long-term fertility of soils.
6. To maintain the genetic diversity of the production system and its surroundings, including the protection of wildlife habitats.
7. To promote the healthy use and proper care of water, water resources and all life therein.
8. To use, as far as possible, renewable resources in locally organized production systems.
9. To give all livestock conditions of life with due consideration for the basic aspects of their innate behaviour.
10. To minimize all forms of pollution.
11. To allow every one involved in organic production and processing a quality of life which meets their basic needs and allows an adequate return and satisfaction from their work, including a safe working environment.
12. To progress towards an entire production, processing, and distribution chain which is both socially just and ecologically responsible.

Advantages of organic farming

- Nutrition - Improved soil health makes food dramatically superior in mineral content
- Poison-free - Free of contamination with health harming chemicals like pesticides, fungicides and herbicides.
- Food tastes better
- Food keeps longer - can be stored longer
- Disease and pest resistance - because of healthy plants
- Weed competitiveness - Healthier crops able to compete
- Lower input costs - No costly chemicals used, nutrients are created in-situ (in the farm)

- Drought resistance
- More profitable - Due to greater food value of organic produce consumers are willing to pay premium prices
-

Disadvantages of organic farming

- Productivity - Low productivity is often reported as the quantum nutrient used comparatively lower
- Labour intensive - Cultivation requires more labour especially for weed control
- Skill - requires considerable skill to farm organically Ex. Choice of alternatives for control of pests
- Lack of convenience in management compared to easier management like fertilizer application in conventional methods

Synonyms of organic farming

Eco-farming
Biological farming
Bio-dynamic farming
Macrobiotic agriculture

Eco-farming

- Farming in relation to ecosystem.
- It has the potential for introducing mutually reinforcing ecological approaches to food production.
- It aims at the maintenance of soil chemically, biologically and physically the way nature would do it left alone.
- Soil would then take proper care of plants growing on it.
- ***Feed the soil, not the plant*** is the watchword and slogan of ecological farming.
-

Biological farming

Farming in relation to biological diversity.

Biodynamic farming

Farming which is biologically organic and ecologically sound and sustainable farming.

Dryland Agriculture

Indian agriculture is predominantly a rainfed agriculture under which both dryfarming and dryland agriculture are included. Out of the 143 million ha of total cultivated area in the country, 101 million ha (i.e. nearly 70%) area are rainfed. In dryland areas, variation in amount and distribution of rainfall influence the crop production as well as socio-economic conditions of farmers. The dryland areas of the country contribute about 42% of the total food grain production. Most of the coarse grains like sorghum, pearl millet, finger millet and other millets are grown in drylands only. The attention has been paid in the country towards the development of dryland farming. Efforts were made to improve crop yields in research projects at Manjari, Solapur, Bijapur, Raichur and Rohtak. An all India co-ordinated research project for Dryland Agriculture was launched by ICAR in 1970 in collaboration with Government of Canada and later Central Research Institute for Dryland Agriculture (CRIDA) was established at Hyderabad.

Characteristics of Dryland Agriculture

Dry land areas may be characterized by the following features,

1. Uncertain, ill-distributed and limited annual rainfall
2. Occurrence of extensive climatic hazards like drought, flood etc.
3. Undulating soil surface
4. Occurrence of extensive and large holdings
5. Practice of extensive agriculture, i.e., prevalence of monocropping etc.
6. Relatively large size of fields
7. Similarity in types of crops raised by almost all the farmers of a particular region
8. Very low crop yield
9. Poor economy of the farmers

Dryland Agriculture

It is the profitable production of useful crops, without irrigation, on lands (arid and semi arid) that receive annual rainfall of less than 750mm

Rainfed Agriculture

It is the profitable production of useful crops, without irrigation, on lands (humid & subhumid regions) that receive annual rainfall of more than 750mm

Difference between rainfed and irrigated farming

	Rainfed farming	**Irrigated farming**
1	In a certain part of the year crop is grown where rainfall received	Through out the year depending upon the water availability
2	Crops/crop varieties having drought tolerance or less water requirement are used	According to the need, crops or their varieties are selected
3	Duration of crops depends on the rainfall duration/ growing period most of the times short duration (LGP)	Depending upon the need
4	Mixed cropping is beneficial	Generally pure cropping is done
5	Due to limitation of moisture one or two crops in a year is possible	More than two crops in a year are grown, subject to availability of water
6	The field is ploughed to deep to increase infiltration of rains	No need for deep ploughing to conserve soil moisture
7	Land is prepared immediately after rainfall	Land is prepared according to optimum time of sowing
8	Risk of crop failure is expected due to insufficient soil moisture or drought	No risk of crop failure

Improved dryland technologies

Following are the various improved techniques and practices recommended for achieving the objective of increased and stable crop production in dryland areas.

- Crop planning: Crop varieties for dryland areas should be of short duration through resistant tolerant and high yielding which can be harvested within rainfall periods and have sufficient residual moisture in soil profile for post-monsoon cropping.
- Planning for weather: Variation in yields and output of the dryland agriculture is due to the observation in weather conditions especially rainfall. An aberrant weather can be categorized in three types viz.,
    a. Delayed onset of monsoon.
    b. Long gaps or breaks in rainfall and
    c. Early cessation of rains towards the end of monsoon season.

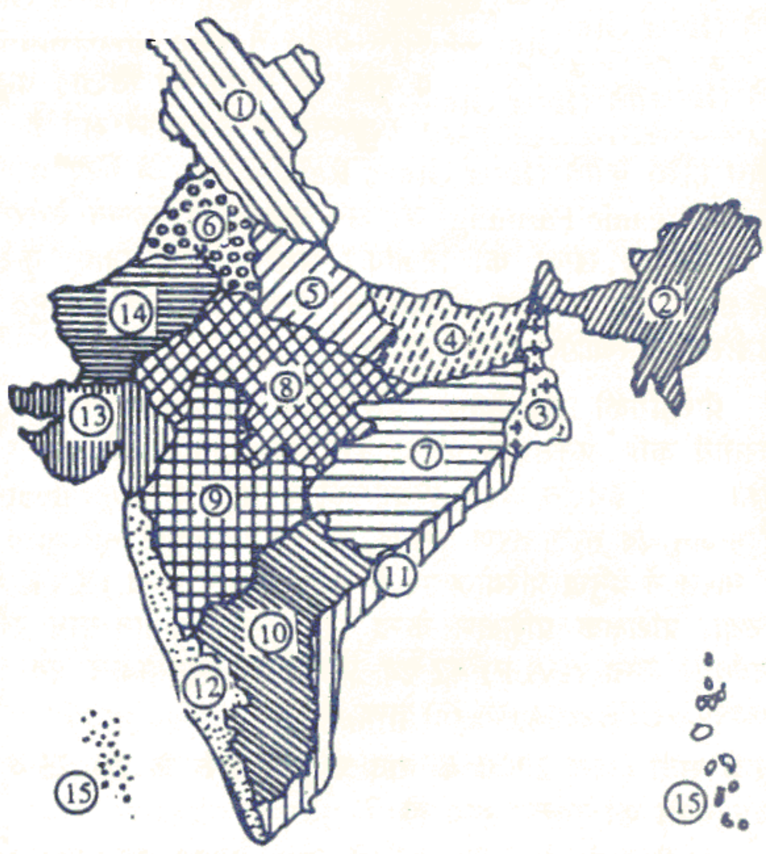
    Farmers should make some changes in normal cropping schedule for getting some production in place of total crop failure.
- Crop substitution: Traditional crops/varieties which are inefficient utilizer of soil moisture, less responsive to production input and potentially low producers should be substituted by more efficient ones.
- Cropping systems: Increasing the cropping intensities by using the practice of intercropping and multiple cropping is the way of more efficient utilization of resources. The cropping intensity would depend on the length of growing season, which in turn depends on rainfall pattern and the soil moisture storage capacity of the soil.
- Fertilizer use: The availability of nutrients is limited in drylands due to the limiting soil moisture. Therefore, application of the fertilizers should be done in furrows below the seed. The use of fertilizers is not only helpful in providing nutrients to crop but also, helpful in efficient use of soil moisture. A proper mixture of organic and inorganic fertilizers improves moisture holding capacity of soil and increase during tolerance.
- Rain water management: Efficient rain water management can increase agricultural production from dryland areas. Application of compost and farm yard manure and raising legumes add the organic matter to the soil and increase the water holding capacity. The water, which is not retained by the soil, flows out as surface runoff. This excess runoff water can be harvested in storing dugout ponds and recycled to donar areas in the server stress during rainy season or for raising crops during winter.
- Watershed management: Watershed management is a approach to optimize the use of land, water and vegetation in a area and thus, to provide solution drought, moderate floods, prevent soil erosion, improve water availability and increase fuel, fodder and agricultural production on a sustained basis.
- Alternate Land use: All drylands are not suitable for crop production. Same lands may be suitable for range/ pasture management and for tree farming and ley farming, dryland horticulture, agro-forestry systems including alley cropping. All these systems which are alternative to crop production are called as alternate land use systems. This system helps to generate off-season employment mono-cropped dryland and also, minimizes risk, utilizes off-season rains, prevents degradation of soils and restores balance in the ecosystem. The different alternate land use systems are alley cropping, agri-horticultural systems and silvi-pastoral systems, which utilizes the resources in better way for increased and stabilized production from drylands.

AGRO-CLIMATIC ZONES OF INDIA AND ANDHRA PRADESH

Planning Commission has demarcated the geographical area of India into 15 agro-climatic regions. These are:

1. **Western Himalayan Region:** Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh, Uttaranchal. The region consists of skeletal soils of cold region, podsolic soil, mountainous soil, hilly brown soil. Lands have steep slopes in undulating terrain.
2. **Eastern Himalayan Region:** Assam Sikkim, West Bengal and all North-Eastern states. These region falls under high rainfall and high forest cover. Shifting cultivation is practiced in nearly one third of the cultivated area and this causes degradation of the soil, with heavy runoff, soil erosion and flood.
3. **Lower Gangetic Plains Region:** West Bengal, soils are mostly alluvial and are prone to floods.
4. **Middle Gangetic Plains Region:** Uttar Pradesh, Bihar. About 39 percent of the gross cropped area of this region is irrigated.
5. **Upper Gangetic Plains Region:** Uttar Pradesh. Irrigation is trough canals and tube wells. A good potential for exploitation of ground water.
6. **Trans-Gangetic Plains Region:** Punjab, Haryana, Delhi and Rajasthan. These regions have the highest sown areas, highest irrigated area, high cropping intensity and high ground water utilization.
7. **Eastern Plateau and Hills Region:** Maharashtra, Uttar Pradesh, Orissa and West Bengal. Irrigation is through canals and tanks. The soils are shallow and medium in depth.
8. **Central Plateau and Hills Region:** Madhya Pradesh, Rajasthan, Uttar Pradesh.
9. **Western Plateau and Hills Region:** Maharashtra, Madhya Pradesh and Rajasthan. The average rainfall of this zone is 904 mm.

10. **Southern Plateau and Hills Region:** Andhra Pradesh, Karnataka, Tamil Nadu. Dry farming is adopted and the cropping intensity is 111 percent.
11. **East Coast Plains and Hills Region:** Orissa, Andhra Pradesh, Tamil Nadu and Pondicherry. Irrigation is through canals and tanks.
12. **West Coast Plains and Ghats Region:** Tamil Nadu, Kerala, Goa, Karnataka, Maharashtra. Variety of cropping pattern, rainfall and soil types.
13. **Gujarat Plains and Hills Region:** Gujarat. This zone is arid with low rainfall in most parts. Irrigated through tube wells and wells.
14. **Western Dry Region:** Rajasthan. Hot sandy desert, erratic rainfall, high evaporation, scanty vegetation. The ground water is often deep and often brackish. Famine and drought are common features of this region.
15. **The Islands Region:** Andaman and Nicobar Islands, Lakshadweep. These regions are typical equatorial with rainfall of 3000 mm spread over eight to nine months. Largely forest zone with undulated land.



Agro climatic Zones of Andhra Pradesh

The cropped area in Andhra Pradesh is divided into seven zones based on the agro-climatic conditions. The classification mainly concentrates on the range of rainfall received, type and topography of the soils.

1. **Krishna – Godavari Zone**: It covers East Godavari Part, West Godavari, Krishna, Guntur, and contiguous areas of Khammam, Nalgonda and Prakasam. Rainfall of this zone is 800-1100mm. Soil type is deltaic alluvium, red soils with clay, red loams, coastal sands and saline soils. Paddy, Groundnut, Jowar, Bajra, Tobacco, cotton, chillies, Sugarcane and Horticultural Crops are the important crops grown.
2. **North Coastal Zones:** Covers Srikakulam, Vizianagaram, Visakhapatnam and uplands of East Godavari districts. This zone receives a rainfall of 1000-1100 mm mainly from south west monsoon. Soil type is red soils with clay base, pockets of acidic soils, laterite soils, Soils with PH 4-5. Main crops grown in these zones are Paddy, Groundnut, Jowar, Bajra, Mesta, Jute, Sun hemp, Sesame, Black gram and Horticultural Crops.
3. **Southern Zone**: Districts in this zone are Nellore, Chittoor, Southern parts of Prakasam and Cuddapah and Eastern parts of Anantapur. Rainfall received is about 700-1100 mm. Soil type is Red loamy soils, Shallow to moderately deep. Crops like Paddy, Groundnut,cotton Sugarcane. Millets and Horticultural Crops are mainly grown.

4. **North Telangana Zone**: Adilabad, Karimnagar, Nizamabad, Medak (Northern part), Warangal (Except N.W.Part), Eastern tips of Nalgonda and Khammam are the districts in this zone. Rainfall received is about 900-1500 mm. Soil type is Chalkas, Red sandy soils, Dubbas, Deep Red loamy soils, Very deep black cotton soils. Paddy,Sugarcane,Castor,Jowar, Maize, Sunflower, Tuemeric, Pulses and Chillies are the important crops.
5. **Southern Telangana Zone**: Hyderabad, Rangareddy, Mahabubnagar (except southern border), Nalgonda (except North eastern border), Medak (Southern parts), Warangal (North Western Part) are the districts covered. This zone receives a rainfall of about 700-900 mm. Soil type is red earth with loamy sub soil (Chalkas). Paddy, Sunflower, Safflower, Grapevine, Sorghum, Millets, Pulses and Orchard crops are the important crops.
6. **Scarce rainfall zone**: the districts covered are Kurnool, Anantapur, Prakasam (western parts), Cuddapah (Northern part), Mahabubnagar (Southern border). Receives a rainfall of 500-750 mm. Soil type is red earths with loamy soils (Chalkas), red sandy soils and black cotton soils in pockets. Cotton,Korra,Sorghum,Millets, Groundnut, Pulses, Paddy are the important crops.
7. **High altitude and Tribal areas**: Northern borders of Srikakulam, Vizianagaram and Visakhapatnam, East Godavari and Khammam are the districts covered. This zone receives a rainfall more than 1400 mm. Horticultural Crops, Millets, Pulses Chillies, Turmeric and Pepper are the important crops grown.

WEEDS – HARMFUL AND BENIFICIAL EFFECTS

Weeds are plants that are unwanted in a given situation and may be harmful, dangerous or economically detrimental. Weeds are a serious threat to primary production and biodiversity. They reduce farm and forest productivity, displace native species and contribute significantly to land and water degradation. The costs of weeds to the natural environment are also high, with weed invasion being ranked second only to habitat loss in causing biodiversity decline.

Despite considerable government and private sector investment, weed invasion still represents a major threat to both the productive capacity of land and water and the integrity of our natural ecosystems. An efficient weed control program can only be developed after the weed has been properly identified. Weeds can be managed using many different methods. The most effective management of weeds is usually achieved through collaboration and co-operation, in partnerships between the community, land owners, agriculture, industry and the various levels of government, using a combination of methods in conjunction with a thorough follow-up campaign.

Weed management is an important component of plant protection improving the production potential of crops. It includes management of the weeds in a way that the crop sustains its production potential without being harmed by the weeds. Weed management is done through the mechanical, cultural and chemical means. Use of biological control methods in field crops is being considered, but still not much in use. Use of herbicides is an important method in the modern concept of much in use. Use of herbicides is an important method in the modern concept of weed-management technology. New hand-tools and implements have also been designed to assist in wed-management programme.

Characteristics of weeds

Weeds are also like other plants but have special characteristics that tend to put them in the category of unwanted plants.

- Most of the weeds especially annuals produce enormous quantity of seeds, e.g. wild oats (*Avena fatua*), produces 250 seeds per plant, whereas wild amaranth (*Amaranthus viridis*) produces nearly 11 million seeds. It has been observed that among 61 perennial weeds, the average seed-production capacity was 26,500 per plant.
- Weeds have the capacity to withstand adverse conditions in the field, because they can modify their seed production and growth according to the availability of moisture and temperature. They can germinate under adverse soil-moisture conditions, have short period of plant growth, generally grow faster rate and produce seed earlier than most of the crops growing in association.

- Weed seeds remain viable for longer period without losing their viability, e.g. annual meadow grass (*Poa annua*) and scarlet pimpernel (*Anagallis arvensis*) remain viable foe about 8 years; creeping thistle (*Cirsium arvense*) for 20 years and field bind weed (*Convolvulus arvensis*) for about 50 years.
- Weed seeds have a tremendous capacity to disperse from one place to another through wind, water and animals including man. Many of times, weed seeds mimic with the crop seeds due to their size and get transported from one place to another along with them.

Harmful effects

- Weeds have serious impacts on agricultural production. It is estimated that in general weeds cause 5% loss in agricultural production in most of developed countries, 10% loss in less developed countries and 25% loss in least developed countries.

  In India, yield losses due to weeds are more than those from pest and diseases. Yield losses due to weeds vary with the crops. Every crop is exposed to severe competition from weeds. Most of these weeds are self-sown and they provide competition caused by their faster rate of growth in the initial stages of crop growth. In some crops, the yields are reduced by more than 50% due to weed infestation. These loses caused by weeds in some of the important crops are given in the following table.

Loss in crop yields due to weeds

Crop	Reduction in yields due to weeds (%)	Crop	Reduction in yield due to weeds (%)
Rice	41.6	Groundnut	33.8
Wheat	16.0	Sugarcane	34.2
Maize	39.8	Sugar beet	70.3
Millets	29.5	Carrot	47.5
Soybean	30.5	Cotton	72.5
Gram	11.6	Onion	68.0
Pea	32.9	Potato	20.1

- Weeds compete with crops for water soil, nutrients, light, and space, and thus reduce the crop yields. An estimate shows that weeds can deprive the crops 47% N, 42% P, 50% K, 39% Ca and 24% Mg of their nutrient uptake.
- Weeds are also act as alternate hosts that harbor insects, pests and diseases and other micro-organisms. Alternate hosts of some of the pest and diseases

Crop	Pest	Alternate host
Red gram	Gram caterpillar	*Amaranthus, Datura*
Castor	Hairy caterpillar	*Crotalaria sp*
Rice	Stem Borer	*Echinocholoa, Panicum*
Wheat	Black Rust	*Agropyron repens*
Pearl Millet	Ergot	*Cenchrus ciliaris*
Maize	Downy Mildew	*Sacharum spontaneum*

- Some weeds release into the soil inhibitors of poisonous substances that may be harmful to the crop plants, human beings and livestock. Health problems caused by weeds to humans,

Health problem	Weed
Hay fever and Asthma	Pollen of Ambrosia and Franseria
Dermotitis	Parthenium, Ambrosia
Itching and Inflammation	*Utrica sp*
African sleeping sickness	Brush weeds
Malaria, encephaliltisand filaria caused by mosquito	Aquatic weeds like *Pistia lanceolate, Salvinia auriculata*

- Weeds reduce the quality of marketable agricultural produce. Cotamination of weed seeds of *Datura, Argemone, Brassica* etc., is harmful to human health and weed seeds present in the produce cause odd odour sometimes.
- Weeds not only reduce yield but also interfere with agricultural operations. Weeds make mechanical sowing a difficult process and render harvesting difficult, leading to increased expenditure on labour, equipment and chemicals for their removal.
- In aquatic environment, weeds block the flow of water in canals, water-transport system and drainage system, rendering navigation difficult. The dense growth of aquatic weeds pollutes water by deoxygenating it and killing the fishes.
- Weeds are also a nuisance and a fire hazard along railway lines, roads, right-of- ways, airports, forest and industrial sites.

Beneficial Effects

In spite of all the difficulties caused by weeds, they can offer some beneficial properties, particularly when occurring at low densities. These aspects should be utilised in the farming system, although this may make organic management more complicated than chemical based systems. Some of the potential benefits of weeds are listed below:

- Helping to conserve soil moisture and prevent erosion. A ground cover of weeds will reduce the amount of bare soil exposed helping to conserve nutrients, particularly nitrogen which could otherwise be leached away, especially on light soils.
- Food and shelter can be provided for natural enemies of pests and even alternative food sources for crop pests. The actual presence of weed cover may be a factor in increasing effectiveness of biological control of pests and reducing pest damage.
- Weeds can also be valuable indicators of growing conditions in a field, for example of water levels, compaction and pH.
- Weeds can be an important source of food for wildlife, especially birds. Bird populations have been declining on farmland over the last few decades and leaving weeds as a resource has been shown to help revive bird populations.

CLASSIFICATION OF WEEDS

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.

I. Based on life span

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

a. Annual Weeds

Weeds that live only for a season or a year and complete their life cycle in that season or year are called as annual weeds.

These are small herbs with shallow roots and weak stem. Produces seeds in profusion and the mode of propagation is commonly through seeds. After seeding the annuals die away and the seeds germinate and start the next generation in the next season or year following. Most common field weeds are annuals. The examples are

a. Monsoon annual

Commelina benghalensis, Boerhavia erecta

b. Winter annual

Chenopodium album

		
Commelina benghalensis	*Boerhavia erecta*	*Chenopodium album*

b. Biennials

It completes the vegetative growth in the first season, flower and set seeds in the succeeding season and then dies. These are found mainly in non-cropped areas.

Eg. *Alternanthera echinata, Daucus carota*

(c) Perennials

Perennials live for more than two years and may live almost indefinitely. They adapted to withstand adverse conditions. They propagate not only through seeds but also by underground stem, root, rhizomes, tubers etc. And hence they are further classified into

i. **Simple perennials:** Plants propagated only by seeds. Eg. *Sonchus arvensis*

ii. **Bulbous perennials:** Plants which possess a modified stem with scales and reproduce mainly from bulbs and seeds. Eg. *Allium* sp.

iii. **Corm perennials**b Plants that possess a modified shoot and fleshy stem and reproduce through corm and seeds. Eg. *Timothy* (*Phleum pratense*)

Sonchus arvensis

Phleum pratense

iv. **Creeping perennials:** Reproduced through seeds as well as with one of the following.

a. **Rhizome:** Plants having underground stem – *Sorghum halapense*

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

Sorghum halapense

Cynodon dactylon

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

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

Convolvulus arvensis

Cyperus rotundus

II. Based on ecological affinities

a. Wetland weeds

They are tender annuals with semi-aquatic habit. They can thrive as well under waterlogged and in partially dry condition. Propagation is chiefly by seed. Eg. *Ammania baccifera, Eclipta alba*

Ammania baccifera

Eclipta alba

b. Garden land weeds (Irrigated lands)

These weeds neither require large quantities of water like wetland weeds nor can they successfully withstand extreme drought as dryland weeds. Eg.*Trianthema portulacastrum, Digera arvensis*

	
Trianthema portulacastrum	*Digera arvensis*

c. Dry lands weeds

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, Argemone mexicana.*

	
Tribulus terrestris	*Argemone mexicana*

III. Based on soil type (Edaphic)

(a) Weeds of black cotton soil: These are often closely allied to those that grow in dry condition. Eg., *Aristolochia bracteata*

(b) Weeds of red soils: They are like the weeds of garden lands consisting of various classes of plants. Eg. *Commelina benghalensis*

(c) Weeds of light, sandy or loamy soils: Weeds that occur in soils having good drainage. Eg. *Leucas aspera*

(d) Weeds of laterite soils: Eg. *Lantana camara, Spergula arvensis*

Aristolochia bracteata

Leucas aspera

Lantana camara

Spergula arvensis

IV. Based on place of occurrence

(a) Weeds of crop lands: The majority of weeds infests the cultivated lands and cause hindrance to the farmers for successful crop production. Eg. *Phalaris minor* in wheat

(b) Weeds of pasture lands: Weeds found in pasture / grazing grounds. Eg. *Indigofera enneaphylla*

Indigofera enneaphylla

Phalaris minor

(c) Weeds of waste places: Corners of fields, margins of channels etc., where weeds grow in profusion. Eg. *Gynandropsis pentaphylla*, *Calotropis gigantea*

Gynandropsis pentaphylla

Calotropis gigantea

(d) Weeds of playgrounds, road-sides: They are usually hardy, prostrate perennials, capable of withstanding any amount of trampling. Eg. *Alternanthera echinata, Tribulus terestris*

V. Based on Origin

(a) Indigenous weeds: All the native weeds of the country are coming under this group and most of the weeds are indigenous. Eg. *Acalypha indica, Abutilon indicum*

Acalypha indica

Abutilon indicum

(b) Introduced or Exotic weeds: These are the weeds introduced from other countries. These weeds are normally troublesome and control becomes difficult. Eg. *Parthenium hysterophorus, Phalaris minor, Acanthospermum hispidum*

Parthenium hysterophorus

Acanthospermum hispidum

VI. Based on cotyledon number

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

(a) Monocots Eg. *Panicum flavidum, Echinochloa colona*

(b) Dicots Eg. *Crotalaria verucosa, Indigofera viscosa*

	
Echinochloa colona	*Crotalaria verucosa*

VII. Based on soil pH

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

(a) Acidophile – Acid soil weeds eg. *Rumex acetosella*

(b) Basophile – Saline & alkaline soil weeds eg. *Taraxacum sp.*

(c) Neutrophile – Weeds of neutral soils eg *Acalypha indica*

	
Rumex acetosella	*Taraxacum sp.*

VIII. Based on morphology

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

(a) Grasses: All the weeds come under the family Poaceae are called as grasses which are characteristically having long narrow spiny leaves. The examples are *Echinocloa colonum, Cynodon dactylon.*

(b) Sedges: The weeds belonging to the family Cyperaceae come under this group. The leaves are mostly from the base having modified stem with or without tubers. The examples are *Cyperus rotundus, Fimbrystylis miliaceae.*

(c) Broad leaved weeds: This is the major group of weeds as all other family weeds come under this except that is discussed earlier. All dicotyledon weeds are broad leaved weeds. The examples are *Flavaria australacica, Digera arvensis, Tridax procumbens*

		
Cynodon dactylon	*Cyperus rotundus*	*Tridax procumbens*

IX. Based on nature of stem

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

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

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

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

		
Prosopis juliflora	*Croton sparsiflorus*	*Amaranthus viridis*

X. Based on specificity

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.

a. Poisonous weeds

The poisonous weeds cause ailment on livestock resulting in death and cause great loss. These weeds are harvested along with fodder or grass and fed to cattle or while grazing the cattle consume these poisonous plants. Eg. *Datura fastuosa, D. stramonium* and *D. metal* are poisonous to animals and human beings. The berries of *Withania somnifera* and seeds of *Abrus precatorius* are poisonous.

		
Datura metal	*Withania somnifera*	*Abrus precatorius*

b. 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. Those parasites which attack roots are termed as root parasites and those which attack shoot of other plants are called as stem parasites. The typical examples are;

1. Total root parasite – *Orabanche cernua* on Tobacco
2. Partial root parasite - *Striga lutea* on sugarcane and sorghum

 *Orabanche cernua* on Tobacco	 *Striga lutea* on sorghum

3. Total stem parasite - *Cuscuta chinensis* on leucerne and onion
4. Partial stem parasite - *Loranthus longiflorus* on mango and other trees.

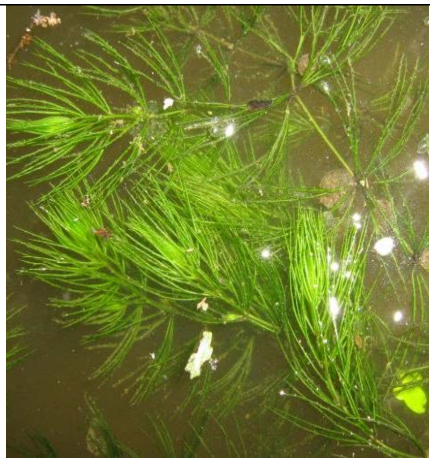
 *Cuscuta chinensis*	 *Loranthus longiflorus* on mango

c. 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, emersed, marginal and floating weeds.

1. **Submersed weeds:** These weeds are mostly vascular plants that produce all or most of their vegetative growth beneath the water surface, having true roots, stems and leaves. Eg. *Utricularia stellaris, Ceratophyllum demersum.*

Utricularia stellaris



Ceratophyllum demersum

2. **Emersed weeds:** These plants are rooted in the bottom mud, with aerial stems and leaves at or above the water surface. The leaves are broad in many plants and sometimes like grasses. These leaves do not rise and fall with water level as in the case of floating weeds. Eg. *Nelumbium speciosum, Jussieua repens.*

Nelumbium speciosum	*Jussieua repens*

3. Marginal weeds: Most of these plants are emersed weeds that can grow in moist shoreline areas with a depth of 60 to 90 cm water. These weeds vary in size, shape and habitat. The important genera that comes under this group are; *Typha, Polygonum, Cephalanthus, Scirpus, etc.*

	
Typha sp.	*Polygonum sp.*

4. Floating weeds: These weeds have leaves that float on the water surface either singly or in cluster. Some weeds are free floating and some rooted at the mud bottom and the leaves rise and fall as the water level increases or decreases. Eg. *Eichhornia crassipes, Pistia stratiotes, Salvinia, Nymphaea pubescens*.

	
Eichhornia crassipes	*Salvinia sp.*

PROPAGATION AND DISSEMINATION OF WEED SEEDS

PROPAGATION

Propagation is the process of multiplying or increasing the number of plants of the same species and at the same time perpetuating their desirable characteristics. Plants may be propagated under two general categories: sexual and asexual propagation.

Reproduction by seed

Reproduction by seed is called sexual reproduction. It requires pollination and fertilization of an egg which results in seed that is capable of producing a new plant. Seed production varies greatly among and within weed species in part due to environmental variability between years, competition from neighboring plants, and genetic variability. For example, while *Canada thistle* has been observed to produce as few as 680 seeds per plant, Curly dock often produces more than 30,000 seeds per plant.

Canada thistle

Vegetative reproduction

In vegetative (asexual) reproduction, a new plant develops from a vegetative organ such as a stem, root, or leaf. Several modifications of these organs are common in perennial weeds, such as underground stems (rhizomes), above-ground stems (stolons), bulbs, corms, and tubers. Although vegetative structures generally do not survive as long in the soil as do seeds, very small structures can result in a new plant. Canada thistle, for example, can produce a new plant from as small as a 1/4-inch section of root.

Vegetative reproduction can be as prolific as seed production. Yellow nut-sedge (*Cyperus esculentus*) has been reported to produce more than 1,900 new plants and more than 6,800 tubers in 1 year.

Cyperus esculentus - tubers

DISSEMINATION / DISPERSAL

A plant seed is a unique genetic entity, a biological individual. However, a seed is in a diapause state, an essentially dormant condition, awaiting the ecological conditions that will allow it to grow into an adult plant, and produce its own seeds. Seeds must therefore germinate in a safe place, and then establish themselves as a young seedling, develop into a juvenile plant, and finally become a sexually mature adult that can pass its genetic material on to the next generation.

The chances of a seed developing are generally enhanced if there is a mechanism for dispersing to an appropriate habitat some distance from the parent plant. The reason for dispersal is that closely related organisms have similar ecological requirements. Obviously, competition with the parent plant will be greatly reduced if its seeds have a mechanism to disperse some distance away. Their ability to spread and remain viable in the soil for years makes eradication nearly impossible.

Seeds have no way to move on their own, but they are excellent travelers. Plants have evolved various mechanisms that disperse their seeds effectively. Many species of plants have seeds with anatomical structures that make them very buoyant, so they can be dispersed over great distances by the winds. In the absence of proper means of their dispersal, weeds could not have moved from one country to another. An effective dispersal of weed seeds and fruits requires two essentials a successful dispersing agent and an effective adaptation to the new environment.

There are two ways of looking at weed seed dispersal

- the expanding range and increasing population size of an invading weed species into a new area
- the part of the process by which an established and stabilized weed species in an area maintains itself within that area

Dissemenation includes two separate processes. They are Dispersal (leaving mother plant) and Post-dispersal events (subsequent movement). Dispersal of seed occurs in 4 dimensions viz.

1. Length and 2. Width: Land/habitat/soil surface area phenomena

3. Height (soil depth, in the air)

4. Time: shatters immediately after ripening (or) need harvesting activity to release seed

Common weed dispersal agents are Wind, Water, Animals, Human, Machinery, etc.

(a) Wind

Many seeds are well adapted to wind travel. Cottony coverings and parachute-like structures allow seeds to float with the wind. Examples of wind-dispersed seeds include common milkweed (*Asclepias syriaca),* common dandelion, Canada thistle, and perennial sowthistle (*Sonchus arvensis).* Weed seeds and fruits that disseminate through wind possess special organs to keep them afloat. Such organs are

1. Pappus – It is a parachute like modification of persistent calyx into hairs.

Eg. Asteraceae family weeds - *Tridax procumbens*

	
Tridax procumbens	Pappus *seed*

2. Comose - Some weed seeds are covered with hairs, partially or fully Eg. *Calotropis* sp.

3. Feathery, persistent styles - Styles are persistent and feathery Eg. *Anemone* sp.

4. Baloon - Modified papery calyx that encloses the fruits loosely along with entrapped air. Eg. *Physalis minima*

5. Wings - One or more appendages that act as wings. Eg. *Acer macrophyllum*

Factors that influence wind dispersal

a. seed weight
b. seed shape
c. structures (wings or pappus)
d. height of release
e. wind speed and turbulence

(b) Water

Aquatic weeds disperse largely through water. They may drift either as whole plants, plant fragments or as seeds with the water currents. Terrestrial weed seeds also disperse through irrigation and drainage water.Weed seed often moves with surface water runoff into irrigation water and ponds, where it is carried to other fields. Weeds growing in ditch banks along irrigation canals and ponds are the major source of weed seed contamination of irrigation water.

Weed seed often remains viable in water for several years, creating a "floating seedbank" and allowing weeds to disperse over large areas in moving water. Field bindweed seed, for example, remains over 50 percent viable after being submerged in water for more than 4 years. Some seeds have special adaptations that aid in water travel. The seedpod of curly dock, for example, is equipped with pontoons that carry the floating seed.

Curly dock

		
Plant	**Seed**	**Mature seed**

(c) Animals

Several weed species produce seeds with barbs, hooks, spines, and rasps that cling to the fur of animals or to clothing and then can be dispersed long distances. Farm animals carry weed seeds and fruits on their skin, hair and hooves. This is aided by special appendages such as Hooks (*Xanthium strumarium*), Stiff hairs (*Cenchrus* spp), Sharp spines (*Tribulus terrestris*) and Scarious bracts (*Achyranthus aspera*). Even ants carry a huge number of weed seeds. Donkeys eat *Prosophis julifera* pods.

		
Xanthium strumarium - hook	*Cenchrus* spp - stiff hair	*Tribulus terrestris - spines*

Weed seed often is ingested and passed through the digestive tracts of animals. Animal droppings provide an ideal nutrient and moisture environment for weed germination. While only a small percentage of the seed remains viable after exposure to an animal's digestive enzymes. The ingested weed seeds are passed in viable form with animal excreta (0.2% in chicks, 9.6% in calves, 8.7% in horses and 6.4% in sheep), which is dropped wherever the animal moves. This mechanism of weed dispersal in called endozoochory. Eg., *Lantana* seeds by birds. *Loranthus* seeds stick on beaks of birds. Viable weed seeds are present in the dung of farm animals, which forms part of the FYM. Besides, addition of mature weeds to compost pit as farm waste also act as source.

(d) Dispersal by Man

Man disperses numerous weed seeds and fruits with raw agricultural produce. Weeds mature at the same time and height along with crop, due to their similar size and shape as that of crop seed man unknowingly harvest the weeds also, and aids in dispersal of weed seeds. Such weeds are called “Satellite weeds” Eg. *Avena fatua*, *Phalaris minor*.

Avena fatua

Phalaris minor

(e) Dispersal by machinery

Weed seeds often are dispersed by tillage and harvesting equipment. Seeds move from field to field on the soil that sticks to tractor tires, and vegetative structures often travel on tillage and cultivation equipment and latter dropping them in other fields to start new infestation. Disc-type cultivation equipment is less likely to drag vegetative plant parts than are shovels or sweeps.

(f) Intercontinental movement of weeds:

Introduction of weeds from one continent to another through crop seed, feed stock, packing material and nursery stock. Eg. *Parthenium hysterophorus*

(g) Crop mimicry dispersal

Weed seed adaptations to look like crop seed: plant body or seed same size, shape, and morphology as crop. Eg: barnyard grass biotype looking like rice escapes hand weeding and is dispersed with rice, nightshade fruit ("berries") same size, shape as dry beans, harvested and dispersed with beans.

(h) As admixtures with crop seed, animal feed, hay and straw.

Weeds probably are spread more commonly during the seeding of a new crop or in animal feed and bedding than by any other method. Seed labels often indicate a tiny percentage of weed seed, but consider this example. If a legume seed contains 0.001 percent dodder (a parasitic annual; *Cuscuta campestris)* seed by weight, there will be eight dodder seeds per 2 kg of legume seed. If the legume seed is sown in a field despite an extremely low dodder seed percentage by weight, the small size of the seed, combined with rapid early-season growth, could result in an infested legume field within a single season.

CROP-WEED ASSOCIATION, CROP-WEED COMPETITION AND ALLELOPATHY

Weeds posseses many growth characteristics and adaptations which enable them to exploit successfully the numerous ecological niches left unocccupied by crop cultures. Weeds compete with themselves and with crop plant. Among the more important adoptations relevent to competitive advantage are properly synchronized germination, rapid establishment and growth of seedlings, tolerance to shading effects by the crop or by other weeds at the time of establishment, quick response to available soil moisture and nutrients, adaptation to the most severe climatic situations of the habitat, adaptations to the edaphic regime, relative immunity to post seeding soil disturbance, practices and resistance to herbicides that are used. In the nitial stages of invasion by weeds of exposed ecological niches, only a very limited competition for resources by the crop and weed may occur, but as establishment of the crop-weed association is completed, competition for the available reources is more obvious.

Plant competition is a natural force whereby crop and weed plants tend to attain a maximum combined growth and yield, with the development of each species being to some extent at the expense of the other. It occurs when the demands of the plants for moisture, nutrients, light, and possibly carbon dioxide exceed the available supply. Competition may develop between crop and weed plants and also between individual plants of each. The ultimate outcome of competition usually results in the development of a characteristic crop-weed association. Crop plants and weeds may grow and mature in the state of mutual supression that is often found in crops where no suitable herbicide is available to control the weeds. The weed suppresses the crop and result in reduction of yield. The crop also suppresses the weeds, a condition often found in row crop cultures. This is a logical sequence in a crop habitat where both cultural and herbicide methods provide effective control.

A principle of plant competition is that the first plants to occupy an area have an advantage over latecomers. This principle is of foremost consideration in practical weed control, where cropping practices are always directed to the establishment of the crop ahead of the weeds.

Competition and allelopathy are the main interactions, which are of importance between crop and weed. Allelopathy is distinguished from competition because it depends on a chemical compound being added to the environment while competition involves removal or reduction of an essential factor or factors from the environment, which would have been otherwise utilized.

CROP WEED COMPETITION

Weeds appear much more adapted to agro-ecosystems than our crop plants. Without interference by man, weeds would easily wipe out the crop plants. This is because of their competition for nutrients, moisture, light and space which are the principle factors of production of crop. Generally, an increase in on kilogram of weed growth will decrease one kilogram of crop growth.

1. Competition for Nutrients

Weeds usually absorb mineral nutrients faster than many crop plants and accumulate them in their tissues in relatively larger amounts.

- *Amaranthus* sp. accumulate over 3% N on dry weight basis and are termed as "nitrophills".
- *Achyranths aspera*, a 'P' accumulator with over 1.5% P_2O_5
- *Chenopodium* sp & *Portulaca* sp. are 'K' lovers with over 1.3% K_2O in dry matter

Mineral composition of certain common weeds on dry matter basis

S.No	Species	N	P_2O_5	K_2O
1.	*Achyranthus aspera*	2.21	1.63	1.32
2.	*Amaranthus viridis*	3.16	0.06	4.51
3.	*Chenapodium album*	2.59	0.37	4.34
4.	*Cynodon dactylan*	1.72	0.25	1.75
5.	*Cyperus rotundus*	2.17	0.26	2.73
Crop plants				
1.	Rice	1.13	0.34	1.10
2.	Sugarcane	0.33	0.19	0.67
3.	Wheat	1.33	0.59	1.44

- ✓ The associated weed is responsive to nitrogen and it utilizes more of the applied 'N' than the crop. Eg. The 'N' uptake by *Echinochloa crusgalli* is more than rice.
- ✓ Nutrient removal by weeds leads to huge loss of nutrients in each crop season, which is often twice that of crop plants. For instance at early stages of maize cultivation, the weeds found to remove 9 times more of N, 10 times more of P and 7 times more of K.

2. Competition for moisture

- In general, for producing equal amounts of dry matter, weeds transpire more water than do most of our crop plants. It becomes increasingly critical with increasing soil moisture stress, as found in arid and semi-arid areas.

- As a rule, C_4 plants utilize water more efficiently resulting in more biomass per unit of water. *Cynodon dactylon* had almost twice as high transpiration rate as pearl millet.
- In weedy fields soil moisture may be exhausted by the time the crop reaches the fruiting stage, i.e. the peak consumptive use period of the crop, causing significant loss in crop yields.

3. Competition for light

- It may commence very early in the cop season if a dense weed growth smothers the crop seedlings.
- It becomes important element of crop-weed competition when moisture and nutrients are plentiful.
- In dry land agriculture in years of normal rainfall the crop-weed competition is limited to nitrogen and light.
- Unlike competition for nutrients and moisture once weeds shade a crop plant, increased light intensity cannot benefit it.

4. Competition for space (CO_2)

Crop-weed competition for space is the requirement for CO_2 and the competition may occur under extremely crowded plant community condition. A more efficient utilization of CO_2 by C_4 type weeds may contribute to their rapid growth over C_3 type of crops.

ALLELOPATHY

Allelopathy is the detrimental effects of chemicals or exudates produced by one (living) plant species on the germination, growth or development of another plant species (or even microorganisms) sharing the same habitat.

Allelopathy does not form any aspect of crop-weed competition, rather, it causes Crop-Weed interference, it includes competition as well as possible allelopathy.

Allelo chemicals are produced by plants as end products, by-products and metabolites liberalised from the plants; they belong to phenolic acids, flavanoides, and other aromatic compounds viz., terpenoids, steroids, alkaloids and organic cyanides.

Allelopathic Effect of Weeds on Crops

(1) Maize

- Leaves & inflorescence of *Parthenium* sp. affect the germination and seedling growth
- Tubers of *Cyperus esculentus* affect the dry matter production

(2) Sorghum

- Stem of *Solanum* affects germination and seedling growth
- Leaves and inflorescence of *Parthenium* affect germination and seedling growth

(3) Wheat

- Seeds of wild oat affect germination and early seedling growth
- Leaves of *Parthenium* affects general growth
- Tubers of *C. rotundus* affect dry matter production
- Green and dried leaves of *Argemone mexicana* affect germination & seedling growth

(4) Sunflower

- Seeds of *Datura* affect germination & growth

Allelopathic Effect of crop plants on weeds

(i) Root exudation of maize inhibits the growth of *Chenopodium album*

(ii) The cold water extracts of wheat straw when applied to weeds reduce germination and growth of *Abutilon* sp.

Allelopathic effect of weeds on weeds

- Extract of leaf leachate of decaying leaves of *Polygonum* contains flavonoides which are toxic to germination, root and hypocotyls growth of weeds like *Amaranthus spinosus*
- Inhibitor secreted by decaying rhizomes of *Sorghum halepense* affect the growth of *Digitaria sanguinalis* and *Amaranthus* sp.

Factors influencing allelopathy

a. Plant factors

i. Plant density: Higher the crop density the lesser will be the allelo chemicals it encounters
ii. Life cycle: If weed emerges later there will be less problem of allelochemicals
iii. Plant age: The release of allelochemicals occurs only at critical stage. For eg. in case of *Parthenium*, allelopathy occurs during its rosette & flowering stage.
iv. Plant habit: The allelopathic interference is higher in perennial weeds.
v. Plant habitat: Cultivated soil has higher values of allelopathy than uncultivated soil.

b. Climatic factors: The soil & air temperature as well as soil moisture influence the allelo chemicals potential

c. Soil factors: Physico-chemical and biological properties influence the presence of allelochemicals.

d. Stress factors: Abiotic and Biotic stresses may also influence the activity of allelochemcals

Mechanism of action of allelochemicals

- Interfere with cell elongation
- Interfere with photosynthesis
- Interfere with respiration
- Interfere with mineral ion uptake

- Interfere with protein and nucleic acid metabolism

Use of Allelopathy in biological control of weeds:

1. Use of cover crop for biological control
2. Use of alleopathic chemicals as bio-herbicides

Effect of weed competition on crop growth and yield

1. Crop growth and yield is affected
2. Crop suffers from nutritional deficiency
3. Leaf area development is reduced
4. Yield attributes will be lowered
5. Reduce the water use by the crop
6. Affect the dry matter production
7. Lowers the input response
8. Causes yield reduction
9. Pest and disease incidence will be more

Losses Caused by Weeds

A. Reduction in crop yield

Weeds compete with crop plants for nutrients, soil moisture, space and sunlight. In general an increase in one kilogram weed growth corresponds to reduction in one kilogram of crop growth. Depending on type of weed, intensity of infestation, period of infestation, the ability of crop to compete and climatic conditions the loss varies. The table below depicts the percentage range of yield loss due to weeds in some important field crops.

Table1.1.Yield losses due to weeds in some important crops

Crop	Yield loss range (%)	Crop	Yield loss range (%)
Rice	9.1 – 51.4	Sugarcane	14.1 – 71.7
Wheat	6.3 – 34.8	Linseed	30.9 – 39.1
Maize	29.5 – 74.0	Cotton	20.7 – 61.0
Millets	6.2 – 81.9	Carrot	70.2 – 78.0
Groundnut	29.7 – 32.9	Peas	25.3 – 35.5

Among the pests weeds account for 45 % reduction in yield while the insects 30%, diseases 20% and other pests 5%.

B. Loss in crop quality

If a crop contains weed seeds it is to be rejected, especially when the crop is grown for seed. For example, the wild oat weed seeds are similar in size and shape of the crops like barley, wheat, and its admixture may lead to rejection for seed purpose. Contamination by poisonous weed seeds is unacceptable and increases costs of crop cleaning. The leafy vegetables much suffers due to weed problem as the leafy weed mixture spoil the economic value.

C. Weeds as reservoirs of pests and diseases

Weeds form a part of community of organisms in a given area. Consequently, they are food sources for some animals, and are themselves susceptible to many pests and diseases. However, because of their close association with crop they may serve as important reservoirs or alternate host of pests and diseases.

D. Interference in crop handling

Some weeds can make the operation of agricultural machinery more difficult, more costly and even impossible. Heavy infestation of *Cynadon dactylon* causes poor ploughing performance.

E. Reduction in land value

Heavy infestation by perennial weeds could make the land unsuitable are less suitable for cultivation resulting in loss in its monetary value. Thousands of hectare of cultivable area in rice growing regions of India have been abandoned or not being regularly cultivated due to severe infestation of nutgrass (*Cyperus rotundus*) and other perennial grasses.

F. Limitation of crop choice

When certain weeds are heavily infested, it will limit the growth of a particular crop. The high infestation of parasitic weeds such as *Striga lutea* may limit the growing of sorghum or sugarcane.

G. Loss of human efficiency

Weeds reduce human efficiency through physical discomfort caused by allergies and poisoning. Weeds such as congress weed (*Parthenium hysterophorus*) causes itching. Thorny weeds like *Solanum* spp. restrict moment of farm workers in carrying out farm practices such as fertilizer application, insect and disease control measures, irrigation, harvesting etc.

H. Problems due to aquatic weeds

The aquatic weeds that grow along the irrigation canals, channels and streams restricts the flow of water. Weed obstruction cause reduction in velocity of flow and increases stagnation of water and may lead to high siltation and reduced carrying capacity. Aquatic weeds form breeding grounds for obnoxious insects like mosquitoes. They reduce recreational value by interfering with fishing, swimming, boating, hunting and navigation on streams and canals.

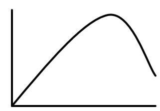
I. Other problems

Weeds are troublesome not only in crop plants but also in play grounds and road sides etc. *Alternanthera echinata* and *Tribulus terrestris* occurs in many of the playgrounds causing annoyance to players and spectators.

Factors affecting the competitive ability of crops against weeds

a. Density of weeds

Increase in density of weed decrease in yield is a normal phenomena. However, it is not linear as few weeds do not affect the yields so much as other weed does and hence, it is a sigmoidal relationship.



b. Crop density

Increase in plant population decreases weed growth and reduce competition until they are self competitive. Crop density and rectangularity are very important in determining the quantum and quality of crop environment available for the growth of weeds. Wide row spacing with simultaneous high, intra-row crop plant population may induce dense weed growth. In this respect, square planting of crops in which there are equal row and plant spacing should be ideal in reducing intra-crop plant competition.

c. Type of weeds species

The type of weeds that occur in a particular crop influences the competition. Occurrence of a particular species of weed greatly influences the competition between the crop & weed. For eg. *E. crusgalli* in rice, *Setaria viridis* in corn and *Xanthium* sp. in soybean affects the crop yield. Flavaria australasica offers more competition than the grasses

d. Type of crop species and their varieties

Crops and their varieties differ in their competing ability with weeds e.g., the decreasing order of weed competing ability is as: barley, rye, wheat and oat. High tolerance of barley to competition from weeds is assigned to its ability to develop more roots that are extensive during initial three weeks growth period than the others.

Fast canopy forming and tall crops suffer less from weed competition than the slow growing and short stature & crops. Dwarf and semi-dwarf varieties of crops are usually more susceptible to competition from weeds than the tall varieties became they grow slowly and initial stage. In addition, their short stature covers the weeds less effectively. When we compare the crop-weed competition between two varieties of groundnut TMV 2 (Bunch) and TMV 3 (Spreading), TMV 2 incurred a loss of over 30% pod yield under uncontrolled weed - crop competition while TMV 3 lost only about 15% in its yield. The main reason is due to the spreading nature of TMV 3, which smothered weeds. Longer duration cultivars of rice have been found more competitive to weeds than the short duration ones.

e. Soil factors

Soil type, soil fertility, soil moisture and soil reaction influences the crop weed competition. Elevated soil fertility usually stimulates weeds more than the crop, reducing thus crop yields. Fertilizer application of weedy crop could increase crop yields to a much lower level than the yield increase obtained when a weed free crop is applied with fertilizer.

Weeds are adapted to grow well and compete with crops, in both moisture stress and ample moisture conditions. Removal of an intense moisture stress may thus benefit crops more than the weeds leading to increased yields. If the weeds were already present at the time of irrigation, they would grow so luxuriantly as to completely over power the crops. If the crop in irrigated after it has grown 15 cm or more in a weed free environment irrigation could hasten closing in of crop rows, thus suppressing weeds.

Abnormal soil reactions often aggravate weed competition. It is therefore specific weed species suited to different soil reactions exist with us, our crops grow best only in a specified range of soil pH. Weeds would offer more intense competition to crops on normal pH soils than on normal pH soils.

f. Climate

Adverse weather condition, Eg. drought, excessive rains, extremes of temperature, will favour weeds since most of our crop plants are susceptible to climatic stresses. It is further intensified when crop cultivation is stratified over marginal lands. All such stresses weaken crops inherent capacity to fight weeds.

g. Time of germination

In general, when the time of germination of crop coincides with the emergence of first flush of weeds, it leads to intense Crop-Weed interference. Sugarcane takes about one month to complete its germination phase while weeds require very less time to complete its germination.

Weed seeds germinate most readily from 1.25 cm of soil and few weeds can germinate even from 15cm depth. Therefore, planting method that dries the top 3 to 5 cm of soil rapidly enough to deny weed seeds opportunity to absorb moisture for their germination usually postpones weed emergence until the first irrigation. By this time the crop plants are well established to compete with late germinating weeds.

h. Cropping practices

Cropping practices, such as method of planting crops, crop density and geometry and crop species and varieties have pronounced effects on Crop-Weed interference.

i. Crop maturity

Maturity of the crop is yet another factor which affects competition between weeds & crop. As the age of the crop increases, the competition for weeds decreases due to its good establishment. Timely weeding in the early growth stages of the crop enhances the yield significantly.

Critical period of weed competition

Critical period of weed competition is defined as the shortest time span during the crop growth when weeding results in highest Economic returns.

The critical period of crop-weed competition is the period from the time of sowing up to, which the crop is to be maintained in a weed free environment to get the highest economical yield. The weed competition in crop field is invariably severe in early stages of crop than at later stages. Generally in a crop of 100 days duration, the first 35 days after sowing should be maintained in a weed free condition. There is no need to attempt for a weed free condition throughout the life period of the crop, as it will entail unnecessary additional expenditure without proportionate increase in yield. Critical period of weed competition for important crops ae as follows

S.No.	**Crops**	**Days from sowing**	**S.No.**		**Days from sowing**
1.	Rice (Lowland)	35	7.	Cotton	35
2.	Rice (upland)	60	8.	Sugarcane	90
3.	Sorghum	30	9.	Groundnut	45
4.	Finger millet	15	10.	Soybean	45
5.	Pearl millet	35	11.	Onion	60
6.	Maize	30	12.	Tomato	30

It becomes clear that weed free condition for 2-8 weeks in general are required for different crops and emphasizes the need for timely weed control without which the crop yield gets drastically reduced.

METHODS OF WEED CONTROL – PHYSICAL & CULTURAL

For designing any weed control programme in a given area, one must know the nature & habitat of the weeds in that area, how they react to environmental changes & how they respond to herbicides. Before selecting a method of weed control one, much have information on the number of viable seeds nature of dispersal of seeds, dormancy of seeds, longevity of buried seeds & ability to survive under adverse conditions, life span of the weed, soil textures moisture and (In case of soil applied volatile herbicides the herbicide will be successful only in sandy loam soil but not in clayey soil. Flooding as a method of weed control will be successful only in heavy soil & net in sandy soil) the area to be controlled.

Principles of weed control are;

a) Prevention
b) Eradication
c) Control
d) Management

Preventive weed control

It encompasses all measures taken to prevent the introduction and/or establishment and spread of weeds. Such areas may be local, regional or national in size. No weed control programme is successful if adequate preventive measures are not taken to reduce weed infestation. It is a long term planning so that the weeds could be controlled or managed more effectively and economically than is possible where these are allowed to disperse freely. Following preventive control measures are suggested for adoption wherever possible & practicable.

1. Avoid using crop that are infested with weed seeds for sowing
2. Avoid feeding screenings and other material containing weed seeds to the farm animals.
3. Avoid adding weeds to the manure pits.
4. Clean the farm machinery thoroughly before moving it from one field to another. This is particularly important for seed drills
5. Avoid the use of gravel sand and soil from weed-infested
6. Inspect nursery stock for the presence of weed seedlings, tubers, rhizomes, etc.
7. Keep irrigation channels, fence-lines, and un-cropped areas clean
8. Use vigilance. Inspect your farm frequently for any strange looking weed seedlings. Destroy such patches of a new weed by digging deep and burning the weed along with its roots. Sterilize the spot with suitable chemical.

9. Quarantine regulations are available in almost all countries to deny the entry of weed seeds and other propagules into a country through airports and shipyards.

Weed free crop seeds

It may be produced by following the pre-cautionary measures.

i. Separating crop seeds from admixture of crop & weed seeds using physical differences like size, shape, colour, weight / texture & electrical properties.
ii. Using air-screen cleaners & specific gravity separators, which differentiate seeds based on seed size, shape, surface area & specific gravity.
iii. Through means of Seed certification we can get certified seeds and can be used safely because the certified seeds contain no contaminant weed seeds
iv. Weed laws are helpful in reducing the spread of weed species & in the use of well adapted high quality seeds. They help in protecting the farmers from using mislabeled or contaminated seed and legally prohibiting seeds of noxious weeds from entering the country.
v. Quarantine laws enforce isolation of an area in which a severe weed has become established & prevent the movement of the weed into an uninfected area.
vi. Use of pre-emergence herbicides also helpful in prevention because herbicides will not allow the germination of weeds.

b. Eradication: (ideal weed control rarely achieved)

It infers that a given weed species, its seed & vegetative part has been killed or completely removed from a given area & that weed will not reappear unless reintroduced to the area. Because of its difficulty & high cost, eradication is usually attempted only in smaller areas such as few hectares or few thousand m^2 or less. Eradication is often used in high value areas such as green houses, ornamental plant beds & containers. This may be desirable and economical when the weed species is extremely noxious and persistent as to make cropping difficult and economical.

c. Control

It encompasses those processes where by weed infestations are reduced but not necessarily eliminated. It is a matter of degree ranging from poor to excellent. In control methods, the weeds are seldom killed but their growth is severely restricted, the crop makes a normal yield. In general, the degree of weed control obtained is dependent on the characters of weeds involved and the effectiveness of the control method used.

d. Weed management

Weed control aims at only putting down the weeds present by some kind of physical or chemical means while weed management is a system approach whereby whole land use planning is done in advance to minimize the very invasion of weeds in aggressive forms and give crop plants a strongly competitive advantage over the weeds.

Weed control methods are grouped into cultural, physical, chemical and biological. Every method of weed control has its own advantages and disadvantages. No single method is successful under all weed situations. Many a time, a combination of these methods gives effective and economic control than a single method.

MECHANICAL WEED CONTROL

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

1. Tillage

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

2. Hoeing

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

3. Hand weeding

It is done by physical removal or pulling out of weeds by hand or removal by implements called khurpi, which resembles sickle. It is probably the oldest method of controlling weeds and it is still a practical and efficient method of eliminating weeds in cropped and non-cropped lands. It is very effective against annuals, biennials and controls only upper portions of perennials.

4. Digging

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

5. Sickling and mowing

Sickling is also done by hand with the help of sickle to remove the top growth of weeds to prevent seed production and to starve the underground parts. It is popular in sloppy areas where only the tall weed growth is sickled leaving the root system to hold the soil in place to prevent soil erosion. **Mowing** is a machine-operated practice mostly done on roadsides and in lawns.

6. Burning

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

8. Flooding

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

Merits of Mechanical Method

1) Oldest, effective and economical method
2) Large area can be covered in shorter time
3) Safe method for environment
4) Does not involve any skill

5) Weeding is possible in between plants

6) Deep rooted weeds can be controlled effectively

Demerits of Mechanical Method

1) Labour consuming

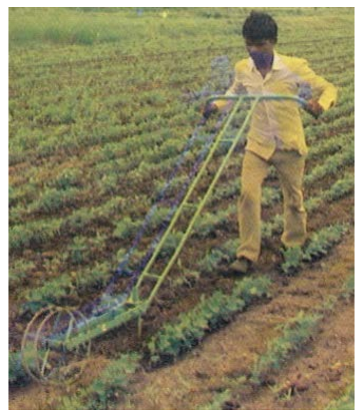
2) Possibility of damaging crop

3) Requires ideal and optimum specific condition

Mechanical weeders

Dry Land Weeder

It is used for weeding in row crops for removing shallow rooted weeds. It has been designed ergonomically for easy operation. Useful in dryland and gardenland crops and is ideal at a soil moisture content of 8 to 10 per cent.



At the extreme end of the arm 120 mm diameter star wheel is fixed. A cutting blade is fitted to the arm 200mm to the back of the star wheel the star wheel facilitates easy movement of the tool. The operating width of the blade is 120 mm. Ideal to remove shallow rooted weeds. The workable moisture content has to be 8 to 10 %

Power rotary weeder

- For mechanical control of weeds in crops such as sugarcane, tapioca, cotton, tomato and pulses whose rows spacing is more than 45 cm.

The rotary weeder consists of three rows of discs mounted with 6 numbers of curved blades in opposite directions alternatively in each disc. These blades when rotating enable cutting and mulching the soil. The width of coverage of the rotary tiller is 500 mm and the depth of operation can be adjusted to weed and mulch the soil in the cropped field.

Tractor drawn weeding cum earthing up equipment

- For weeding and intercultural operations in between row crops in a single pass


An inter cultivator cum earthing up equipment was developed and fitted to a standard tractor drawn ridger. Three number of sweep type blades are affixed to the ridger frame for accomplishing the weeding operation in between standing rows of crops. Three ridger bottom fitted behind the sweep blade, work on the loosened soil mass and aid in earthing up by forming ridges and furrows. Weeding efficiency is 61 per cent.

Tractor operated multi row rotary weeder

- For weeding and intercultural operations in between row crops like sugarcane, cotton, maize, etc. in a single pass


The multi row rotary weeder consists of a set of cutting blades, which penetrate in to the soil, removing the weeds in the crop rows. The cutting blade has also been used as an inclined plane for elevating and converging the soil. The rotating blades are used to cut the weeds and pulverizing the soil. Weeding efficiency is 71 per cent.

Cono weeder

- For weeding between rows of paddy crop

The cono weeder has two conical rotors mounted in tandem with opposite orientation. Smooth and serrated blades mounted alternately on the rotor uproot and burry weeds because the rotors create a back and forth movement in the top 3 cm of soil, the cono weeder can satisfactorily weed in a single forward pass without a push pull movement. It is easy to operate by a single operator. The weeder does not sink in puddled soil. Field capacity 0.18 ha/day. Star, Peg type and Twin hoe wheel weeding.

CULTURAL WEED CONTROL

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

1. Field preparation

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

2. Summer tillage

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

3. Maintenance of optimum plant population

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

4. Crop rotation

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

5. Growing of intercrops

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

6. Mulching

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

7. Solarisation

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

8. Stale seedbed

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

9. Blind tillage

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

10. Crop management practices

Good crop management practices that play an important role in weed control are

a. Vigorous and fast growing crop varieties are better competitors with weeds.
b. Proper placement of fertilizers ensures greater availability of nutrients to crop plants, thus keeping the weeds at a disadvantage.
c. Better irrigation practices to have a good head start over the weeds
d. Proper crop rotation programme

e. Higher plant population per unit area results in smothering effect on weed growth

Merits of Cultural Method

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

Demerits of Cultural Method

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

METHODS OF WEED CONTROL - CHEMICAL AND BIOLOGICAL METHODS

HERBICIDAL CONTROL OF WEEDS

Herbicides are chemicals capable of killing or inhibiting the growth of plants. In the last 40 years or so, man has greatly improved upon his weeding efficiency by supplementing the conventional weeding methods with herbicides. It has saved farmers of undue, repeated inter-cultivations and hoeing, and has helped him in obtaining satisfactory weed control where physical methods often fail. Today, we have over 1501 herbicides in common use for selective and non-selective weed control in different areas. These chemicals vary greatly in their (a) molecular structures, (b) mobility within plants, (c) selectivity, (d) fate in soils, and (e) response to environment. Important properties and uses of some common herbicides in use today are discussed later in Chapter 13.

Many chemicals have shown high codes of selectivity to certain crops, killing the weeds effectively. But proper selection of the herbicide, its rate, time, and method of application are very important to obtain the desire degree of weed control and crop selectivity.

Herbicides are tools, and tool must be used with care. Many developing nations have made a good beginning in the use of herbicides in agriculture, but more comprehensive research needs to be done before extending it to new situations.

Benefits of Herbicides

Herbicides were developed in the western world primarily to overcome the shortage of farm labour for weeding crops. However, during the past four decades, slowly the utility of herbicides has also been realized in the labour-rich tropical world, for varied reasons. Given adequate labour and money to remove weeds manually, still many advantages accrue from the judicious use of herbicides. Important among these are the following:-

1. In monsoon season incessant rainfall may make physical weeding infeasible. Herbicides can be used to ensure freedom of crops from weeds under such a condition. Also, during the early crop growth period when many fields need weeding simultaneously, even in labour-rich countries like India, Pakistan, Bangladesh, Nepal, Nigeria, and Sudan, there is certainly a weeding bottleneck in crop production. The soil applied herbicides can be of great help in these regions in boosting crop production.

2. Herbicides can be employed to control weeds as they emerge from the soli to eliminate weed crop interference even at a very early stage of crop growth. But by physical methods weeds are removed after they have offered considerable competition to the crops, and rarely at the critical time. Thus, herbicides provide benefits of timely weed control.

3. Herbicides can kill many weeds that survive by mimicry, for example, wildoat (*Avena* spp.) in wheat and barnyardgrass (*Echinochola* spp.) in rice. Weeds that resemble crop plants usually escape physical weeding.

4. Herbicidal control does not dictate strict row spacing's. In physical weed control, on the other hand, the crop rows have to be sufficiently wide to accommodate weeding implements, else hand weeding and hand-pulling of weeds has to be resorted to.

5. Herbicides bring about longer lasting control of perennial weeds and brushes than is possible with any physical control method. Many modern herbicides can translocate considerably deep in the underground system of weeds and damage them.

6. Herbicides are convenient to use on spiny weeds which cannot be reached manually.

When cultivators or hoes are worked hard in an attempt to uproot the established weeds, they may cut many feeding roots of a crop like maize, which are appreciable in the first 10 cm depth of the soil. Their lateral growth fully occupies the inter-row spaces.\

7. Herbicides are safe on erodible lands where tillage may accelerate soil and water erosion. Excessive tillage, in any case, spoils soil structure, reduces organic matter content, and depletes moisture status of the soil.

8. Herbicides kill weeds in *situ* without permitting their dissemination. Tillage on the other hand, may fragment the vegetative propagules of the weeds and drag them to new sites.

9. Herbicide sprays easily reach the weeds growing in obstructed situations, such as utility-right-of-way, under fruit trees, and on undulating lands.

Some other benefits of using herbicides include (a) fewer labour problems, (b) greater possibility of farm mechanization, (c) easier crop harvesting and (d) lower cost of farm produce. In dry land agriculture, effective herbicidal control ensures higher water use by crops and less crop failures due to drought.

Limitations of Herbicides

Like any other method of weed control, herbicides have their own limitations. But with proper precautions these limitations can be overcome, markedly. Important limitations in the use of herbicides are as follows.

1. In herbicidal control there is no automatic signal to stop a farmer who may be applying the chemical inaccurately till he sees the results in the crops sprayed or in the rotation crops that follow.

2. Even when herbicides are applied accurately, these may interact with environment to produce un-intended results. Herbicide drifts, wash-of, and run-off can cause considerable damage to the neighbouring crops, leading to unwarranted quarrels.

3. Depending upon the diversity in farming, a variety of herbicides must be stocked on a farm to control weeds in different fields. On the contrary, for physical control of weeds a farmer has to possess only one or two kinds of weeding implements for his entire farm.

4. Above all, herbicidal control requires considerable skill on the part of the user. He must be able to identify his weeds and possess considerable knowledge about herbicides and their proper usages. Sometimes, an error in the use of herbicides can be very costly.

5. In herbicide treated soils, usually, crop failures cannot be made up by planning a different crop of choice. The selection of the replacement crop has to be based on its tolerance to the herbicide already applied.

6. Military use of herbicides is the greatest misfortune of their discovery. In Vietnam, 2,4-D and 2,4,5-T, for example, were used for defoliating forests and crops, leading to miseries to the innocent civilians. In future, the chemical warfare with residual herbicides may be even more devastating, which must be avoided at all costs.

BIOLOGICAL CONTROL

Use of living organism's viz., insects, disease organisms, herbivorous fish, snails or even competitive plants for the control of weeds is called biological control. In biological control method, it is not possible to eradicate weeds but weed population can be reduced. This method is not useful to control all types of weeds. Introduced weeds are best targets for biological control.

Qualities of bio-agent

1. The bio-agent must feed or affect only one host and not other useful plants
2. It must be free of predators or parasites.
3. It must readily adapt to environment conditions.
4. The bio-agent must be capable of seeking out itself to the host.
5. It must be able to kill the weed or atleast prevent its reproduction in some direct or indirect way.
6. It must possess reproductive capacity sufficient to overtake the increase of its host species, without too much delay.

Merits

1) Least harm to the environment
2) No residual effect
3) Relatively cheaper and comparatively long lasting effect
4) Will not affect non-targeted plants and safer in usage

Demerits

1) Multiplication is costlier
2) Control is very slow
3) Success of control is very limited
4) Very few host specific bio-agents are available at present

Mode of action

a. Differential growth habits, competitive ability of crops and varieties prevent weed establishment Eg. Groundnut, cowpea fast growing and so good weed suppresser.
b. Insects kill the plants by exhausting plant food reserves, defoliation, boring and weakening structure of the plant.
c. Pathogenic organisms damage the host plants through enzymatic degradation of cell constituents, production of toxins, disturbance of harmone systems, obstruction in the translocation of food materials and minerals and malfunctioning of physiological processes.

Outstanding and feasible examples of biological weed control

a. Larvae of *Coctoblastis cactorum*, a moth borer, control prickly pear *Opuntia* sp. The larvae tunnel through the plants and destroy it. In India it is controlled by cochinial insects *Dactylopius indicus* and *D. tomentosus*

b. *Lantana camara* is controlled by larvae of C*rocidosema lantana*, a moth bores into the flower, stems, eat flowers and fruits.
c. *Cuscuta* spp. is controlled by M*elanagromyza cuscutae*
d. *Cyperus rotundus* - *Bactra verutana* a moth borer
e. *Ludiwigia parviflora* is completely denuded by *Altica cynanea* (steel blue beetle)

f. Herbivorous fish Tilapia controls algae. Common carp, a non-herbivorous fish controls sub-mersed aquatic weeds. It is apparently due to uprooting of plants while in search of food. Snails prefer submersed weeds.

Bio-Herbicides/ Mycoherbicides

Defn: The use of plant pathogen which are expected to kill the targeted weeds.

These are native pathogen, cultured artificially and sprayed just like post-emergence herbicides each season on target weed, particularly in crop areas. Fungal pathogens of weed have been used to a larger extent than bacterial, viral or nematode pathogens, because, bacteria and virus are unable to actively penetrate the host and require natural opening or vectors to initiate disease in plants.

Here the specific fungal spores or their fermentation product is sprayed against the target weed. Some registered mycoherbicides in western countries are tabulated below.

No	Product	Content	Target weed
1.	Devine	A liquid suspension of fungal spores of *Phytophthora palmivora* causes root rot.	Strangle vine (*Morrenia odorata*) in citrus
2.	Collego	Wettable powder containing fungal spores of *Colletotrichum gloeosporoides* causes stem and leaf blight	Joint vetch (*Aeschyomone virginica*) in rice, soybean
3.	Bipolaris	A suspension of fungal spores of *Bipolaris sorghicola*	Jhonson grass (*Sorghum halepense*)
4.	Biolophos	A microbial toxin produced as fermentation product of *Steptomyces hygroscopicus*	Non-specific, general vegetation

INTEGRATED WEED MANAGEMENT

An integrated weed management may be defined as the combination of two or more weed-control methods at low input levels to reduce weed competition in a given cropping system below the economical threshold level. It has proved to be a valuable concept in a few cases, though much is still to be done to extend it to the small farmers' level.

Integrated Weed Management (IWM) approach aims at minimizing the residue problem in plant, soil, air and water. An IWM involves the utilization of a combination of mechanical, chemical and cultural practices of weed management in a planned sequence, so designed as not to affect the ecosystem. The nature and intensity of the species to be controlled, the sequence of crops that are raised in the rotation, the standard of crop husbandry, and the ready and timely availability of any method and the economics of different weed-management techniques are some of the potent considerations that determine the success for the exploitation of the IWM approach.

Why IWM

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

Concept

- Uses a variety of technologies in a single weed management with the objective to produce optimum crop yield at a minimum cost taking in to consideration ecological and socio-economic constraints under a given agro-ecosystem.
- A system in which two or more methods are used to control a weed. These methods may include cultural practices, natural enemies and selective herbicides.

FAO Definition

It is a method whereby all economically, ecologically and toxicologically justifiable methods are employed to keep the harmful organisms below the threshold level of economic damage, keeping in the foreground the conscious employment of natural limiting factors.

IWM is the rational use of direct and indirect control methods to provide cost-effective weed control. Such an approach is the most attractive alternative from agronomic, economic and ecological point of view.

Among the commonly suggested indirect methods are land preparation, water management, plant spacing, seed rate, cultivar use, and fertilizer application. Direct methods include manual, cultural, mechanical and chemical methods of weed control.

The essential factor in any IWM programme is the number of indirect and direct methods that can be combined economically in a given situation. For example, increased frequency of ploughing and harrowing does not eliminate the need for direct weed control. It is, therefore, more cost-effective to use fewer pre-planting harrowing and combine them with direct weed control methods.

There is experimental evidence that illustrates that better weed control is achieved if different weed control practices are used in combination rather than if they are applied separately.

Good IWM should be

a. Flexible enough to incorporate innovations and practical experiences of local farmers.
b. Developed for the whole farm and not for just one or two fields and hence it should be extended to irrigation channels, road sides and other non-crop surroundings on the farm from where most weeds find their way in to the crop fields.
c. Economically viable and practically feasible.

Advantages of IWM

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

IWM of *Cuscuta* in Lucerne

1. In fields with history of Cuscuta (dodder), adopt crop raotations with non-susceptible crops. Grow lucerne only once in three years in such fields.
2. Do not move animals and machinery from the dodder infested fields to the new ones.
3. Treat densely infested patches of lucerne with a non-residue herbicide like paraquat.
4. Do not feed the cuscuta infested crop to the animals.
5. Do not collect the lucerne seeds from the crop infested with dodder.

SELECTIVITY AND MODE OF ACTION OF HERBICIDE

Selective herbicides have been used extensively since the introduction of 2,4-D in the late '40s. They have been one of the miracles of modem agriculture, releasing thousands of people from the drudgery of hand weeding. A selective herbicide is one that kills or retards the growth of an unwanted plant or "weed" while causing little or no injury to desirable species. 2,4-D used in turf will kill many of the broadleaf weeds that infest turf while not significantly injuring the turfgrass. But selectivity is a fickle, dynamic process. Excessive rates of 2,4-D applied to stressed turfgrass may injure the turf. Selectivity has always depended on proper herbicide application. Normally herbicides work selectively within a given rate of application. Too little herbicide and no weed control, too much and crop injury may occur. But selectivity is more complex than this. It is a dynamic process that involves the interaction of the plant, the herbicide, and the environment.

I. The Plant

Factors that involve plant response include: genetic inheritance, age, growth rate, morphology, physiology, and biochemistry. The genetic make-up of a plant determines how that plant responds to herbicides and its environment. The age of the plant often determines how well an herbicide works, older plants are generally much more difficult to control than seedlings.

Preemergence herbicides often work only on plants during the germination process and will have little effect on older plants. Plants which are growing rapidly are usually more susceptible to herbicides. The morphology of a plant can help to determine its susceptibility to herbicides. Annual weeds in a deep rooted crop can be controlled because the herbicide is concentrated in the first inch of soil where the weeds and weed seeds are. Weeds with exposed growing points may be killed by contact sprays, while grasses with protected growing points may be burned back, but escape permanent injury. Certain leaf properties can allow better spray retention and thus better kill (broadleaf species vs. grasses or hairy vs. smooth leaves). Sprays tend to be retained on pigweed and mustard leaves and bounce off of onion or grass species.

The physiology of a plant can determine how much of an herbicide will be absorbed onto the plant and the speed with which it is transported to its site of action. Plants with thick waxy cuticles or hairy leaf surfaces may not absorb sufficient herbicide to be injured. Wetting agents in herbicide formulations are used to combat these leaf characteristics and increase absorption. The transport rate of herbicides in plants varies. Usually susceptible plants transport herbicide more readily than resistant ones. Some plants can adsorb herbicides along the transport pathway, preventing them from reaching their site of action.

Biochemical reactions also account for selectivity. Most herbicides have a biochemical reaction within susceptible plants which accounts for their herbicidal activity. They may bind to critical enzymes within susceptible plants and block important metabolic processes (glyphosate), they may block photosynthesis (diuron) or respiration, or they may affect cell division (trifluralin). Herbicides may be absorbed as relatively innocuous chemicals (2,4-DB) and activated to deadly compounds (2,4-D) within susceptible plants. Other herbicides (atrazine) may be detoxified within some plants (com) while killing weeds which fail to metabolize the herbicide.

II. The Herbicide

Herbicides are quite specific in their structures as to whether or not herbicidal activity is possible. Slight changes in conformation or structure will alter herbicidal activity. Trifluralin and benefin differ in only a methyl group moved from one side of the molecule to the other, yet trifluralin is about twice as active as benefin. Esters of phenoxy (MCPP etc.) acids are usually much more active than are amines. The manner of formulation of an herbicide can affect its selectivity. The most extreme case of this might be granular formulations which bounce off desirable plants to reach the soil where they then limit germinating weeds. Other substances known as adjuvants or surfactants are often added to improve the application properties of a liquid formulation and increase activity. The manner in which an herbicide is applied can affect its selectivity.

When a broad-spectrum postemergence herbicide like glyphosate is applied as a shielded, directed, or wicked application within a susceptible crop, susceptible foliage is avoided and selectivity is achieved with this normally non-selective herbicide. Herbicides can be grouped into families based on the type of action that they have within affected plants **(their mode of action).**

III. The Environment

There are many ways that the environment interacts with herbicide selectivity. The soil determines how much of soil applied herbicides are available for activity. Sandy soils, with low organic content, are much more active and conversely less selective than clay soils with high organic content at a given rate of herbicide application.

Irrigation or rainfall amount and timing influence the depth to which herbicides may move in the soil and plant growth and stress, all of which can increase or decrease herbicide selectivity. Temperature affects the rate of herbicide transport, the rate of biochemical reactions, plant growth, plant stress, and ultimately herbicide selectivity. Wind, relative humidity, insects, plant p athogens, and nutritional status also affect plant growth and stress which can increase or decrease herbicide selectivity.

MODE OF ACTION

The term mode of action refers to the sequence of events from absorption into plants to plant death. The mode of action of the herbicide influences how the herbicide is applied. For example, contact herbicides that disrupt cell membranes, such as acifluorfen (Blazer) or paraquat (Gramoxone Extra), need to be applied postemergence to leaf tissue in order to be effective. Seedling growth inhibitors, such as trifluralin (Treflan) and alachlor (Lasso), need to be applied to the soil to effectively control newly germinated seedlings.

To be effective, herbicides must 1) adequately contact plants; 2) be absorbed by plants; 3) move within the plants to the site of action, without being deactivated; and 4) reach toxic levels at the site of action. The application method used, whether preplant incorporated, preemergence, or postemergence, determines whether the herbicide will contact germinating seedlings, roots, shoots, or leaves of plants.

The herbicide families listed below are grouped on the basis of how they affect plants (THEIR MODE OF ACTION)

1. The Growth Regulator Herbicides (2,4-D, MCPP, dicamba, and triclopyr). These are mostly foliar applied herbicides which are systemic and translocate in both the xylem and phloem of the plant. They mimic natural plant auxins, causing abnormal growth and disruption of the conductive tissues of the plant. The injury from this family of herbicides consists of twisted, malformed leaves and stems.

2. The inhibitors of amino acid synthesis (glyphosate, halosulfuron, imazethapyr, and sulfometuron). Both foliar and soil applied herbicides are in this family. Glyphosate translocates in the phloem with photosynthate produced in the leaves. Others in this family move readily after root or foliar absorption. These herbicides inhibit certain enzymes critical to the production of amino acids. Amino acids are the building blocks of proteins. Once protein production stops, growth stops. Symptoms are stunting and symptoms associated with lack of critical proteins.

3. Cell membrane disrupters - with soil activity (oxyfluorfen, lactofen, and acifluorfen). Soil and foliar applied with limited movement in soil. These herbicides enter the plant through leaves, stems, and roots, but are limited in their movement once they enter the plant. Membrane damage is due to lipid peroxidation. Symptoms are necrosis of leaves and stem.

4. Lipid biosynthesis inhibitors (diclofop, fluazifop, sethoxydim, and clethodim). Foliar applied Diclofop has both soil and foliar activity. Herbicides in this family move in both the xylem and phloem of the plant and inhibit enzymes critical in the production of lipids. Lipids are necessary to form plant membranes which are essential to growth and metabolic processes. Symptoms include stunting and death of tissue within the growing points of plants.

5. Pigment inhibitors (norflurazon, fluridone, and amitrol). Soil applied and move in the xylem except amitrol, which moves in both phloem and xylem. These herbicides inhibit carotinoid biosyntehsis, leaving chlorophyll unprotected from photooxidation. This results in foliage which lacks color. Symptoms include albino or bleached appearance of foliage.

6. Growth inhibitors of shoots (thiocarbamate herbicides including: EPTC, cycloate, pebulate, and molinate). Soil applied and somewhat volatile, requiring incorporation. Enter the plant through the roots and translocated through the xylem with the transpiration stream to the growing points in the shoot. Mode of action is unclear, but affects developing leaves in growing points of susceptible plants. Symptoms include stunting and distortion of seedling leaves.

7. Herbicides which disrupt cell division (trifluralin, DCPA, dithiopyr, oryzalin, pronamide, pendimethalin, and napropamide). All are soil applied, with limited movement in the soil. Absorbed through roots or emerging shoot tips. Once absorption takes place, movement is limited (site of action is near the site of absorption). These herbicides inhibit cell division or mitosis, except pronamide and napropamide which stop cell division before mitosis. Symptoms include stunting and swollen root tips.

8. Cell membrane disrupters - no soil activity (paraquat, diquat, glufosinate, acids, oils, soaps). These herbicides are foliar applied with no soil activity. They enter the plant through the leaves and stems and do not move significantly within the plant once absorbed. These herbicides either act directly on cell membranes (acids, soaps. oils) or react with a plant process to form destructive compounds which result in membrane damage. Symptoms include rapid necrosis of the leaves and stem.

9. Inhibitors of photosynthesis (atrazine, simazine, metribuzin, cyanazine, prometryn, diuron, linuron, tebuthiuron, and bromacil). These are soil applied herbicides, however, all except simazine also have foliar activity. They move readily in the plant in the xylem with the transpiration stream where they concentrate in the leaves at the site of photosynthesis. Once there they block the electron transport system of photosynthesis, causing a build up of destructive high energy products which destroy chlorophyll and ultimately the leaf tissues. Symptoms include chlorotic (yellowed) leaves which become necrotic.

Herbicide Resistance

Herbicide resistance probably develops through the selection of naturally occurring biotypes of weeds exposed to a particular family of herbicides over a period of years. A biotype is a population of plants within the same species that has specific traits in common. Resistant plants survive, go to seed, and create new generations of herbicide resistant weeds.

Mechanisms for resistance vary depending on herbicide family. Resistant biotypes may have slight biochemical differences from their susceptible counterparts that eliminates sensitivity to certain herbicides. Also, while photosynthesis is inhibited in triazine herbicide susceptible biotypes, because of a slight change in a chloroplast protein, triazine resistant biotypes are able to continue normal photosynthesis upon exposure to triazine herbicides. The potential for developing herbicide resistant biotypes is greatest when an herbicide has a single site of action.

Regardless of the mechanism for resistance, becoming familiar with the herbicide mode of action can help design programs that prevent the introduction and spread of herbicide resistant weeds. Management programs for herbicide resistance should emphasize an integrated approach that stresses prevention. Dependence on a single strategy or herbicide family for managing weeds will surely increase the likelihood of additional herbicide resistance problems in the future. Some guidelines for an integrated approach to managing herbicide resistant weeds are given below.

Strategies for preventing or managing herbicide resistance

- Practice crop rotation.
- Rotate herbicide families and use herbicides with different modes of action.
- Use herbicide mixtures with different modes of action.
- Control weedy escapes and practice good sanitation to prevent the spread of resistant weeds.
- Integrate cultural, mechanical, and chemical weed control methods.

Effect of sub lethal dosage

When herbicides are applied on the soil, neighbouring fields may be affected by drift. The high doses of herbicides applied to previous crop may be harmful to the succeeding crop. However, these sub lethal doses may be occassionally helpful based on crop and the herbicide used.

Herbicides show stimulatory effects on crops and toxic effects on sensitive crops even at sub lethal doses. Which show stimulatory effects are phenoxys, triazines, ureas and uracils. In fact, 2, 4-D was first used for its hormonal effect before its herbicidal properties were discovered.

Phenoxy herbicides have grtowth promoting activities at lower doses similar to indolacetic acid (IAA). They are active at the meristamatic tissues causing increased metabolic activities and cosequently higher grain protein content and yield. Protein content of wheat is increased by dusting 5g/ha of 2,4-D mixed with micronutrients like iron and copper. Even higher dose, say 0.5 to 1.3 kg/ha applied to the soil as herbicide before sowing increases the protein content of wheat. The other crops which show stimulatory effect due to herbicide application are beans, potato, sugarcane, soybean etc.

Among triazines, simazine and atrazine produce favourable effects at sub lethal doses. They increase nutrient absorption, chlorophyll and protein content. Simazine at 0.06 ppm increased nutrient uptake and yield of maize, but at 0.3 ppm concentration the yield decreased. The sub lethal effects caused by drifts are rarely toxic except to sensitive crops. Spray drift of 2,4 D causes epinasty on cotton plants.

Amitrole at 10 to 100 ppm sprayed on tobacco or wheat causes chlorosis due to chloroplast malformation and reduction in chlorophyll and carotenoids. Soil residues of herbicides appilied to the previous crops may affect germination of sensitive crops.

COMPATIBILITY OF HERBICIDES WITH OTHER AGRO CHEMICALS

Simultaneous or sequential application of herbicides, insecticides, fungicides, antidotes, fertilizers etc., is followed in a single cropping season. These chemicals may undergo a change in physical and chemical characters, which could lead to enhancement or reduction in the efficacy of one or more compounds. The interaction effects were seen much later in the growing season or in the next season due to build up of persistent chemicals or their residues in the soil. Knowledge on the interactions of various chemicals can be helpful in the formulation and adoption of a sound and effective plant protection programme. It can also help to exploit the synergistic and antagonistic interactions between various pesticides for an effective eradication of weed and other pest problems.

When two or more chemicals accumulate in the plant, they may interact and bring out responses. These responses are classified as additive, synergistic, antagonistic, independent and enhancement effects.

i) Additive effect: It is the total effect of a combination, which is equal to the sum of the effects of the components taken independently.

ii) Synergistic effect: The total effect of a combination is greater or more prolonged than the sum of the effects of the two taken independently. Eg. The mixture of 2,4-D and chlorpropham is synergistic on monocot species generally resistant to 2,4-D. Similarly, low rates of 2,4-D and picloram have synergistic response on *Convolvulus arvensis.* Atrazine and alachlor combination, which shows synergism is widely used for an effective control in corn.

iii) Antagonistic effect: The total effect of a combination is smaller than the effect of the most active component applied alone. Eg. Combination of EPTC with 2,4-D, 2,4,5-T or dicamba have antagonistic responses in sorghum and giant foxtail. Similarly, chlorpropham and 2,4-D have antagonism. When simazine or atrazine is added to glyphosate solution and sprayed the glyphosate activity is reduced. This is due to the physical binding within the spray solution rather than from biological interactions within the plant.

iv) Independent effect: The total effect of a combination is equal to the effect of the most active component applied alone.

v) Enhancement effect: The effect of a herbicide and non-toxic adjuvant applied in combination on a plant is said to have an enhancement effect if the response is greater than that obtained when the herbicide is used at the same rates without the adjuvant. Eg. Mixing Ammonium sulphate with glyphosate.

Herbicide-moisture interaction

Soil applied herbicides fail when there is a dry spell of 10-15 days after their application. Pre-emergence herbicides may be lost by photo-decomposition, volatilization and wind blowing while some amount of water is desirable to activate the soil applied herbicides, excess of it may leach the herbicide to the crop seed and root zone. This may injure the crops and on other side, results in poor weed control. Heavy showers may wash down herbicides from the foliage.

Continuous wet weather may induce herbicide injury in certain crops by turning them highly succulent. Eg. Maize plants are normally tolerant to Atrazine but they become susceptible in wet weather, particularly when air temperature is low. Extra succulence has been found to increase atrazine absorption and low temperature decreases its metabolism inside the plants. Quality of water used may also determine herbicide action. Dusty water reduces action of paraquat. Calcium chloride rich water reduces glyphoste phytotoxicity.

Herbicide-insecticide interaction

These chemicals are usually not harmful at recommended rates. The tolerance of plants to a herbicide may be altered in the presence of an insecticide and vice versa. The phyto-toxicity of monuron and diuron on cotton and oats is increased when applied with phorate. Phorate interacts antagonistically with trifluralin to increase cotton yield, by stimulating secondary roots in the zone of pesticide incorporation.

Propanil interacts with certain carbamate and phosphate insecticides used as seed treatments on rice. But chlorinated hydrocarbon insecticides as seed treatment have not interacted with propanil. When propanil is applied at intervals between 7 and 56 days after carbofuron treatment, it results in greater injury to rice vegetatively.

Herbicide-pathogens / fungicides interaction

Herbicides interact with fungicides also. Dinoseb reduces the severity of stem rot in groundnut. In sterilized soil, chloroxuron is not causing any apparent injury to pea plants, while in the presence of *Rhizoctonia solani* in unsterilized soil it causes injury. Oxadiazon reduces the incidence of stem rot caused by the soil borne pathogen *Sclerotium rolfsii* L. in groundnut. Diuron and triazine which inhibit photosynthesis may make the plants more susceptible to tobacco mosaic virus. On the other hand, diuron may decrease the incidence of root rot in wheat.

Herbicide-fertilizer interaction

Herbicides have been found to interact with fertilizers in fields. E.g., fast growing weeds that are getting ample nitrogen show great susceptibility to 2,4-D, glyphosate than slow growing weeds on poor fertility lands. The activity of glyphosate is increased when ammonium sulphate is tank mixed. Nitrogen invigorate (put life and energy in to) the meristamatic activity in crops so much that they susceptible to herbicides. High rates of atrazine are more toxic to maize and sorghum when appled with high rates of phosphorus.

Herbicide-microbes interaction

Microorganisms play a major role in the persistence behaviour of herbicides in the soil. The soil microorganisms have the capacity to detoxify and inactivate the herbicides present in the soil. Some groups of herbicides more easily degrade through microbes than others. The difference lies in the molecular configuration of the herbicide. The microorganisms involved in herbicide degradation include bacteria, fungi, algae, moulds etc. Of these, bacteria predominates and include the members of the genera *Agrobacterium, Arthrobacter, Achromobacterium. Bacillus, Pseudomonas, Streptomyces, Flavobacterium, Rhizobium* etc. The fungi include those of the genera *Fusarium, Penicillium* etc.

WEED MANAGEMENT IN MAJOR FIELD CROPS

RICE

Nursery

Apply any one of the Pre-emergence herbicides viz., Butachlor 2 l/ha, Thiobencarb 2/ha, Pendimethalin 2.5 l/ha, Anilofos 1.25 l/ha on 8th day after sowing to control weeds in the lowland nursery. Keep a thin film of water and allow it to disappear. Avoid drainage of water. This will control germinating weeds.

Transplanted

Pre-emergence

a) Use Butachlor 2.5 l/ha or Thiobencarb 2.5 l/ha or Fluchoralin 2 l/ha or Pendimethalin 3 l/ha or Anilofos 1.25 l/ha as pre-emergence application. Alternatively, pre-emergence application of herbicide mixture viz., Butachlor 1.2 l + 2,4-DEE 1.5 l/ha or Thiobencarb 1.2 l + 2,4-DEE 1.5 l/ha or Fluchoralin 1.0 l + 2,4-DEE 1.5 l/ha or Pendimethalin 1.5 l + 2,4-DEE 1.5 l/ha or Anilofos + 2,4-DEE ready mix at 1.25 l/ha followed by one hand weeding on 30-35 days after transplanting will have a broad spectrum of weed control in transplanted rice.

b) Any herbicide has to be mixed with 50 kg of sand on the day of application (3-4 days after transplanting) and applied uniformly to the field in 2.5 cm depth of water. Water should not be drained for 2 days from the field or fresh irrigation should not be given.

c) Wherever there is possibility of heavy weed infestation, herbicides can also be applied with neem coated urea which could serve as carrier, three to four days after transplanting instead basal application of N at last puddling.

Post-emergence

If pre-emergence herbicides are not used, hand weed on 15th day after transplanting. 2,4-D sodium salt (Fernoxone 80% WP) 1250 g dissolved in 625 l/ha of water is sprayed with a high volume sprayer, three weeks after transplanting or when the weeds are in 3-4 leaf stage.

Late hand weeding

Hand weed a second time, 80-85 days after transplanting, if necessary.

Wet seeded rice

In wet seeded rice apply Thiobencarb at 2.5 l/ha or Pretilachlor 0.9 l/ha on 4DAS/6DAS/8DAS followed by one hand weeding for effecrtive control of weeds OR Pre-emergence application of Pretilachlor + safener at 0.6 l/ha on 4DAS followed by one hand weeding on 40 DAS effectively control weeds.

Rainfed rice

1. First weeding should be done between 15th and 20th day and second weeding may be done 45 days after first weeding. or
2. Use Thiobencarb 2.5 l/ha or Pendimethalin 3 l/ha 8 days after sowing if adequate moisture is available, followed by one hand weeding on 30 to 35 days after sowing.

Direct seeded rice

Thiobencarb/Butachlor at 2.5 l/ha as pre-emergence application one day after wetting / soaking can be applied and it should be followed by hand weeding on 30th day. Sufficient soil moisture should be available for herbicidal use

Semi dry rice

Use Thiobencarb 3 l/ha or Pendimethalin 4 l/ha on 8th day after sowing as sand mix if adequate moisture is available, followed by one hand weeding on 30-35 days after sowing.

Or

Pre-emergence application of pretilachlor 0.6 l/ha followed by post emergence application of 2,4-D Na salt 1.25 kg/ha + one hand weeding on 45DAS.

SORGHUM

1. Apply the pre-emergence herbicide Atrazine 50% WP 500 g/ha on 3 days after sowing as spray on the soil surface, using Backpack/knapsack/Rocker sprayer fitted with a flat fan nozzle using 900 lit of water/ha
2. Sorghum is slow growing in early stages and is adversely affected by weed competition. Therefore keep the field free of weeds upto 45days. For this, after pre-emergence herbicide application, one hand weeding on 30-35 days after sowing may be given.
3. If pulse crop is to be raised as an intercrop in sorghum do not use Atrazine.
4. Hoe and hand weed on the 10th day of transplanting if herbicides are not used. Hoe and weed between 30-35 days after transplanting and between 35-40 days for direct sown crop, if necessary.

Ratoon sorghum

1. Remove the weeds immediately after harvest of the main crop
2. Hoe and weed twice on 15th and 30th day after cutting

Rainfed sorghum

Keep sorghum field free of weeds from second week after germination till 5th week. If sufficient moisture is available spray Atrazine @ 500 g/ha as pre-emergence application within 3 days after the soaking rainfall for sole sorghum while for sorghum based inter-cropping system with pulses, use Pendimethalin 3 l/ha.

CUMBU

Transplanted crop

Spray Atrazine 50 WP 500 g/ha on 3rd day of sowing. Then, one hand weeding on 30-35 days after transplanting may be given. If herbicide is not used, hand weed on 15th day and again between 30-35 days after transplanting.

Direct sown crop

1. Apply the pre-emergence herbicide Atrazine at 500 g/ha, 3 days after sowing as spray on the soil surface using Back-pack/Knapsack/Rocker sprayer fitted with flat type nozzle using 900 lit of water/ha.
2. Apply herbicide when there is sufficient moisture in the soil.
3. Hand weed on 30-35 days after sowing if pre-emergence herbicide is applied.
4. If pre-emergence herbicide is not applied hand weed twice on 15 and 30 days after sowing.

RAGI

1. Apply Butachlor 2.5 l/ha or Fluchloralin 2 l/ha or Pendimethalin 2.5 l/ha, using Back-pack/Knapsack/Rocker sprayer fitted with flat fan type of nozzle with 900 lit of water/ha.
2. Apply herbicide when there is sufficient moisture in the soil or irrigate immediately after the application of herbicide.
3. If pre-emergence herbicide is not applied hand weed twice on 10th and 20th day after transplanting.
4. For rainfed direct seeded crop, apply post emergence herbicide; 2,4-DEE or 2,4-D Na salt at 0.5kg/ha on 10th day after sowing depending on the moisture availability.

MAIZE

1. Apply the pre-emergence herbicide Atrazine 50 at 500 g/ha (900 lit of water), 3 days after sowing as spray on the soil surface using Back-pack/Knapsack/Rocker sprayer fitted with flat fan or deflector type nozzle followed by one hand weeding 40-45 days after sowing. For maize + Soybean intercropping system, apply pre-emergence Alachlor at 4.0 l/ha or Pendimethalin 3.3 l/ha on 3rd after sowing as spray.
2. Apply herbicide when there is sufficient moisture in the soil
3. Do not disturb the soil after the herbicide application
4. Hoe and Hand weed on 17th or 18th day of sowing if herbicide is not applied.

Note: If pulse crop is to be raised as intercrop, do not use Atrazine.

WHEAT

1. Spray Isoproturon 800 g/ha as pre-emergence spraying 3 days after sowing followed by on hand weeding on 35th day after sowing.
2. If herbicide is not applied, give two hand weeding on 20th and 35th day after sowing.

REDGRAM, BLACKGRAM, GREENGRAM, COWPEA, BENGALGRAM

1. Spray Fluchloralin 1.5 l/ha or Pendimethalin 2 l/ha 3 days after sowing mixed with 900 l of water using Back-pack/Knapsack/Rocker sprayer fitted with flat fan type nozzle. Then irrigate the field. Following this one hand weeding may be given 30-35 days after sowing.
2. If herbicide is not given, give two hand weeding on 15 and 35 days after sowing.

SOYBEAN

1. Fluchloralin may be applied to the irrigated crop at 2.0 l/ha or Pendimethalin 3.3 l/ha after sowing followed by one hand weeding 30 days after sowing.
2. If herbicide is not used, give two hand weeding on 20 and 35 days after sowing.
3. Pre-emergence application of Fluchloralin at 2.0 l/ha or Alachlor 4.0 l/ha may be used in soybean wherever labour availability for timely weeding is restricted.

SOYBEAN - RAINFED

1. If sufficient moisture is available, spray Fluchloralin at 2.0 l/ha as pre-emergence within 3 days after sowing.
2. If herbicide is not given, give two hand weeding on 20 and 35 days after sowing.

GROUNDNUT

1. Pre-sowing: Fluchloralin at 2.0 l/ha may be applied and incorporated.
2. Pre-emergence: Fluchloralin 2.0 l/ha applied through flat fan nozzle with 900 lit of water/ha followed by irrigation. After 35-40 days one hand weeding may be given.
3. Pre-emergence application of metolachlor (2.0 l/ha) plus one hand weeding on 30 days after sowing is more profitable.
4. In case no herbicide is applied two hand hoeing and weeding are given 20th and 40th day after sowing.

GINGELLY

Weed and hoe on the 15th and 35th day of sowing. Apply Alachlor at 2.5 l/ha on 3 days after sowing and irrigate the crop immediately.

SUNFLOWER

1. Apply Fluchloralin at 2.0 l/ha before sowing and incorporate or apply as pre-emergence spray on 3 days after sowing followed by irrigation or apply Pendimethalin (3.0 l/ha) as pre-emergence spray on 3 days after sowing. The spray of these herbicides has to be accomplished with Back-pack/Knapsack/Rocker sprayer fitted with flat fan nozzle using 900 lit of water/ha as spray fluid. All the herbicide application is to be followed by one late hand weeding 30-35 days after sowing
2. Hoe and hand weed on the 15th and 30th day of sowing and remove the weeds. Allow the weeds to dry for 2-3 days in the case of irrigated crop and then give irrigation

COTTON

1. Apply pre-emergence herbicides Fluchloralin 2.2 l/ha or Pendimethalin 3.3 l/ha three days after sowing, using a hand operated sprayer fitted with deflecting or fan type nozzle. Sufficient moisture should be present in the soil at the time of herbicide application or irrigate immediately after application. Then hand weed on 35-40 days after sowing.

Note : Do not use Diuron (Karmex) in sandy soil. Heavy rains after application of Karmex may adversely affect germination of cotton seeds.

2. Hoe and hand weed between 18th to 20th day of sowing, if herbicide is not applied at the time of sowing followed by second hand weeding on 35 to 45 DAS.

RICE FALLOW COTTON

1. Pre-emergence application of Fluchloralin 2.2 l/ha or Pendimethalin 3.3 l/ha ensures weed free condition for 40-45 days. This should be followed by one hand weeding and earthing up during 40-45 days. Fluchloralin need incorporation.
2. Take up hoeing and weeding 20 days after sowing.
3. Take up this operation when the top soil dries up comes to proper condition.

RAINFED COTTON

1. Application of Fluchloralin 2.0 l/ha or Pendimethalin 3.3 l/ha or Thiobencarb 3.0 l/ha followed by hand weeding 40 days after crop emergence. At the time of herbicide application sufficient soil moisture must be there. Fluchloralin needs soil incorporation.
2. If sufficient soil moisture is not available for applying herbicides hand weeding may be given at 15-20 days after crop emergence.

SUGARCANE - Pure crop

1. Spray Atrazine 2 kg or Oxyfluurofen 750 ml/ha mixed in 900 lit of water as pre-emergence herbicide on 3rd day of planting, using deflector or fan type nozzle.
2. If pre-emergence spray is not carried out, go for post-emergence spray of gramaxone 2.5lit + 2,4-d sodium salt 2.5 kg/ha in 900 lit of water on 21st day of planting or apply 10% Ammonium sulphate on 45th, 75th and 105th day after planting as **directed spray**.
3. If the parasitic weed Striga is a problem, Post-emergence application of 2,4-D sodium salt 1.75 kg/ha in 650 lit of water/ha has to be sprayed. 2,4-D spraying should be avoided when neighbouring crop is cotton or bhendi or apply 20% urea for the control of Striga as directed spray.
4. If herbicide is not applied work the Junior-hoe along the ridges 25, 55, and 85 days after planting for removal of weeds and proper stirring. Remove the weeds along the furrows with hand hoe.

SUGARCANE - INTERCROP

Pre-emergence application of Thiobencarb 2.5 l/ha under cropping system in sugarcane with soybean, black gram or ground nut gives effective weed control. Raising intercrops is not found to affect the cane yield and quality.

TOBACCO

First hand weeding taken up three weeks after planting. A spade digging is followed on 45 DAT which makes the ridges flat and then reformed one week later to have good weed control.

Control of Orobanche

Remove as and when the shoot appears above the ground level before flowering and seed set. The removed shoots are to be buried or burnt. Trap cropping of greengram or gingelly or sorghum reduces the infestation.

Chemical weed control of Orobanche

Pre-emergence application of Fluchloralin at 1.0 lit/ha or Oxyfluorfen at 0.5 lit/ha one week prior to planting controls most of the weeds.

WEED MANAGEMENT IN HORTICULTURAL CROPS

Traditional vegetable-growing areas are usually situated adjacent to waterways, flood plains, river deltas, marsh zones, and, if herbicides are used, their environmental impact and usage conditions must be taken into account. Another aspect related to the complexity of herbicide use is its soil persistence that can seriously affect the next crops in the rotation as a result of soil residues or carryover. Vegetable rotations are very fast and intensive in many places, and herbicide toxicity can affect the next crop if the cycle of the previous crop is short enough.

We have to consider all these aspects, as well as consumer concerns on the probable presence of pesticide residues in fruit, leaves and roots of these crops and the strict limitations for marketing and export that can invalidate the hard labour and endurance of many workers. Therefore, a careful use of herbicide is compulsory, and good field practices must be followed, especially when recognition of a labelled production is desired. There is a great interest in the integration of tilling practices with chemical control because of the reduction of the herbicide impact and the cost of hand-labour.

SEED BEDS

Many vegetables are grown in seed beds to develop suitable seedlings for transplanting in the field. Soils dedicated to seed beds are usually light, with good tilth, and fertilized to obtain a good plant emergence. Seed beds are usually flood-irrigated and plastic-protected. Here we add some possibilities for weed management.

STALE SEED BEDS

Stale (‘false’) seed beds are sometimes used for vegetables when other selective weed-control practices are limited or unavailable. Basically, this technique consists of the following:

1. Preparation of a seedbed 2-3 weeks before planting to achieve maximum weed-seed germination near the soil surface.
2. Planting the crop with minimum soil disturbance to avoid exposing new weed seed to favourable germination conditions.
3. Treating the field with a non-residual herbicide to kill all germinated weeds just before or after planting, but before crop emergence.

SOLARIZATION

Soil solarization is a broad-spectrum control method, simple, economically feasible and environmentally friendly. It is an effective method for the control of many weeds. It does not affect soil properties and usually produces higher yields (Campiglia *et al.* 2000). There are also some disadvantages in its implementation. For example, previous irrigation is a requirement, (or frequent and abundant rain) and the soil must be kept solarized (non-producing) for a period of at least one month. Results are often variable, depending on weather conditions. Cold (high latitude) or cloudy places are usually not suitable for implementing solarization. Some species can tolerate solarization (e.g. deep rooted perennials: *Sorghum halepense, Cyperus rotundus, Equisetum* spp. and also some big weed seeds such as legumes).

The soil must be clean, surface-levelled and wet, previously to being covered with a thin (0,1-0,2 mm) transparent plastic sheet and very well sealed. The soil must be kept covered during the warmer and sunnier months (30-45 days). Soil temperatures must reach above 40° C to exert a good effect on weed seeds.

After solarization the plastic must be recovered, and the use of deep or mouldboard tillage must be avoided. This system is more suitable for small areas of vegetables, but it has been mechanized for extensive areas of tomatoes. Soil solarization is widely used under plastic greenhouse conditions.

CHEMICAL CONTROL IN SEED BEDS

There are even less registered herbicides for seed beds than for planting crops. Herbicide treatments under plastic cover are always hazardous and careful application should be carried out. Under plastic, high levels of moisture and elevated temperature are common and plants grow very gently. Selectivity could be easily lost and phytotoxicity symptoms may occur, while sometimes they are just temporary. The effects are often erratic. The best way to deal with it is to be prudent and make some trials before a general treatment.

Selective pre-emergence and early post-emergence herbicides for vegetable seedbeds

a) Pre-emergence		
Herbicide	**Dose (kg a.i./ ha)**	Crop
Clomazone	0.18 - 0.27	Pepper, cucumber
DCPA	6.0 - 7.5	Onion, cole crops, lettuce
Metribuzin	0.15 - 0.5	Tomato
Napropamide	1.0 - 2.0	Tomato, pepper, eggplant
Pendimethalin	1.0 - 1.6 1.0 - 2.5	Onion, garlic Lettuce
Propachlor	5.2 - 6.5	Onion, cole crops
b) Post-emergence (crops with at least 3 leaves)		
Clomazone	0.27 -0.36	Pepper
Ioxinil	0.36	Onion, garlic, leek

Linuron	0.5 - 1.0	Asparagus, carrots
Metribuzin	0.075 - 0.150	Tomato
Oxifluorfen	0.18 - 0.24	Onion, garlic
Rimsulfuron	0.0075 -0.015	Tomato

DIRECT-SEEDED AND TRANSPLANTED CROPS

WEED IDENTIFICATION

Dicotyledons (most broad-leaf weeds) and monocotyledons (e.g. grasses) are the two main plant types. Weed grouping has a significant impact on the potential for management. The more closely related a weed is to the host crop, the harder it will be to manage.

Weed and crop family groupings (monocotyledons - 'M')

Family	**Weed examples**	**Related crops**
Apiaceae	slender celery (*Ciclospermum leptophyllum*) Australian carrot (*Daucus glochidiatus*)	celery, carrot, parsley
Amaranthaceae	amaranths (*Amaranthus* spp.)	Chinese amaranthus
Asteraceae	billygoat weed (*Ageratum* spp.) sowthistle (*Sonchus oleraceus*) cobbler's pegs (*Bidens pilosa*) fleabanes (*Conyza* spp.) parthenium (*Parthenium hysterophorus*) potato weed (*Galinsoga parviflora*)	lettuce, artichokes
Brassicaceae	wild turnip (*Brassica tournefortii*) wild radish (*Raphanus raphanistrum*) turnip weed (*Rapistrum rugosum*) shepherd's purse (*Capsella bursa-pastoris*) peppercress (*Lepidium* spp.) lesser swinecress (*Coronopus didymus*)	cabbage, cauliflower, broccoli, brussels sprouts, Chinese cabbage
Chenopodiaceae	fat hen (*Chenopodium* spp.)	beetroot
Convulvulaceae	bell vine (*Ipomoea plebia*) bindweed (*Convolvulus erubescens*)	sweetpotato
Euphorbiaceae	caster oil plant (*Riccinus communis*) caustic creeper (*Euphorbia drummondii*)	cassava

Fabaceae	rattlepod (*Crotalaria* spp.) vetch (*Vicia monantha*) medics (*Medicago* spp.)	peas, beans
Liliaceae (M)	onion weed *(Nothoscordum gracile)*	onion, garlic
Malvaceae	small-flowered mallow (*Malva parviflora*) sida (*Sida* spp.) bladder ketmia (*Hibiscus trionum*) anoda weed (*Anoda cristata*)	okra, rosella, cotton
Solanaceae	apple of Peru (*Nicandra physalodes*) nightshades (*Solanum* spp.) thornapples (*Datura* spp.)	tomato, potato, capsicum, eggplant

CROP ROTATION

Crop rotation is the programmed succession of different crops during a period of time in the same plot or field. It is a key control method to reduce weed infestation in vegetables. Crop rotation was considered for a long time to be a basic practice for obtaining healthy crops and good yields. At present, however, crop rotation is gaining interest and is of value in the context of integrated crop management. Classically, crop rotations are applied as follows:

- Alternating crops with a different type of vegetation: leaf crops (lettuce, spinach, cole), root crops (carrots, potatoes, radish), bulb crops (leeks, onion, garlic), fruit crops (squash, pepper, melon).
- Alternating grass and dicots, such as maize and vegetables.
- Alternating different crop cycles: winter cereals and summer vegetables.
- Avoiding succeeding crops of the same family: *Apiaceae* (celery, carrots), *Solanaceae* (potato, tomato).
- Alternating poor- (carrot, onion) and high-weed competitors (maize, potato).
- Avoiding problematic weeds in specific crops (e.g. *Malvaceae* in celery or carrots, parasitic and perennials in general).

Examples of crop rotations are as follow (Zaragoza *et al.* 1994):

In temperate regions: Pepper - onion - winter cereal

Melon - beans - spinach - tomato

Tomato - cereal - fallow

Lettuce - tomato - cauliflower

Potato - beans - cole - tomato- carrots

Melon - artichoke (x 2) - beans - red beet - wheat - cole

In tropical regions: Tomato - okra - green bean

Sweet potato - maize - mung bean

Introducing a fallow in the rotation is essential for the control difficult weeds (e.g. perennials), cleaning the field with appropriate tillage or using a broad-spectrum herbicide. It is also important to avoid the emission of weed seeds or other propagules.

Mixed cropping

Growing two or more crops at the same time and adjacent to one another is called mixed cropping, or intercropping. The advantages are a better use of space, light and other resources, a physical protection, a favourable thermal balance, better plant defence against some pests and fewer weed problems because the soil is better covered. Sometimes the results are less productive than cultivating just one crop alone. Some examples are:

In temperate regions

- lettuce + carrots;
- cole crops + leeks, onion, celery, tomato;
- maize + beans, soya.

In tropical regions

This technique is very well adapted to the traditional agricultural system:

- maize + beans + squash,
- tomato + pigeon pea,
- sugar cane + onion, tomato.

PREVENTIVE MEASURES

It is necessary to avoid the invasion of new species through the use of clean planting material and to prevent seed dispersal on the irrigation water, implements and machines. A written record of the weed situation in the fields is very useful. Another aspect is to impede perennial weed dispersal (or parasitic weeds) through the opportune use of treatments and tillage and the use of drainage tillage to prevent propagation of some species that need high moisture levels. *(Phragmites* spp., *Equisetum* spp., *Juncus* spp.) It is also necessary to scout the field edges to prevent invasions.

LAND PREPARATION AND TILLAGE

Suitable land preparation depends on a good knowledge of the weed species prevalent in the field. When annual weeds are predominant (Crucifers, *Solanum,* grass weeds) the objectives are unearthing and fragmentation. This must be achieved through shallow cultivation. If weeds have no dormant seeds (*Bromus* spp.), deep ploughing to bury the seeds will be advisable. If the seeds produced are dormant, this is not a good practice, because they will be viable again when they return to the soil surface after further cultivation.

When perennial weeds are present, adequate tools will depend on the types of rooting. Pivot roots *(Rumex* spp.) or bourgeon roots *(Cirsium* spp.) require fragmentation and this can be achieved by using a rotovator or cultivator. Fragile rhizomes (*Sorghum halepense)* require dragging and exposure at the soil surface for their depletion, but flexible rhizomes *(Cynodon dactylon*) require dragging and removal from the field. This can be done with a cultivator or harrow.

Tubers (*Cyperus rotundus)* or bulbs (*Oxalis* spp.) require cutting when rhizomes are present and need to be dug up for exposure to adverse conditions (frost or drought). This can done with mouldboard or disk ploughing. Chisel ploughing is useful for draining wet fields and reducing the infestation of deep-rooted hygrophilous perennials (*Phragmites, Equisetum, Juncus).*

MULCHING MATERIAL

The use of plastic mulching is very popular in many vegetable-growing areas. A non-transparent plastic is used to impede the transmission of photosynthetic radiation through the plastic to the weeds so that the development of weeds is then arrested.

CHEMICAL WEED CONTROL

The best approach to minimize inputs and to avoid any environmental problems is to apply herbicides in the crop row to a width of 10-30 cm. Many herbicides are effective in the control of perennial weeds. Sometimes a combination of two herbicides having a different weed-control spectrum may be used. Mixtures of different herbicide are possible to achieve better efficacy, but previous trials are necessary. Their foliar activity is enhanced by adding a non-ionic surfactant or adjuvant. The use of any herbicide in vegetables requires previous tests to verify its effectiveness in local conditions and selectivity to available crop cultivars.

In general pendimethalin 3.3 l/ha or Fluchloralin at 2 lit/ha or metolachlor 2 l/ha as pre-emergence herbicide is recommended for most of the vegetable crops, followed by one hand weeding 30 days after transplanting.

Selective herbicides for weed control in vegetable crops

Herbicide	**Dose kg a.i./ha**	**Treatment moment**	**Crops**

Alachlor	2.4	Post emergence	Brassica crops, onion
Ethalfluralin	0.8-1.7	Pre Plantation	Tomato, pepper, beans, squash
Linuron	0.50-1.25	Pre emergence	Carrot, artichoke, asparagus, faba bean
Metribuzin	0.10-0.35	Pre/Post emergence	D.s. tomato, carrots, peas
Oxifluorfen	0.36-0.48	Pre/Post emergence	Onion, garlic, cole crops
Oxifluorfen	0.24-0.48	Pre Plantation	Tomato, pepper
Pendimethalin	1.32-1.65	Pre Plantation / pre-plant incorporated	Artichoke, cole, lettuce, leek, pepper, tomato, onion, green peas
Rimsulfuron	7.5-15(g)	Post emergence	Tomato
Trifluralin	0.59-1.44	pre-plant incorporated	Beans, carrots, celery, cole crops, artichoke, onion, pepper, tomato

HAND WEEDING

Apart from chemical weeding, one hand weeding is done 30 days after transplanting.

BIOLOGICAL CONTROL

Myco-herbicides are a preparation containing pathogenic spores applied as a spray with standard herbicide application equipment. Eg: a weevil for the aquatic weed salvinia, rust for skeleton weed, and a caterpillar (*Cactoblastis* sp.) to control prickly pear.