AGR 201 PRINCIPLES OF WEED SCIENCE, IRRIGATION MANAGEMENT AND DRY FARMING (2+1)

THEORY - LECTURE SCHEDULE

1. Weeds, definition weed ecology, weed adaptation - classification and characteristics.
2. Crop - weed interactions - competition for light, space, moisture and nutrients.
3. Weeds on crop growth and yield - losses caused by weeds -economic uses of weeds.
4. Factors affecting the competitive ability of crops against weeds- Critical periods of crop-weed competition-definition - importance in weed management.
5. Principles and methods of weed management - mechanical, cultural, chemical and biological methods-merits and demerits.
6. Herbicide -definition - classification formulations - time of application (pre-plant, pre-emergence, post-emergence)- method of application (sand mix, spray, herbigation).
7. Selective herbicides for crops and cropping systems.
8. Interactions of herbicide with moisture, fertilizers, biofertilizers, insecticides and fungicides.
9. Biological control - bioherbicides -Allelopathy - definition - types - application for weed management.
10. Integrated weed management- approaches and application for different crops and cropping systems.
11. Weed shift - herbicide mixtures - herbicide rotation - herbicide resistance in crops and weeds – safeners, adjuvants and antidotes
12. Development of irrigation in India and Tamil Nadu - Water resources, irrigation potential and irrigation systems of India and Tamil Nadu.
13. Role of water in plant growth – Hydrological Cycle -Water in Soil - plant - atmosphere continuum - absorption of water and evapotranspiration.
14. Soil water movement - saturated and unsaturated flow and vapour movement - Soil moisture constants and their importance in irrigation
15. Moisture extraction pattern of crops- soil moisture stress - plant water stress -effects on crop growth
16. Crop water requirement - Potential evapotranspiration (PET) and consumptive use- Factors affecting crop water requirement - Critical stages – Water requirement of different crops
17. Mid-semester Examination
18. Methods of irrigation - surface (*flooding, beds and channels, border strip, ridges and furrows, alternate furrow, skip furrow, basin furrow, broad bed furrow, surge irrigation*) - Suitability, advantages and limitations
19. Methods of irrigation- subsurface, pressurized irrigation - sprinkler including micro sprinkler and drip irrigation, rain-gun - Suitability, advantages and limitations
20. Water budgeting –Definition& Importance - Irrigation scheduling, definition - different approaches
21. Water use efficiency (WUE) - factors affecting water use efficiency and measures to increase water use efficiency - Irrigation efficiency indices- Definition, factors affecting irrigation efficiency indices
22. Agronomic practices for use of problem water - saline, effluent, sewage water
23. Command area development- contingent crop plan in major irrigation projects of Tamil Nadu - Drainage – importance and methods
24. Dry farming and rainfed farming definition -- Aridity - Drought – definition - Impact of drought on crop production.
25. Dry farming regions - Climatic characteristics - Rainfall - intensity, distribution and reliability, aberrations.
26. Soil and moisture constraints and their management in drylands – tillage - control of water and wind erosion - mechanical, agronomic and vegetative methods.

27. Recycling and reducing loss of soil moisture - mulching – anti-evaporants and anti-transpirants.
28. Rainfall use efficiency - choice of crops and cropping system - intercropping (biological water harvesting) - sequential cropping - crop substitution and their importance.
29. Establishment of optimum population -seed hardening – pre-monsoon sowing - time, method and depth of sowing - density and geometry.
30. Soil fertility management - fertilizer use efficiency - time and method of application
31. Integrated nutrient management for rainfed crops.
32. Contingent crop planning for different aberrant weather situations – Integrated dry farming technologies.
33. Alternate land use systems based on soil capability classification – description – agroforestry systems
34. Watershed development - micro and macro watershed - scope - components of watershed technology.

PRACTICAL - PRACTICAL SCHEDULE

1. Identification, collection and observation on general characters of weeds of arable lands
2. Identification and acquiring skill on the use of tools and implements used for mechanical method of weed control and working out their efficiencies.
3. Study of herbicides and their formulations and working out herbicide requirement for different crops.
4. Calibration of sprayer and preparation of spray fluid, selection of nozzles and practising the methods of application of herbicides for different crops - granular, spray and herbigation.
5. Working out weed control efficiency and evaluation of weed control methods.
6. Practising methods for control of perennial, problematic and aquatic weeds.
7. Estimation of soil moisture.
8. Measurement of irrigation water with different devices.
9. Methods of irrigation - Acquiring skill in land shaping for different surface irrigation methods- operation of sprinkler and drip irrigation systems.
10. Estimation of crop water requirement.
11. Calculation of Irrigation efficiencies.
12. Mapping of arid and semi arid regions of World and India.
13. Rainfall analysis and crop planning.
14. Estimation of length of growing periods using weekly rainfall data.
15. Acquiring skill in land shaping methods for in situ moisture conservation.
16. Preparation cropping scheme for different dry farming situations.
17. Practical Examination

REFERENCES

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11. Gupta, U.S. 1995. Production and improvement of crops for drylands. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi.
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Lec. 1 WEEDS – DEFINITION CLASSIFICATION AND CHARACTERISTICS – WEED DISSEMINATION

Weeds are the plants, which grow where they are not wanted (Jethro Tull, 1731) Weeds can also be referred to as plants out of place.

Weeds compete with crops for water, soil nutrients, light and space (ie CO_2) and thus reduce crop yields.

Definition: Weeds are unwanted and undesirable plant that interfere with utilization of land and water resources and thus adversely affect crop production and human welfare.

Sometimes Agriculture also defined as a battle with weeds as they strongly compete with crop plants for growth factors.

Origin of weeds

Weeds are no strangers to man. They have been there ever since he started to cultivate crops about 10,000 BC and undoubtedly recognized as a problem from the beginning. To him, any plant in the field other than his crop became weed. Again the characters of certain weed species are very similar to that of wild plants in the region. Some of the crops for example including the wheat of today are the derivatives of wild grass. Man has further improved them to suit his own taste and fancy. Even today they are crossed with wild varieties to transfer the desirable characters such as drought and disease resistance. So the weeds are to begin with essential components of native and naturalized flora but in course of time these plants are well placed in new environment by the conscious and unconscious efforts of man. Hence, it is considered that many weeds principally originated from two important and major arbitrarily defined groups.

1. By man's conscious effort
2. By invasion of plants into man created habits

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

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, Boerhaavia erecta

b. Winter annual

Chenopodium album

(b) Biennials: It completes the vegetative growth in the first season, flower and set seeds in the succeeding season and then die. These are found mainly in non-cropped areas.

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: Plants that possess a modified shoot and fleshy stem and reproduce through corm and seeds. Eg. *Timothy* sp.

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*

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*

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*

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*

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, Convolvulus arvensis*

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*

IV. Based on place of occurrence

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

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

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

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

(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*

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*

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 stricta*

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

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*

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*

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
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 consumes these poisonous plants. Eg. *Datura fastuosa, D. stramonium* and *D. metel* are poisonous to animals and human beings. The berries of *Withania somnifera* and seeds of *Abrus precatorius* are poisonous.

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 of different parasitic weeds are;

1. Total root parasite – *Orabanche cernua* on Tobacco
2. Partial root parasite - *Striga lutea* on sugarcane and sorghum
3. Total stem parasite - *Cuscuta chinensis* on leucerne and onion
4. Partial stem parasite - *Cassytha filiformis* on orange trees and *Loranthus longiflorus* on mango and other trees.

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,*

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*

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 come under this group are; *Typha*, *Polygonum*, *Cephalanthus*, *Scirpus*, *etc*.

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*.

CHARACTERISTICS OF WEEDS

Nature has bestowed the following qualities on weeds:

1. Produces larger number of seeds compare to crops
2. Most of the weed seeds are small in size and contribute enormously to the seed reserves.
3. Weed seeds germinate earlier and their seedlings grow faster.
4. They flower earlier and mature ahead of the crop they infest.
5. They have the capacity to germinate under varied conditions, but very characteristically, season bound. The peak period of germination always takes place in certain seasons in regular succession year after year.
6. Weed seeds possess the phenomenon of dormancy, which is an intrinsic physiological power of the seed to resist germination even under favourable conditions.
7. Weed seeds do not lose their viability for years even under adverse conditions.
8. Most of the weeds possess C_4 type of photosynthesis, which is an added advantage during moisture stress.
9. They possess extensive root system, which go deeper as well as of creeping type.

WEED DISSEMINATION: Dispersal of weeds

Dispersal of mature seeds and live vegetative parts of weeds is nature's way of providing non-competitive sites to new individuals. Had there been no way of natural dispersal of weeds, we would not have had them today in such widely spread and vigorous forms. In the absence of proper means of their dispersal, weeds could not have moved from one country to another. "Weeds are good travelers"

An effective dispersal of weed seeds and fruits requires two essentials

(1) A successful dispersing agent
(2) An effective adaptation to the new environment

Common weed dispersal agents are

(a) Wind, (b) Water, (c) Animals and (d) Human

(a) Wind: 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 Eg. *Tridax procumbens*
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*

(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.

(c) Animals: Birds and animals eat many weed fruits. 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. 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.

(d) 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*.

(e) Manure and silage: 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.

(f) Dispersal by machinery: Machinery used for cultivation purposes like tractors can easily carries weed seeds, rhizomes and stolons when worked on infested fields and latter dropping them in other fields to start new infestation.
(g) Intercontinental movement of weeds: Introduction of weeds from one continent to another through 1. Crop seed, 2. Feed stock, 3. Packing material and 4. Nursery stock. Eg. *Parthenium hysterophorus*

Lect. 2 WEED ECOLOGY – ADAPTATIONS – CROP WEED INTERACTIONS – COMPETITION FOR LIGHT, SPACE MOISTURE AND NUTRIENTS – ALLELOPATHY

Knowing weed biology such as seed production capacity, germination dormancy and their ecological adaptations will help in formulating suitable weed control measures.

Weed ecology:

Ecology is the interrelationship between organisms and their environment.

We concerned with growth characteristics and adaptations that enable weeds to survive the change in the environment. Man plays an important role in changing the environment by altering the crop husbandry practices and by maintaining weed free monocrop or multicrop culture.

Survival mechanism: The seed is the primary means of survival mechanism of annual weeds while the vegetative parts such as buds, rhizomes tubers and bulbs offer on additional mechanism for perennial weeds.

a. Sexual reproduction: Through sexual reproduction abundant and small seeds are produced. Annual and biennial weeds depend on seed production, as the sole means of propagation and survival of perennial weeds are less dependent on this mechanism.

The seed production capacity of some of the weeds is

Ontogeny	Seeds/plant	Name of weed/crop	Seeds/plant
Perennials	16,629	*Amaranthus retroflexus*	1,96,405
Biennials	26,600	*Solanum nigrum*	1,78,000
Annuals	20,832	*Chenopodium album*	72,000
		Trianthema portulacastrum	52,000
		Wheat & Rice	90 to 100

A few weeds may produce seed through apomixis i.e without fertilization. Eg. Ferns reproduce by spores.

b. Vegetative reproduction: Vegetative structures normally rely upon parent for their plant nutrient conferring their competitive advantage but has disadvantage also owing to their genetically identical nature and as such may not well adapted to change in environment. The vegetative structures include stolons, rhizomes, tubers, bulb, corms and roots.

Seed dormancy as survival mechanism

Weed seeds possess a variety of special germination mechanisms adapted to changes in temperature, moisture, aeration, exposure to light, depth of burial of seeds etc., When conditions are unfavourable for germination, they can remain dormant or delay germination.

Conditions favourable for weeds seed germination are

a. Seeds of many weeds require an exposure to light for germination. This is regulated by bluish-green protein pigment called phytochrome.

b. Many weed seeds germinate under aerobic conditions while some require anaerobic condition. Soil turnover during ploughing and other operations exposes the seeds to light and induces germination.
c. Periodicity of germination is another specialised germination mechanism. *Amaranths* spp have a definite pattern of peaks of germination at regular intervals.
d. Summer annuals favour higher temperature & winter annuals germinate at lower temperatures some weeds germinate freely throughout the year.

Seed Dormancy: Dormancy is a state of seeds and buds in which they are alive but not germinated. If all weed seeds were to germinate at one time, their seedlings could be destroyed. Dormancy allows storage of millions of weed seeds in soil and enables them to grow in flushes over years. In this context, the old gardeners saying "*One year Seeding seven years Weeding*" is very appropriate. In fact, weed seeds have been found viable even after 20-80 years of burial in soil.

Weed seeds exhibit three lands of dormancy.

(1) Enforced Dormancy : It is due to deep placement of weed seeds in soil during ploughing of the field. Weed seeds germinate readily when they are restored to top 3 to 5 cm. Enforced Dormancy is a non-specific character of seed. Cultivation encounters enforced dormancy by bringing the weeds to surface where they are exposed to light besides better aeration. High soil temperature and NO_3 content of surface soil may further help in breaking seed dormancy.

(2) Innate dormancy: It is a genetically controlled character and it is a feature of specific weed seeds which fail to germinate even if they are present in the top 3-5cm soil and adequate soil moisture and temperature provided to them. The possible reasons are the presence of

(i) Hard seed coats e.g., *Setaria*, *Ipomoea*, *Xanthium* spp.
(ii) Immature embryos e.g., *Polygonum*

In certain weed seeds particularly of Xerophyttic origin, presence of inhibitors is responsible for innate dormancy. It can be overcome with passage of time, or under the influence of some climatic pressure.

(3) Induced Dormancy: Induced dormancy results from some sudden physiological change in normally non-dormant weed seeds under the impact of marked rise in temperature and or CO_2 content of soil, low O_2 pressure, water logging etc.

Wild oat (Avena fatua) seeds exhibit all three kinds of dormancy.

Persistence of weeds (Adaptation)

Persistence is an adaptive potential of a weed that enables it to grow in any environment. In an agricultural situation, the cropping system with its (associated habitat) management practices, determines the persistence of weed species. It is largely influenced by climatic, edaphic (soil) and biotic factors, which affect its occurrence, abundance, range and distribution.

FACTORS AFFECTING PERSISTENCE

A. Climatic factors

The important climatic factors are light, temperature, rainfall, wind and humidity.

Light:

Light intensity, quality and duration are important in influencing the germination, growth, reproduction and distribution of weeds. Photoperiod governs flowering time, seed setting and maturation and on the evolution of various ecotypes within a weed species. Tolerance to shading is a major adaptation that enables weeds to persist.

Temperature:

Temperature of atmosphere and soil affects the latitudinal and longitudinal distribution of weeds. Soil temperature affects seed germination and dormancy, which is a major survival mechanism of weeds.

Rainfall:

Rainfall has a significant effect on weed persistence and distribution. More rainfall or less rainfall determines reproduction & survival.

Wind:

Wind is a principal factor in the dissemination of weeds.

Climate can effect variations in cuticle development, pubescence, vegetative growth, vigour, competitiveness *etc*. Climate thus has a profound effect on the persistence of weeds which can adapt to a wide variety of climates.

B. Soil factors:

Soil factors are soil water, aeration, temperature, pH and fertility level and cropping system.

Some weed species are characteristically alkali plants, known as basophilic (pH 8.5) which can grow well in alkali soils and those grow in acidic soil is known as Acidophiles.

Basophiles		Acidophiles	Neutophiles
Alkaligrass	– *Puccinalia* spp.	*Cynodon dactylon*	common weed
Quack grass	– *Agrophyron repens*	*Digitaria sanguinalis*	

Several weed species of compositae family grow well in saline soils. A shift in soil pH, towards acid side due to continuous use of Ammonium sulphate as a 'N' source could cause a shift in the weed spectrum.

Many weeds can grow well in soils of low fertility level however, can adapt well to soils of high fertility also. Weeds also has adaptation to moist soil, drought condition etc.

C. Biotic factors: In a cropping situation, the major effects on weeds are those exerted by the crop as it competes for available resources. Once, a particular weed species is introduced, its persistence is determined by the degree of competition offered by the crop and also the agricultural practices associated with the growing of a crop may encourage or discourage specific weeds.

Eg. Ponding of water – *Cynodon* dies
Repeated cultivation – discourage nut sedge.

Crops that serve as hosts to parasitic weeds, (Sorghum – Striga) crop-induced stimulants are examples of other biotic factors.

CROP-WEED INTERACTIONS

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

Sl. 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

- χ 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.
- χ 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.

- χ 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

- β It may commence very early in the cop season if a dense weed growth smothers the crop seedlings.
- β It becomes important element of crop-weed competition when moisture and nutrients are plentiful.
- β In dry land agriculture in years of normal rainfall the crop-weed competition is limited to nitrogen and light.
- β 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) <u>Maize</u>:

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

(2) <u>Sorghum</u>:

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

(3) <u>Wheat</u>:

- 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) <u>Sunflower</u>:

- 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

Lect. 3 **EFFECT OF WEED COMPETITION ON GROWTH AND YIELD, LOSSES CAUSED BY WEEDS – ECONOMIC USES OF WEEDS.**

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 sunlightand in general an increase in one kilogram weed growth corresponds to reduction in one kilogram of crop growth. Hence, the crop is smothered and have a final say on crop yield. 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 terresstris* occurs in many of the playgrounds causing annoyance to players and spectators.

ECONOMIC USES OF WEEDS:

a. Weeds are indirectly responsible for crop cultivation, but for them cultivated crops may not receive much attention
b. As manure: When weeds are ploughed in, they add to the soil plenty of humus. Excellent compost can be made out of many weed plants. e.g. *Calotropis gigantea*, *Croton sparsiflorus* (Syn: *C. bonflandianum*) and *Tephrosia purpurea* are used as green leaf manure for rice. In wetlands, weeds are said to form a sort of rotation with paddy and are valuable in preventing loss of nitrates.
c. As human food: Weeds serve as human food e.g. *Amaranthus viridis* and Digera arvensis used as greens.
d. As fodder: Most weeds are eaten by cattle and weeds like *Rynchosia aurea, R. capitata* and *Clitoria terneata* are very good fodder legumes.
e. Weed as fuel: *Prosopis juliflora* very invasive in nature and notorious tree weed commonly used as fire wood. People make charcoal out of it and is marketed.
f. Weed as soil binders: *Panicum repens* is an excellent soil binder; keeps bunds in position and prevents soil erosion. We can also use Hariyali.

g. Weed as medicine: Many weeds have great therapeutic properties and used as medicine. Eg.

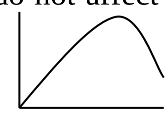
Phyllanthus niruri	– Jaundice
Eclipta alba	– Scorpion sting
Centella asiatica	– Improves memory
Cynodon dactylon	– Asthma, piles
Cyperus rotundus	– Stimulates milk secretion

h. Weed as mats and screens: Stems of *Cyperus pangorei* and *Cyperus corymbosus* are used for mat making while *Typha angustata* is used for making screens.
i. Weed as indicators: Weeds are useful as indicators of good and bad soils. *E. colonum* occurs in rich soils while *Cymbopogon* denotes poor light soil and Sedges are found in ill-drained soils.

Lect. 4 **FACTORS AFFECTING THE COMPETITIVE ABILITY OF CROPS AGAINST WEEDS – CRITICAL PERIODS OF CROP WEED COMPETITION, DEFINITIONS AND IMPORTANCE IN WEED MANAGEMENT, CRITICAL PERIODS FOR DIFFERENT CROPS**

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 reduces 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 influence the competition between the crop & weed. For eg. *E. crusgalli* in rice, *Setaia 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. Few weeds 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:

Defn: 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

Sl.No.	**Crops**	**Days from sowing**			**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 educed.

Lect. 5 PRINCIPLES AND METHODS OF WEED CONTROL - MECHANICAL, CULTURAL, CHEMICAL AND BIOLOGICAL METHODS – DESCRIPTION AND COMPARISION OF THEIR MERITS AND DEMERITS.

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

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

7. Burning: 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

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 possibilities of a certain weed species or group of species occurring is greater if the same crop is grown year after year. In many instances, crop rotation can eliminate 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

i) Vigorous and fast growing crop varieties are better competitors with weeds.

ii) Proper placement of fertilizers ensures greater availability of nutrients to crop plants, thus keeping the weeds at a disadvantage.

iii) Better irrigation practices to have a good head start over the weeds

iv) Proper crop rotation programme

v) 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 can not be controlled
4. Practical difficulty in adoption

BIOLOGICAL WEED CONTROL

Use of living organisms 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.

CHEMICAL WEED CONTROL

Using chemicals, generally referred as herbicides, for the control of weeds is called chemical weed control. In 1944 - discovery of 2,4-D Na salt as a land mark in herbicide usage.

Merits

1) Herbicide can be recommended for adverse soil and climatic conditions, as manual weeding is highly impossible during monsoon season.
2) Herbicide can control weeds even before they emerge from the soil so that crops can germinate and grow in completely weed-free environment at early stages. It is usually not possible with physical weed comfort.
3) Weeds, which resemble like crop in vegetative phase may escape in manual weeding. However, these weeds are controlled by herbicides.
4) Herbicide is highly suitable for broadcasted and closely spaced crops.
5) Controls the weeds without any injury to the root system of the associated standing crop especially in plantation crops like Tea and Coffee.
6) Reduces the need for pre planting tillage
7) Controls many perennial weed species
8) Herbicides control the weed in the field itself or *insitu* controlling where as mechanical method may lead to dispersal of weed species through seed
9) It is profitable where labour is scarce and expensive
10) Suited for minimum tillage concept
11) Highly economical

Demerits

1) Pollutes the environment
2) Affects the soil microbes if the dose exceeds
3) Herbicide causes drift effect to the adjoining field
4) It requires certain amount of minimum technical knowledge for calibration
5) Leaves residual effects
6) Some herbicide is highly costlier
7) Suitable herbicides are not available for mixed and inter-cropping system.

Lect. 6 HERBICIDE & WEEDICIDE DEFINITION – CLASSIFICATION OF HERBICIDES BASED ON VARIOUS ASPECTS

Herbicide: It is a chemical used to kill some targeted plants.

Principles of chemical weed control

The selectivity exhibited by certain chemicals to cultivated crops in controlling its associated weeds without affecting the crops forms basis for the chemical weed control. Such selectivity may be due to differences in the morphology, differential absorption, differential translocation, differential deactivation etc.

CLASSIFICATION OF HERBICIDES

1) Based on Method of application

i) Soil applied herbicides: Herbicide act through root and other underground parts of weeds. Eg. Fluchloralin

ii) Foliage applied herbicides: Herbicide primarily active on the plant foliage Eg.Glyphosate, Paraquat

2) Based on Mode of action

i) Selective herbicide: A herbicide is considered as selective when in a mixed growth of plant species, it kills some species without injuring the others. Eg. Atrazine

ii) Non-selective herbicide: It destroys majority of treated vegetation Eg. Paraquat

3 Based on mobility

i) Contact herbicide: A contact herbicide kills those plant parts with which it comes in direct contact Eg. Paraquat

ii) Translocated herbicide: Herbicide which tends to move from treated part to untreated areas through xylem / phloem depending on the nature of its molecule. Eg. Glyphosate

4) Based on Time of application

i) Pre - plant application (PPI): Application of herbicide before sowing or along with sowing. Either it is foliar applied or incorporated in soil soon after its application. Pre-plant foliar spraying of glyphosate to control perennial weeds like *Cyperus rotundus* and pre-plant soil incorporation of Fluchloralin to control weeds in ground nut

ii) Pre – emergence: Herbicide is applied to soil soon after sowing a crop before emergence of weeds Eg. Atrazine, Pendimethalin, Butachlor, Thiobencarb, Pretilachlor

iii) Post - emergence: When herbicide is applied to kill young weeds standing in the crop plants or application after the emergence of weed and crop. Eg. Glyphosate, Paraquat, 2,4-D Na Salt.

iv) Early post emergence: Another application of herbicide in the slow growing crops like potato, sugarcane, 2-3 week after sowing is classified as early post emergence.

1. **Based on molecular structure**
    a. **INORGANIC COMPOUNDS**
    b. **B. ORGANIC COMPOUNDS**

Herbicide formulation – time of application – preplant, pre emergence, post emergence - methods of application – granular, spray, herbigation – application equipments

Formulations

Herbicides in their natural state may be solid, liquid, volatile, non-volatile, soluble or insoluble. Hence these have to be made in forms suitable and safe for their field use. An herbicide formulation is prepared by the manufacturer by blending the active ingredient with substances like solvents, inert carriers, surfactants, stickers, stabilizers etc

Objectives in herbicide formulations are;

a. Ease of handling
b. High controlled activity on the target plants

Need for preparing herbicide formulation

❖ To have a product with physical properties suitable for use in a variety of types of application equipment and conditions.
❖ To prepare a product which is effective and economically feasible to use
❖ To prepare a product which is suitable for storage under local conditions?

Types of formulation

I. **Emulsifiable concentrates** (EC): A concentrated herbicide formulation containing organic solvent and adjuvants to facilitate emulsification with water eg., Butachlor

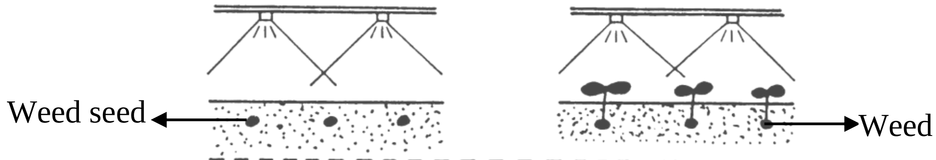
ii. **Wettable powders** (WP): A herbicide is absorbed by an inert carrier together with an added surface acting agent. The material is finely ground so that it may form a suspension when agitated with a required volume of water eg., Atrazine

iii. **Granules** (G): The inert material (carrier) is given a granular shape and the herbicide (active ingredient) is mixed with sand, clay, vermiculite, finely ground plant parts (ground corn cobs) as carrier material. eg., Alachlor granules.

iv. **Water soluble concentrates** (WSC) eg., paraquat

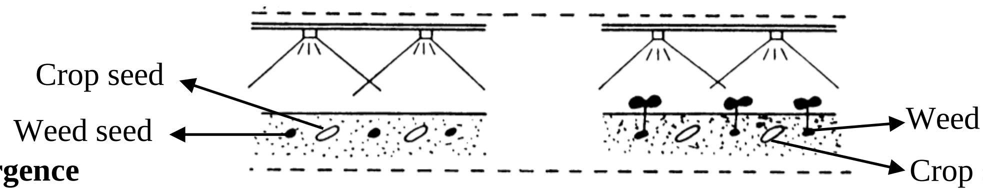
Time of application of herbicides
Pre-planting

Application of herbicides before the crop is planted or sown. Soil application as well as foliar application is done here. For example, fluchloralin can be applied to soil and incorporated before sowing rainfed groundnut while glyphosate can be applied on the foliage of perennial weeds like *Cyperus rotundus* before planting of any crop.



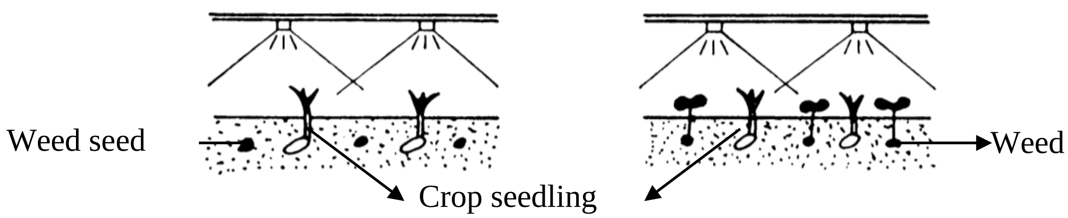
Pre-emergence

Application of herbicides before a crop or weed has emerged. In case of annual crops application is done after the sowing of the crop but before the emergence of weeds and this is referred as pre-emergence to the crop while in the case perennial crops it can be said as pre-emergence to weeds. For example soil application by spraying of atrazine on 3rd DAT to sugarcane can be termed as pre-emergence to cane crop while soil application by spraying the same immediately after a rain to control a new flush of weeds in a inter-cultivated orchard can be specified as pre-emergence to weed.



Post-emergence

Herbicide application after the emergence of crop or weed is referred as post-emergence application. When the weeds grow before the crop plants have emerged through the soil and are killed with a herbicide then it is called as early post-emergence. For example spraying 2,4-D Na salt to control parasitic weed striga in sugarcane is called as post-emergence while spraying of paraquat to control emerged weeds after 10-15 days after planting potato can be called as early post-emergence.



METHODS OF APPLICATION

1. Spraying
2. Broadcasting

Factors influencing the methods of application are

a. Weed-crop situation
b. Type of herbicides
c. Mode of action and selectivity
d. Environmental factors
e. Cost and convenience of application

Depending on the target site, the herbicides are classified in to

i. Soil applied herbicides
ii. Foliage applied or foliar herbicides

Different methods by which these herbicides are applied is tabulated below

	Soil application		Foliar application
a.	Surface	i.	Blanket spray
b.	Sub surface	ii.	Directed spray
c.	Band	iii.	Protected spray
d.	Fumigation	iv.	Spot treatment
e.	Herbigation		

SOIL APPICATION OF HERBICIDES

a. Surface application

Soil active herbicides are applied uniformly on the surface of the soil either by spraying or by broadcasting. The applied herbicides are either left undisturbed or incorporated in to the soil. Incorporation is done to prevent the volatilization and photo-decomposition of the herbicides.

Eg. Fluchoralin – Left undisturbed under irrigated condition

- Incorporated under rainfed condition

b. Subsurface application

It is the application of herbicides in a concentrated band, about 7-10 cm below the soil surface for controlling perennial weeds. For this special type of nozzle is introduced below the soil under the cover of a sweep hood.

Eg. Carbamate herbicides to control *Cyperus rotundus*

Nitralin herbicides to control *Convolvulus arvensis*

c. Band application

Application to a restricted band along the crop rows leaving an untreated band in the inter-rows. Later inter-rows are cultivated to remove the weeds. Saving in cost is possible here. For example when a 30 cm wide band of a herbicide applied over a croprows that were spaced 90 cm apart , then two-third cost is saved.

d. Fumigation

Application of volatile chemicals in to confined spaces or in to the soil to produce gas that will destroy weed seeds is called fumigation. Herbicides used for fumigation are called as fumigants. These are good for killing perennial weeds and as well for eliminating weed seeds.

Eg. Methyl bromide, Metham

f. Herbigation

Application of herbicides with irigation water both by surface and sprinkler systems. In India farmers apply fluchloralin for chillies and tomato, while in western countries application of EPTC with sprinkler irrigation water is very common in Lucerne.

FOLIAR APPLICATION

i. Blanket spray

Uniform application of herbicides to standing crops without considering the location of the crop. Only highly selective herbicides are used here.

Eg. Spraying 2,4-Ethyl Ester to rice three weeks after transplanting

ii. Directed spray

Application of herbicides on weeds in between rows of crops by directing the spray only on weeds avoiding the crop. This could be possible by use of protective shield or hood. For example, spraying glyphosate in between rows of tapioca using hood to control *Cyperus rotundus*.

iii. Protected spray

Applying non-selective herbicides on weeds by covering the crops which are wide spaced with polyethylene covers etc. This is expensive and laborious. However, farmers are using this technique for spraying glyphosate to control weeds in jasmine, cassava, banana.

iv. Spot treatment

It is usually done on small areas having serious weed infestation to kill it and to prevent its spread. Rope wick applicator and Herbicide glove are useful here.

Lect.7 SELECTIVE HERBICIDES FOR CROPS AND CROPPING SYSTEMS

The success of weed control programme depends on the following factors:

1. Study of weed flora
2. Selection of proper herbicide
3. Use of correct dose
4. Stage and time of application
5. Method of application
6. Calibration of sprayer

Factors influencing choice of herbicides

1. Crop factor

Monocots and dicots show differential tolerance to a herbicide, accordingly depending on type of crop cultivated the choice of herbicides varies. Eg. Monocots like rice has tolerence to 2,4-D Na salt while dicots like soybean gets killed when used as post-emergence.

2. Nature of weeds present

Based on the type of major weeds present in a situation, the herbicides are suggested accordingly. For eg., If more grassy weeds – fluzipop butyl is used while 2,4-D Na salt is used to control broad-leaved weeds.

3. Site of application

Soil applied herbicides – Atrazine, fluchloralin
Foliar applied herbicides – glyphosate

4. Time of application

(i) Pre-emergence herbicides – metolachlor
(ii) Post-emergence herbicides – paraquat

5. Farming situation

Wetland – water soluble herbicides butachlor
Garden land – Wettable powders – Atrazine

Water bodies – Diquat.

6. Duration of weed control

Short duration – less persistent herbicide - Anilofos
Long period – residual herbicides – atrazine

7. Cropping system

Maize + pulse combination - Isoproturon used and not atrazine
Maize followed by pulse use pendimethalin
Maize followed by cereal – Atrazine

8. Cost

In case of rice though butachlor, fluchloralin, pendimethalin etc. are recommended mostly butachlor is used because of it is cheaper than all other chemicals but not in control of weeds.

RECOMMENDATION OF HERBICIDES FOR IMPORTANT CROPS

Crop	Herbicide	Dose (kg ai/ha)	Trade name and formulation	Time of application
1. Rice	Butachlor	1.25	Machete 50% EC Delchlor 50% EC	Pre-emergence
	Thiobencarb	1.25	Thunder 50% EC Saturn 50% EC	Pre-emergence
	Anilophos	0.40	Arozin 30% EC Aniloguard 30% EC	Pre-emergence
	Fluchloralin	0.90	Basalin 45% EC	Pre-emergence
	Pendimethalin	0.90	Stomp 30% EC	Pre-emergence
	2,4-D Na salt	1.00	Fernoxone 80% SS	Post-emergence
2. Rice (Upland direct sown)	Thiobencarb	1.25	Saturn 50% EC	Pre-emergence (8 DAS)
	Pretilachlor	0.45	Refit 50% EC	Pre-emergence
3. Sorghum	Atrazine	0.25	Atrataf 50% WDP	Pre-emergence
4. Ragi (Transplanted)	Butachlor	1.25	Machete 50% EC	Pre-emergence
	Pendimethalin	0.75	Stomp 30% EC	Pre-emergence
5. Maize	Atrazine	0.25	Atrataf 50% WDP	Pre-emergence
6. Cumbu	Atrazine	0.25	Atrataf 50% WDP	Pre-emergence
7. Cotton	Metolachlor	1.00	Dual 50% EC	Pre-emergence
	Fluchloralin	1.00	Basalin 45% EC	Pre-emergence
	Pendimethalin	1.00	Stomp 30% EC	Pre-emergence
	Diuron	0.40	Karmex 50% WP	Pre-emergence
8. Groundnut	Metolachlor	1.00	Dual 50% EC	Pre-emergence
	Fluchloralin	0.90	Basalin 45% EC	Pre-emergence
9. Sunflower	Fluchloralin	0.90	Basalin 45% EC	Pre-emergence
	Pendimethalin	0.90	Stomp 30% EC	Pre-emergence
10.Vegetables	Fluchloralin	1.00	Basalin 45% EC	Pre-emergence
	Pendimethalin	1.00	Stomp 30% EC	Pre-emergence
11. Sugarcane	Atrazine	1.00	Atrataf 50% WDP	Pre-emergence
12. Pulses	Fluchloralin	0.70	Basalin 45% EC	Pre-emergence
	Pendimethalin	0.60	Stomp 30% EC	Pre-emergence
13. Wheat	Isoproturon	0.60	Arelon 75% WP	Pre-emergence
Cropping Systems				
1. Sorghum + Cowpea	Pendimethalin	0.90	Stomp 30% EC	Pre-emergence
2. Sugarcane + Pulses	Thiobencarb	1.25	Saturn 50% EC	Pre-emergence
3. Maize + Soybean	Pendimethalin	1.00	Stomp 30% EC	Pre-emergence
	Alachlor	2.00	Lasso 50% EC	Pre-emergence

Lect. 8 INTERACTION OF HERBICIDES WITH MOISTURE, FERTILIZERS, BIO FERTILIZERS, INSECTICIDES & FUNGICIDES

Simultaneous or sequential application of herbicides, insecticides, fungicides, antidotes, fertilizers etc are 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, result 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 decrease 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.

Lect. 9 BIOLOGICAL CONTROL AND BIO-HERBICIDE, ITS IMPORTANCE IN WEED MANAGEMENT

Bio control

Defn: The use of living organisms to suppress a pest population, making it less abundant and thus less damaging than that it would otherwise be.

Control or suppression of weeds by the action of one or more organisms through natural means or by manipulation of weed, organism or environment.

Use of living organism viz., insects, disease-causing organisms, herbivorous fish, snails or even competitive plants for the control of weeds is 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:

i. Differential growth habits, competitive ability of crops and varieties prevent weed establishment Eg. Groundnut, cowpea fast growing and so good weed suppresser.
ii. Insects kill the plants by exhausting plant food reserves, defoliation, boring and weakening structure of the plant.
iii. 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

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

Definition: 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.

Mycoherbicides

Defn: A fungal pathogen which, when applied inundatively, kill plants by causing a disease.

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

Lect 10. INTEGRATED WEED CONTROL - CONCEPT AND IMPORTANCE

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.

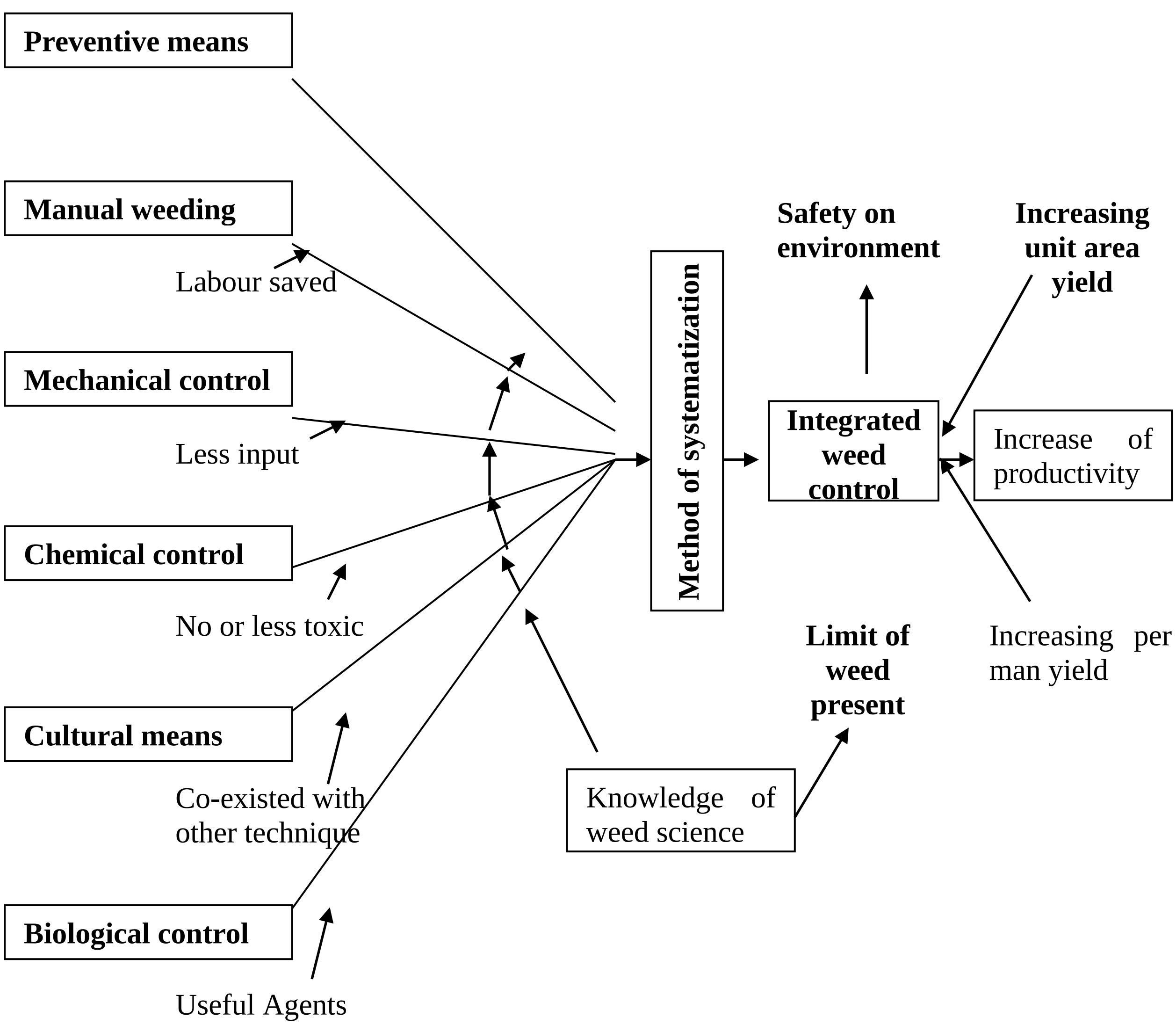
Advantages of IWM

- 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

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

A conceptional model of IWC by Noda, K. (1977)



IWM for Different Crops - Cropping System based Management
(Refer students' presentation)

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 herbicides are not used as pre-emergence, 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

i. 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
ii. 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.
iii. If pulse crop is to be raised as an intercrop in sorghum do not use Atrazine.
iv. 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

i. Remove the weeds immediately after harvest of the main crop
ii. 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 the 3rd day. 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

i. 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.
ii. Apply herbicide when there is sufficient moisture in the soil.
iii. Hand weed on 30-35 days after sowing if pre-emergence herbicide is applied.

iv. If pre-emergence herbicide is not applied hand weed twice on 15 and 30 days after sowing.

RAGI

i. 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.
ii. Apply herbicide when there is sufficient moisture in the soil or irrigate immediately after the application of herbicide.
v. If pre-emergence herbicide is not applied hand weed twice on 10th and 20th day after transplanting.
iii. 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

i. 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.
ii. Apply herbicide when there is sufficient moisture in the soil
iii. Do not disturb the soil after the herbicide application
iv. 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

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

REDGRAM, BLACKGRAM, GREENGRAM, COWPEA, BENGALGRAM

i. 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.
ii. If herbicide is not given, give two hand weeding on 15 and 35 days after sowing.

SOYBEAN

i. 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.
ii. If herbicide is not used, give two hand weeding on 20 and 35 days after sowing.
iii. 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

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

GROUNDNUT

i. Pre-sowing: Fluchloralin at 2.0 l/ha may be applied and incorporated.

ii. 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.

iii. Pre-emergence application of metolachlor (2.0 l/ha) plus one hand weeding on 30 days after sowing is more profitable.

iv. 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

i. 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

ii. 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

SAFFLOWER

Hoe and hand weed on 25th and 40th day of sowing.

CASTOR

Hoe and weed on 20th and 40th day of sowing.

COTTON

i. 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.

ii. 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

i. 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.

ii. Take up hoeing and weeding 20 days after sowing.

iii. Take up this operation when the top soil dries up comes to proper condition.

RAINFED COTTON

i. 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.
ii. 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

i. 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.
ii. 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**.
iii. 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.
iv. 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.

VEGETABLES

Apply pendimethalin 3.3 l/ha or Fluchloralin at 2 lit/ha or metolachlor 2 l/ha as pre-emergence followed by one hand weeding 30 days after transplanting.

Lect.11 RECENT TRENDS IN WEED MANAGEMENT - HERBICIDE MIXTURES - HERBICIDE ROTATION - HERBICIDE TOLERANCE AND RESISTANCE IN CROPS AND WEEDS -ADJUVANTS, ANTIDOTES, SAENERS - HERBICIDE RESIDUE MANAGEMENT

Herbicide mixtures: Involves mixing of two or more herbicides used for effective and economical weed control.

Advantages of Mixture

1. A mixture will broaden the spectrum of herbicidal action and kill a variety of weeds
2. It may increase the effectiveness;
3. In a mixture one herbicide may prevent rapid degradation of the other and increase its efficacy
4. A mixture offers the possibility of reducing the dose of each of the herbicide necessary for weed control leading to low residue

Two types of mixtures

(i) Tank mixtures made with the desired herbicides and rates before application eg., Anilophos + 2,4-D EE – rice

(ii) Ready mix – formulated by the manufacturer. Ready mix available in the world market eg., 2,4-D+Glyphosate, Paraquat+2,4,-D, Atrazine+metolachlor, paraquat+oxyfluorfen.

Herbicide rotation

The practice of following a systematic, rotational sequence of herbicide used in the same field to prevent or control formation of herbicide resistant weeds.

In a rotational programme a soil-applied or foliage applied herbicide or both are used in a sequence to take care of annual as well as perennial weeds. The choice of herbicide depends on the tolerance of crops to particular herbicides, type of weed spectrum, intensity of weed infestation, soil and climatic factors etc.,

The best rotational programme will aim at maximum cumulative cost benefit ratio and least residual problems and least build-up of tolerant weeds.

Advantages

(i) Helps in preventing emergence of tolerant weed species (Herbicide is captured in vacuole and inactivated excluding the herbicide from site of action).
(ii) Reduces the quantities of herbicide required for optimum weed control over the years.
(iii) Provides most effective weed control for the duration of crop growth.
(iv) Reduces the building up of herbicide residue problems.
(v) It offers high cumulative cost-benefit ratio over the years

Weed survey and mapping may be done every year and if any shift in weed flora, appropriate changes in herbicide rotation should be made.

Herbicide tolerance and Resistance

Herbicide Resistance: Naturally occurring inheritable ability of some weed biotypes within a population to survive a herbicide treatment that would, under conditions of use effectively control the weed population (Rubin, 1991)

- *Senecio vulgaris* resistance to triazine group of herbicide was noticed during 1970
- World wide 183 weeds have developed resistance to herbicides till 1997
- In India the most common example is *Philaris minor*
- The highest resistance in 61 weed species was recorded for atrazine
- USA alone found to have 49 herbicide resistant weeds, the highest in the world

Tolerance: The term tolerance refers to the partial resistance and presently the usage of the term is discouraged due to inconsistency in quantifying the degree of tolerance.

Gross Resistance: When a weed biotype exhibits resistant to two or more herbicides due to the presence of a single herbicide mechanism.

Multiple resistance: It is a situation where resistant plants posses two or more distinct resistant mechanism to a single herbicide or groups of herbicides.

Basic principles of herbicide resistance

1. Time, dose and method of application of herbicide variation
2. Variation in phenotypes of a population
3. Genetic variation by mutation or activation of pre existing genes

Conditions favourable for development of Herbicide resistance

a. Repeated use of same herbicide or use of herbicide with same mode of action due to the practices of monoculture
b. Areas where minimum/zero tillage is followed
c. Fields where farmers rely on only herbicides for high degree/level of weed control including nurseries, orchards
d. Non-crop situations like road sides, railway tracks etc. where herbicides are repeated used may be at higher doses than cropped situation

Resistance was exhibited in crop is due to

1. Herbicide metabolism by crops making them inactive
2. Absence of certain metabolic process in crops compared to weeds and thus tolerating the herbicides
3. Crops couples the herbicide molecule

Herbicide antidote

Chemicals which are used to inactivate the applied herbicides are called as antidotes. Eg. Paraquat spray can be inactivated by spraying 1% ferric chloride

Safeners / Protectants

Substances used for protecting crop plants, which are otherwise susceptible or less tolerant to some herbicides at doses required for good weed control.
eg., Naphthalic anhydride (NA) – 0.5g / kg of seed for rice to protect against molinate and alachlor

R – 27788 – soil application protects maize from alachlor and metolachlor

Mode of Action: Safeners enter the target plants and compete there with herbicide molecules for a binding site on some native enzyme.

ADJUVANTS

Adjuvants are chemicals employed to improve the herbicidal effects, sometimes making a difference between satisfactory and unsatisfactory weed control.

Mode of Action: Adjuvants aid the herbicide availability at the action site in plants.

Some important kinds of adjuvants are

1. Surfactant (Surface active agents)

(a) Aid in wetting the waxy leaf surface with aqueous herbicide sprays (wetting agents)
(b) In spreading the hydrophilic herbicides uniformly over the foliage (spreaders)
(c) In the penetration of herbicide into the target leaves and stems (penetrates)

A water drop is held as a ball on a waxy leaf surface. (Take water in a beaker, if you dip a leaf of *Cynodon dactylon* and pull it back, you can see the leaf without wetting. But if you add a drop of surfactant you can readily wet the foliage.). With the addition of surfactant, the water drop flattens down to wet the leaf surface and let the herbicide act properly.

2. Stabilizing agents:

These include
(i) Emulsifiers
(ii) Dispersing agents

(i) Emulsifiers: A substance which stabilizes (reduces the tendency to separate) a suspension of droplets of one liquid which otherwise would not mix with the first one. It substitutes for constant agitation of spray liquids during field operation.
Eg., ABS, Solvaid, 15-5-3, 15-5-9.

(ii) Dispersing agents: They stabilize suspensions. They keep fine parricides of wettable powder in suspension in water even after initial vigorous agitation has been withdrawn. They act by increasing the hydration of fine particles of WP laden with the herbicides.

3. Coupling agents (Solvents and co-solvents)

Chemical that is used to solubalize a herbicide in a concentrated form; the resulting solution is soluble with water in all proportions. Eg., 2,4-D is insoluble in water, but it can be dissolved in polyethylene glycol to make it water soluble.

Common solvents: Benzene, acetone, petroleum ether, carbon tetrachloride

4. Humicants (Hygroscopic agents)

Humicants prevent rapid drying of herbicide sprays on the foliage, thus providing an extended opportunity of herbicide absorption Eg. glycerol.

5. Deposit builders (Stickers or filming agents)

Chemicals added to herbicide concentrates to hold the toxicant in intimate contact with the plant surface. They also reduce washing off of the toxicant from the treated foliage by rain. Eg., Several petroleum oils, Du pont spreader sticker, Citowett.

6. Compatibility agents

Used to intimately mix fertilizers and pesticides in spray liquids Eg. Compex

7. Activators (Synergists)

Chemicals having cooperative action with herbicides that the resultant phytotoxicity is more than the effect of the two working independently.
Eg., Paraffinic oils, Ammonium thiocyanate, Urea and Ammonium chloride to enhance 2,4 –D phytotoxicity

8. Drift control agents

Herbicide spray drifts may pose serious hazards to non-target plants. Eg., 2,4-D on cotton. Solution is to spray herbicide liquids in large droplets.
Thickening agents eg., (Decagin, Sodium alginate)

MANAGEMIENT OF HERBICIDE RESIDUES IN SOIL

An ideal soil applied herbicide should persist longenough to give an acceptable period of weed control but not so long that soil residues after crop harvest limit the nature of subsequent crops which can be grown. Various management techniques have been developed which can help to niinimise the residue hazards in soil.

A. Use of Optimum dose of herbicide

Hazards from residues of herbicides can be minimised by the application of chemicals at the lowest dosage by which the desired weed control is achieved. Besides, applying herbicides in bands rather as broadcast will reduce the total amount of herbicide to be applied. This will be practicable in line sown crops or crops raised along ridges, such as cotton, sugarcane, sorghum, maize etc.

B. Application of farm yard manure

Farmyard manure application is an effective method to mitigate the residual toxicity of herbicides. The herbicide molecules get adsorbed in their colloidal fraction and make them unavailable for crops and weeds. Besides, FYM enhances the microbial activity which in turn degrade the herbicide at a faster rate.

C. Ploughing/cultivating the Land

Ploughing with disc plough or intercultivators reduces the herbicide toxicity, as the applied herbicide is mixed to a large volume of soil and gets diluted. In case of deep ploughing the herbicide layer is inverted and buried in deeper layers and thereby the residual toxicity got reduced

D. Crop rotation

Ragi – Cotton – Sorghum is the common crop rotation under irrigated field conditions of Coimbatore district. Fluchloralin 0.9 kg or butachlor 0.75 kg/ha + Hand weeding at 35 DAT for ragi + sunflower (border crop), pendimethalin 1.0 kg/ha + hand weeding on 35 DAS for cotton intercropped with onion and two manual weeding at 15 and 35 DAS for sorghum inter cropped with cowpea is the recommended weed control practice. The above weed management schedule did not show any residual effect in the cropping system because the herbicides are changed for every crop.

E. Use of non phyto-toxic oil

Atrazine residual hazard could be reduced by mixing non phyto-toxic oil which would also enhance the weed killing potency

F. Use of activated carbon

Activated carbon has a high adsorptive capacity because of its tremendous surface area which vary from 600 - 1200 m^2/g. Incorporation of 50 kg/ha of activated charcoal inactivated completely chlorsulfuron applied at 1.25 and 2.50 kg/ha and did not affect the yield of maize compared to untreated control. Application of charcoal at 5.0 kg/ha along the seed line reduced the residual toxicity of atrazine in soybean crop.

G. Use of safeners and antidotes

A new development in herbicide usage is the use of safeners and antidotes in order to protect the crop plant from possible damage by a herbicide. This means that it may be possible to use certain herbicides on crops that would normally be affected by herbicide. NA (1,8-naphthalic anhydride) has been used as a seed dressing on rice to protect the crop against molinate and alachlor. Another herbicide safener cyometrinil is used along with metolachlor in grain sorghum and other crop species.

H. Leaching the soil

Leaching the herbicide by frequent irrigation is possible especially in case of water soluble herbicides. In this case, the herbicides are leached down to lower layers i.e. beyond the reach of the crop roots.

(Exercise: Collect Maximum Residue Limit (MRL) permissible in crops for five common herbicides)

LEC. 12. DEVELOPMENT OF IRRIGATION IN INDIA AND TAMIL NADU - WATER RESOURCES, IRRIGATION POTENTIAL AND IRRIGATION SYSTEMS OF INDIA AND TAMIL NADU

IMPORTANCE OF IRRIGATION MANAGEMENT

Irrigation

Simply, irrigation can be stated as application of water to the soil for crop growth and development. The application of water to plants is made naturally through rainfall and artificially through irrigation.

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

Management

Regulating, the activities based on the various resources for its efficient use and better out put. i.e., allocation of all the resources for maximum benefit and to achieve the objectives, without eroding the environment is called management. Otherwise it can be stated as planning, executing, monitoring, evaluating and re-organizing the whole activities to achieve the target.

Irrigation Management

Management of water based on the soil and crop environment to obtain better yield by efficient use of water without any damage to the environment.

Management of water, soil, plants, irrigation structure, irrigation reservoirs, environment, social setup and it's inter liked relationship are studied in the irrigation management.

For this we have to study

- ❖ The soil physical and chemical properties
- ❖ Biology of crop plants
- ❖ Quantity of water available
- ❖ Time of application of water
- ❖ Method of application of water
- ❖ Climatological or meteorological influence on irrigation and
- ❖ Environment and its changes due to irrigation

Management of all the above said factors constitute **Irrigation Agronomy**: Management of irrigation structures, conveyances, reservoirs constitute **Irrigation Engineering**; and social setup, activities, standard of living, irrigation policies, irrigation association and farmer's participation, cost of irrigation etc., constitute **Socio-economic** study.

Except Economics and Engineering all the other components are grouped under Agronomy. Sociology has a major role in irrigation management in a large system. Hence Engineering, Economics, Social science and Agronomy are the major faculties come under Irrigation Management.

Irrigation management is a complex process of art and science involving application of water from source to crop field. The source may be a river or a well or a canal or a tank or a lake or a pond.

Maintaining the irrigation channels without leakage and weed infestation, applying water to field by putting some local check structure like field inlet and boundaries for the area to be irrigated etc., need some skill. These practices are the art involving practices in irrigation management.

Time of irrigation and quantity of water to be applied (when to irrigate? and how much to irrigate?) based on soil types, climatic parameters, crop, varieties, growth stages, season, quality of water, uptake pattern of water by plants, etc., and method of application (How best to irrigate) includes conveyance of water without seepage and percolation losses and water movement in soil, are the process involving scientific irrigation management.

Simply, it is a systematic approach of art and science involved in soil, plant and water by proper management of the resources (soil, plant and water) to achieve the goal of crop production.

Importance of Irrigation management

Water is essential not only to meet agricultural needs but also for industrial purposes, power generation, live stock maintenance, rural and domestic needs etc. But the resource is limited and cannot be created as we require. Hence irrigation management it very important:

- ❖ To the development of nation through proper management of water resources for the purpose of crop production and other activities such as industrialization, power generation etc., which in turn provides employment opportunities and good living condition of the people.
- ❖ To store the regulate the water resources for further use or non-season use
- ❖ To allocate the water with proper proportion based on area and crop under cultivation. (Balanced equity in distribution)
- ❖ To convey the water without much loss through percolation and seepage (Efficiency in use)
- ❖ To apply sufficient quantity to field crops. (Optimization of use)
- ❖ To utilize the water considering cost-benefit (Economically viable management)
- ❖ To distribute the available water without any social problem (Judicial distribution)
- ❖ To meet the future requirement for other purposes like domestic use of individual and to protect against famine (Resource conservation).
- ❖ To protect the environment from over use or misuse of water (Environment safe use).

Impact of excess and insufficient irrigation water in crops

Avoid excess or insufficient water to the crops

Excess irrigation leads to wastage of large amount of water, leaching of plant nutrients, destruction of beneficial microbes, increase of expenses on drainage, accumulation of salt leading to salinity and alkalinity, water logging leading to physiological stress and yield loss or crop failure.

Insufficient irrigation leads to reduction in quality of food grains, loss in crop yield or crop failure, poor soil environment etc.

Water becomes a limiting resource due to the multi-various demand from sectors like agriculture, livestock, industries, power generation and increased urban and rural domestic use. The increasing population increases the needs of industrial complexes and urbanization to meet the basic requirement and also to provide employment opportunities. So the demand for water is increasing day by day and hence, it is essential to study water potential and its contribution to agriculture which is turn is going to feed the growing population.

Sources of water

Rainfall is the ultimate source of all kind of water. Based on its sources of availability it can be classified as surface water and subsurface water.

Surface water includes precipitation (including rainfall and dew) water available from river, tank, pond; Lake Etc., Besides, snowfall could able to contribute some quantity of water in heavy snowfall area like Jammu, Kashmir and Himalaya regin.

Subsurface water includes subsurface water contribution, underground water, well water etc.

Rain fall

Seasons of rainfall can be classified s follows

1. Winter (Cold dry period	-	January – February
2. Summer (Hot weather period	-	March – May

3. Kharif (South-West monsoon) - June – September
4. Rabi (North-East monsoon) - October – December

South-west monsoon

It comprises the month June, July, August and September which contributes about 70% of rainfall to India except for extreme North of Jammu and Kashmir and extremes South of Tamil Nadu. Hence the success of agriculture in India depends on timely onset, adequate amount and even distribution of this South West Monsoon (SWM). This season is also called as Kharif season.

North East monsoon

It comprises the months of October, November and December. North East Monsoon (NEM) contributed rainfall to South Eastern part of peninsular India Tamil Nadu receives its 60% of rainfall from NEM (North East Monsoon). This season is also called as Rabi season.

Winter

It comprises of the month of January and February. It contributes very little rainfall.

Summer

Comprises of the months of March, April and May and contributes little summer showers.

Characteristics of good rainfall

1. Quantity should be sufficient to replace the moisture depleted from the root zone.
2. Frequency should be so as to maintain the crop without any water stress before it starts to wilt.
3. Intensity should be low enough to suit the soil absorption capacity.

Indian rainfall does not have the above good characteristics to maintain the crop through rainfall alone.

Characteristic features of Indian rainfall

- Annual Average rainfall is 1190 mm
- There is wide variation in the quantity of rainfall received from place to place. Highly erratic, undependable, variation in seasonal rainfall either in excess or deficit are the nature of Indian rainfall. For example a place in Rajasthan receives practically nil rainfall at the same time Chirapunji about 3000 mm rainfall.
- Rainfall is not uniformly distributed throughout the year. It is seasonal, major quantity is in the South West Monsoon, (SWM alone contributing 70% of total rainfall) i.e. in the month of June to September followed by North East Monsoon (NEM) from October to December. It summer and winter the amount of rainfall is very little.
- With in the season also the distribution is not uniform. A sudden heavy downpour followed by dry spell for a long period is common occurrence.
- Rainfall distribution over a large number of days is more effective than heavy down pour in a short period, but it is in negative trend in India
- Late starting of seasonal monsoon
- Early withdrawal of monsoon and
- Liability to failure are the freakish behaviour of Indian rainfall. Timely and uniform distribution of rainfall is important for better crop planning and to sustain crop production.

IRRIGATION – HISTORY AND STATISTICS

Irrigation has been practiced since time immemorial, nobody knows when it was started but evidences say that it is the foundation for all civilization since great civilization were started in the river basins of Sind and Nile.

This civilization came to an end when the irrigation system failed to maintain crop production.

There are some evidences that during the Vedic period (400 B.C) people used to irrigate their crops with dug well water. Irrigation was gradually developed and extended during the Hindus, Muslims and British periods.

The Grand Anaicat (KALLANAI) constructed across the river Cauvery is an outstanding example for the irrigation work by a Chola king the great Karikala Cholan during second century. The Veeranarayanan Tank and Gangai Konda Cholapuram tank was constructed during 10^{th} century in TN. Anantaraja Sagar in AP was constructed during 13th century.

Early Mauryan king Samudragupta and Ashoka took great interest in the construction of wells and tanks. Later Moghul kings or North India and Hindu kings of South India focused their attention, in the establishment of canals, dams, tanks etc. British Government initiated their work during 19th century in remodeling and renovation of the existing irrigation system. The Upper Ganga canal, Krishna and Godaveri delta system, Mettur and Periyar dams are the great irrigation structures built by the British rulers. After independence, Irrigation activities have been accelerated and number of multipurpose river valley projects like Bhakrea-nangal in Punjab, Tungabhadra in Andraprdesh, Damodar Valley in Madya Pradesh were established.

Irrigation Development during five year plans

In 1950 – 51 the gross irrigated area was 22.5 million ha. After completion of 1 five year plan the gross irrigated area was enlarged to 26.2 million ha. Further it was gradually increased to 29, 35.5, 44.2, 53.5; 75 million has respectively over the II, III, IV, V, VI & VII five years plans. The expected increase through VIII and IX five year plans area 95 and 105 m ha respectively.

Classification of irrigation work or projects

The irrigation projects can be classified as 1. major 2. medium 3. minor based on financial limits or expenditure involved in the scheme.

1. Major – more than 50 million Rupees : It covers cultural command area of more than 10,000 hectares
2. Medium – 2.5 million to 50 million Rupees : It covers cultural command area of 2000 – 10,000 hectares
3. Minor – less than 2.5 million Rupees : It covers cultural command area of 2,000 hectares.

The minor irrigation work consists of irrigation tanks, canals and diversion work for the welfare of small of farmers.

Indian has may perennial and seasonal rivers which flow from outside and within the country. Among this some important rivers of different states are given below.

Important irrigation projects in India

State	Project Name
A.P.	Godavari delta system, Krishna delta system, Nagarjuna sagar (Krishna)
Bihar	Gandala
Punjab	Western Jamuna, Bhakranangal Sutlej, Beas
Gujarat	Kakrapare – Tapti Narmada
M.P.	Gandhi sagar (Chambal, Ranap setab, sagar
Maharastra	Bhima Jayakwadi (Godavari)

Kerala	Kalada, Mullai Periyar
Karnataka	Ghataprabha, Malaprapha and Turga
Orissa	Hirkand and mahanathi
U.P	Upper ganga canal, Ramaganga
W.B	Damodar Valley
Rajasthan	Rajasthan Canal (Sutlej)
Tamil Nadu	Mettur – Lower Bhavani Project
	Parambikulam Alliyar Project
	Periyar Vaigai, Cauvery delta
	Tamiarabarani, Other river basins in TN is given in Map

India's water budget

Total geographical area = 328M.ha.
Average annual rainfall = 1190mm
In million hectare metre = 1190 x 328 = 392 M ha m
Contribution from snowfall = 8 M ha m
Total = 400 m ha m.

The rainfall below 2.5 mm is not considered for water budgeting, since it will immediately evaporate from surface soil without any contribution to surface water or ground water.

When rainfall occurs, a portion of it immediately evaporates from the ground or transpires from vegetation, a portion infiltrates into the soil and the rest flows over surface as run off.

There are on an average 130 rainy days in a year in the country out of which the rain during 75 days considered as effective rain. The remaining 55 days are very light and shallow which evaporates immediately without any contribution to surface or ground water recharge. Considering all these factors it is estimated that out of 400 million hectare meter of annual rainfall 70 million hectare meter is lost to atmosphere through evaporation and transpiration, about 115 million hectare meter flows as surface run-off and remaining 215 million hectare meter soaks or infiltrates into the soil profile

Surface run-off

Surface run off consists of direct run off from rainfall, melting of snowfall and flow in streams generated from ground water. Total surface run-off has been estimated by Irrigation Commission of India in 1972 as follows.

a) Total surface run off 180 M ha m
b) Rain fall contribution 115 M ha m
c) Contribution from outside the country through steams and rivers 20 M ha m
d) Contribution from regeneration from ground water in Stream and rivers 45 M ha m
Total 180 M ha m

Disposal of surface run off

The surface runoff is disposed in three ways

1. Stored in reservoirs
2. Disappears by means of percolation, seepage and evaporation

3. Goes to sea as waste

The waster stored in reservoirs is lost through evaporation and some amount through seepage. The rest in utilized for various purposes mainly for irrigation and drinking water.

Total surface run off	= 180 M ha m
Stored in reservoir and tanks	= 15 M ha m
Flow in the river	= 165 M ha m
Utilization from the river by diversion tank and direct pumping	= 15 M ha m
Water goes to sea as waste	= 150 M ha m
On full development work expected utilization	= 45 M ha m
Water flows to sea	= 105 M ha m

Land utilization pattern of India

Total geographical area	= 328.00 M ha
Net area reported	= 307.47 M ha
Area under forest	= 65.90 M ha
Area under non agricultural use, barren and uncultivable waste	= 100. 45 M ha
Net Area sown	= 141.12 M ha
Net area irrigated	= 31.20 M ha
Gross area sown	= 164.00 M ha
Gross area irrigated	= 80.50 M ha

Land utilization pattern in Tamil Nadu

Total geographical area	= 13.00 M ha
Area under forest	= 2.00 M ha
Non agricultural area	= 1.40 M ha
Barren and uncultivated	= 0.80 M ha
Pastures	= 0.20 M ha
Tree	= 0.20 M ha
Culturable waste	= 0.50 M ha
Culturable fallow	= 0.90 M ha
Other fallow	= 0.50 M ha
Gross area under cultivation	= 7.30 M ha
Net area sown	= 6.30 M ha
Gross area irrigated	= 3.50 M ha
Net area irrigated	= 2.70 M ha

Tamil Nadu Ground Water Potential

Average rainfall	= 850 mm
Ground water potential	= 36872 Mm^3
G. water utilization	= 19,801 Mm^3
Unutilized	= 46.3%

Percentage of area depends upon ground water in various parts of Tami Nadu

Salem	= 83%
Dharmapuri	= 65.3%
Coimbatore	= 51.3%
Madurai	= 45.1%
Trichy	= 34.9%
Tirunelveli	= 35.0%

Water Resources in India and Tamil Nadu

Distribution of irrigated area in '000 hectares

	Canal	Tanks	Wells	Other
India	12,776	4,123	12,034	2,601
Tamil Nadu	931	924	820	35

World Irrigation Statistics

Sl.No.	Countries	Area irrigated in million hectares
1	Australia	1.150
2	Botswana	0.002
3	Brazil	0.141
4	Burma	0.753
5	Canada	0.627
6	Ethiopia	0.030
7	France	2.600
8	India	37.640
9	Indonesia	3.797
10	Iran	4.000
11	Iraq	3.107
12	Israel	0.153
13	Japan	3.390
14	Pakistan	11.970
15	USSR	9.900
16	USA	16.932
17	China	74.000

LEC. 13. ROLE OF WATER IN PLANT GROWTH – HYDROLOGICAL CYCLE - WATER IN SOIL - PLANT - ATMOSPHERE CONTINUUM - ABSORPTION OF WATER AND EVAPOTRANSPIRATION

IMPORTANCE OF WATER – THE LIQUID GOLD

Plants and any from of living organisms cannot live without water, since water is the most important constituent about 80 to 90% of most plant cell.

Role of water in crop and crop production can be grouped as

A) Physiological importance

- The plant system itself contains about 90% of water
- Amount of water varies in different parts of plant as follows
- Apical portion of root and shoot >90%
- Stem, leaves and fruits - 70 - 90%
- Woods - 50 - 60%
- Matured parts - 15 - 20%
- Freshly harvested grains - 15 - 20%
- It acts as base material for all metabolic activities. All metabolic or biochemical reactions in plant system need water.
- It plays an important role in respiration and transpiration
- It plays an important role in photosynthesis
- It activates germination and plays in important role in plant metabolism for vegetative and reproductive growth
- It serves as a solvent in soil for plant nutrients
- It also acts as a carrier of plant nutrients from soil to plant system
- It maintains plant temperature through transpiration
- It helps to keep the plant erect by maintaining plant's turgidity
- It helps to transport metabolites from source to sink

B) Ecological Importance

- It helps to maintain soil temperature
- It helps to maintain salt balance
- It reduces salinity and alkalinity
- It influences weed growth
- It influences atmospheric weather
- It helps the beneficial microbes
- It influences the pest and diseases
- It supports human and animal life
- It helps for land preparation like ploughing, puddling, etc.,
- It helps to increase the efficiency of cultural operations like weeding, fertilizer application etc., by providing optimum condition.

The multifarious uses of good quality water for the purpose of irrigation, industrial purposes, power generation, livestock use, domestic use for urban and rural development, are increasing the demand for water. Due to increasing cost of irrigation projects and limited supply of good quality water, it becomes high valuable commodity and hence it is stated as Liquid Gold. Further, historical evidences indicate that all civilization established on water base due to proper management and disappear due to improper management of the same water base. All the superior varieties, organic manure, inorganic fertilizer, efficient labour saving implements, better pest and disease management techniques can be implemented only when sufficient water is applied to the crop. The diversified value of water can be quoted as follows:

Water as a source of sustenance
Water as an instrument of agriculture
Water as a community good
Water as mean of transportation
Water as an industrial commodity
Water as a clean and pure resource
Water as a beauty
Water as a destructive force to be controlled
Water as a fuel for urban development
Water as place for recreation and wild life habitat

As indicated by Sir.C.V.Raman water is the ELIXER of Life which makes wonders in earth if it is used Properly, Efficiently, Economically, Environmentally, Optimally, Equitably and Judicially.

Hydrological Cycle

Solid – liquid- gaseous form (refer any standard book)

State of water as solid – ice, its temperature – presence as ice, icebergs and Ice Mountains, ice glaciers and their role on water availability

As water – ocean – extent of ocean – their role on water availability

Gaseous form – clouds and their formation – precipitation – forms of precipitation etc.

Water in Soil - plant - atmosphere continuum

Soil physical properties influencing irrigation

Soil is a three-phase system comprising of the solid phase made of mineral and organic matter and various chemical compounds, the liquid phase called the *soil moisture* and the gaseous phase called the *soil air*. The main component of the solid phase is the soil particles, the size and shape of which give rise to pore spaces of different geometry. These pore spaces are filled with water and air in varying proportions, depending on the amount of moisture present. The presence of solid particles, liquid (soil solution) and gas (soil air) constitute a complex polyphasic system. The volume composition of the three main constituents in the soil system varies widely. A typical silt loam soil, for example, contains about 50 per cent solids, 30 per cent water and 20 per cent air. In addition to the three basic components, soil usually contains numerous living organisms such as bacteria, fungi, algae, protozoa, insects and small animals which directly or indirectly affect soil structure and plant growth. The most important soil properties influencing irrigation are its infiltration characteristics and water holding capacity. Other soil properties such as soil texture, soil structure, capillary conductivity, soil profile conditions, and depth of water table are also given consideration in the management of irrigation water.

Water Relations of Soil

The mineral and organic compounds of soil from a solid (though not rigid) *matrix*, the interstices of which consists of irregularly shaped pores with a geometry defined by the boundaries of the matrix (Fig. 7.5). The pore space, in general, is filled partly with soil air and liquid vapour and partly with the liquid phase of soil water. Soil moisture is one of the most important ingredients of the soil. It is also one of its most dynamic properties. Water affects intensely many physical and chemical reactions of the soil as well as plant growth.

The properties of water can be explained by the structure of its molecule. Two atoms of hydrogen and one atom of oxygen combine to form a molelargely determined by that of the oxygen ion. The two hydrogen ions take up practically no space. Water molecules do not exist individually. The hydrogen in the water serves as a connecting link from one molecule to the other.

Soil serves as the storage reservoir for water. Only the water stored in the root zone of a crop can be utilized by it for its transpiration and buildup of plant tissues. When ample water is in the root zone, plants can obtain their daily water requirements for proper growth and development. As the plants continue to use water, the available supply diminishes, and unless more water is added, the plants stop growing and finally die. Before the stage is reached when crop growth is adversely affected, it is necessary to irrigate again. The amount of water to be applied to each irrigation, and the frequency of irrigation are dependent on the properties of the soil and the crop to be irrigated.

Kinds of soil water: When is added to a dry soil either by rain or irrigation, it is distributed around the soil particles where it is held by adhesive and cohesive forces; it displaces air in the pore spaces and eventually fills the pores. When all the pores, large and small, are filled, the soil is said to be saturated and is at its maximum retentive capacity. The following re the three main classes of soil water:

(i) Hygroscopic water. Water held tightly to the surface of soil particles by adsorption forces.

(ii) Capillary water. Water held by forces of surface tension and continuous films around soil particles and in the capillary spaces.

(iii) Gravitational water. Water that moves freely in response to gravity and drains out of the soil.

Adhesion is the attraction of solid surfaces for water molecules. Adhesion is operative only at the solid-liquid interface and hence the film of water established by it is very thin. Cohesion is the attraction of water molecules for each other. This force makes possible a marked thickness of the films of water established by hydration until they attain microscopic size. As the film gets thicker and thicker the forces of gravity act and water flows downward through the large pores. Such water is loosely held. Thus, when a soil is near saturation it is easy to remove an increment of water, but as moisture becomes less and less in the soil, the greater will be the force required to remove a unit amount of moisture.

When a dry soil samples is exposed to water vapour, it will take up moisture. The amount adsorbed depends on the nature and magnitude of the surface exposed the temperature and the degree of humidity. The moisture thus adsorbed is the water of hydration, water of adhesion, or commonly the hygroscopic water. When the air saturation is 100 per cent the maximum amount of such moisture will be acquired.

The capillary water is held between tensions of about 31 atmospheres and one-third atmosphere. Between 31 and 15 atmospheres, capillary adjustment is very sluggish. Comparatively easy movement does not occur until the water film thickens and pressures near one-third atmosphere are reached. As a result of its energy relations, the capillary water is the only fluid water bearing solutes, that remains in the soil for any length of time, if drainage is satisfactory. Thus, it functions physically and chemically as the soil solution. The principal factors influencing the amount of capillary water in soils are the structure, texture and organic matter. The finger the texture of the mineral soil particles, the greater is likely its capillary capacity. Granular soil structure produces higher capillary capacity. Presence of organic matter increases the capillary capacity.

Water held in the soil at tensions of one-third atmosphere or less will respond to gravity and move downward, hence the name gravitational water. The water thus affected is that present in the non-capillary (large) pores. Of the three forms of water, only capillary and gravitational water are of interest to the irrigationists since hygroscopic water is not available to plants.

Movement of water into soils: The movement of water from the surface into the soil is called *infiltration*. The infiltration characteristics of the soil are one of the dominant variables influencing irrigation. *Infiltration rate* is the soil characteristic determining the maximum rate at which water can enter the soil under specific conditions, including the presence of excess water. It has the dimensions of velocity. The actual rate at which water is entering the soil at any given time is termed the *Infiltration velocity*.

The infiltration rate decreases during irrigation. The rate of decrease is rapid initially and the infiltration rate tends to approach a constant value. The nearly constant rate that develops after some time has elapsed from the start of irrigation is called the *basic infiltration rate.*

Factors Affecting Infiltration Rate

The major factors affecting the infiltration of water into the soil are the initial moisture content, condition of the soil surface, hydraulic conductivity of the soil profile, texture, porosity, and degree of swelling of soil colloids and organic matter, vegetative cover, duration of irrigation or rainfall and viscosity of water. The antecedent soil moisture content has considerable influence on the initial rate and total amount of infiltration, both decreasing as the soil moisture content rises. The infiltration rate of any soil is limited by any restraint to the flow of water into and through the soil profile. The soil layer with the lowest permeability, either at the surface or below it, usually determines the infiltration rate. Infiltration rates are also affected by the porosity of the soil which is changed by cultivation or compaction. Cultivation influences the infiltration rate by increasing the porosity of the surface soil and breaking up the surface seals. The effect of tillage on infiltration usually lasts only until the soil settles back to its former condition of bulk density because of subsequent irrigations.

Infiltration rates are generally lower in soils of heavy texture than on soils of light texture. The influence of water depth over soil on infiltration rate was investigated by many workers. It has been established that in surface irrigation, increased depth increases initial infiltration slightly but the head has negligible effect after prolonged irrigation. Infiltration rates are also influenced by the vegetal cover. Infiltration rates on grassland is substantially higher than bare uncultivated land. Additions of organic matter increase infiltration rate substantially. The hydraulic conductivity of the soil profile often change during infiltration, not only because of increasing moisture content, but also because of the puddling of the surface caused by reorientation of surface particles and washing of finger materials into the soil. Viscosity of water influences infiltration. The high rates of infiltration in the tropics under otherwise comparable soil conditions is due to the low viscosity of warm water.

Soil Moisture Retention and Movement

The moisture content of a sample of soil is usually defined as the amount of water lost when dried at 105^0C, expressed either as the weight of water per unit weight of dry soil or as the volume of water pr unit volume of bulk soil. Although useful, such information is not a clear indication of the availability of water for plant growth. The difference exists because the water retention characteristics may be different for different soils.

The forces that keep soil and water together are based on the attraction between the individual molecules, both between water and soil molecules (adhesion) and among water molecules themselves (cohesion). In the wet range surface tension is the most important force, while in the dry range adsorption is the main factor. Thus, the higher the moisture content, the smaller is the attraction of the soil for water. The energy of water tension in a soil depends on the specific surface as well as the structure of the soil and on its solute content. When water is present in fine capillaries, the energy with which it is attached is a function of the surface tension and capillary size but when it is present in bigger pores, it is bound loosely to the soil and can be acted upon by gravity. When salts dissolve in water, they decrease the free energy of water. Soil water, by virtue of the salts dissolved in it has a lower free energy than pure water. Further, soil water that is bound to solid particles as hygroscopic water is tightly held by the surface of contact and has a low free energy by virtue of binding forces. Thus, there are two types of interactions which decrease the free energy of water, namely, (i) due to the solubility of salts, (ii) due to the interaction of water and solid surface. Both these add together in decreasing the energy of soil water. Thus, the retention of water in the soil and the tendency of water to move in the soil are consequences of energy effects. Study evaporation and transpiration in the Lecture 16.

LEC. 14. SOIL WATER MOVEMENT - SATURATED AND UNSATURATED FLOW AND VAPOUR MOVEMENT - SOIL MOISTURE CONSTANTS AND THEIR IMPORTANCE IN IRRIGATION

Soil Moisture Tension

Soil moisture tension is a measure of the tenacity with which water is retained in the soil and shows the force per unit area that must be exerted to remove water from a soil. The tenacity is measured in terms of the potential energy of water in the soil measured, usually with respect to free water. It is usually expressed in atmospheres, the average air pressure at sea level. Other pressure units like cm of water or cm or mm of mercury are also often used (1 atmosphere = 1036 cm of water or 76.39 cm of mercury). It is also sometimes expressed in bars (1 bar = 10^6 dynes / cm^2 = 1023 cm of water column.

$$1 \text{ millibar} = \frac{1}{1000} \text{ bar}).$$

Soil moisture tension is brought about at the smaller dimensions by surface tension (capillarity), and at the higher dimensions by adhesion. Buckingham (1907) introduced the concept of ‘capillary potential’ to define the energy with which water is held by soil. This term, however, does not apply over the entire moisture range. In a wet soil, as long as there is a continuous column of water, it might be called ‘hydrostatic potential’, in the intermediate range the term ‘capillary potential’ is appropriate. In the dry range the term ‘hygroscopic potential’ would be suitable. However, the term ‘soil moisture potential’, ‘soil moisture suction’ and ‘soil moisture tension’ are often used synonymously to cover the entire range of moisture (Khonke, 1968).

pF of soils: Scholfield (1935) suggested the use of the logarithm of soil moisture tension and gave the symbol pF of this logarithm which is an exponential expression of a free-energy difference (based on the height of a. water column above free-water level in cm). The pF function, analogous to the acidity-alkalinity scale pH, is defined as the logarithm to the base 10 of the numerical value of the negative pressure of the soil moisture expressed in cm of water.

$pF = \log_{10}{}^{h}$ in which
h = soil moisture tension in cm of water

If the osmotic tension is negligible, *i.e.*, at low salt concentration, the pF of the soil moisture may nearly equal the logarithm of the capillary tension expressed in cm of water.

Soil Moisture Characteristics

Soil moisture tension is not necessarily an indication of the moisture content of neither the soil nor the amount of water available for plant use at any particular tension. These are dependent on the texture, structure and other characteristics of the soil and must be determined separately for each soil. Generally sandy soils drain almost completely at low tension, but fine textured clays still hold a considerable amount of moisture even at such high tensions that plant growing in the soil may wilt. Moisture extraction curves, also called moisture characteristic curves, which are plots of moisture content versus moisture tension, show the amount of moisture a given soil holds at various tensions. Knowledge of the amount of water held by the soil at various tensions is required, in order to understand the amount of water that is available to plants, the water that can be taken up by the soil before percolation starts, and the amount of water that must be used for irrigation.

Soil moisture stress

Soil-moisture tension as discussed in the preceding paragraphs is based on pure water. Salts in soil water increase the force that must be exerted to extract water and thus affect the amount of water available to plants. The increase in tension caused by salts is from *osmotic pressure*. If two solutions differing in concentration are separated by a membrane impermeable to the dissolved substance, such as a cell membrane in a plant root, water moves from the solution of lower concentration to the one of higher concentration. The force with which water moves across such a membrane is called osmotic pressure and is measured in atmospheres.

Plant growth is a function of the soil moisture stress which is the sum of the soil moisture tension and osmotic pressure of soil solution. In many irrigated soils, the soil solution contains an appreciable amount of salts. The osmotic pressure developed by the soil solution retards the uptake of water by plants. Plants growing in a soil in which the soil-moisture tension is, say, I atmosphere apparently can extract enough moisture for good growth. But if the osmotic pressure of the soil solution is, say, 10 atmospheres, the total stress is 11 atmospheres and the plants cannot extract enough water for good growth. Thus, for successful crop production in soils having appreciable salts, the osmotic pressure of the soil solution must be maintained as low as possible by controlled leaching and the soil moisture tension in the root zone is maintained in a range that will provide adequate moisture to the crop.

Soil moisture constants

Soil moisture is always being subjected to pressure gradients and vapour pressure differences that cause it to move. Thus, soil moisture cannot be said to be constant at any pressure. However, it has been found experimentally that certain moisture contents described below are of particular significance in agriculture and these are often called soil moisture 'constants'.

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

Field capacity. The field capacity of soil is the moisture content after drainage of gravitational water has become very slow and the moisture content has become relatively stable. This situation usually exists one to three days after the soil has been thoroughly wetted by rain or irrigation. The terms field capacity, field-carrying capacity, normal moisture capacity and capillary capacity are often used synonymously. At field capacity, the large soil pores are field with air, the micro pores are filled with water and any further drainage is slow. The field capacity is the upper limit of available moisture range in soil moisture and plant relations. The soil moisture tension at field capacity varies from soil to soil, but it generally ranges from 1/10 to 1/3 atmospheres.

Filed capacity is determined by ponding water on the soil surface in an area of about 2 to 5 sq m and permitting it to drain for one to three days, with surface evaporation prevented. Evaporation may be prevented by spreading a polythene sheet or a thick straw mulch on the ground surface. One to three days after the soil is thoroughly wetted, soil samples are collected with an auger from different soil depths at uniform intervals throughout the wetted zone. The moisture content is determined by the gravimetric method.

Moisture equivalent. Moisture equivalent is defined as the amount of water retained by a sample of initially saturated soil material after being subjected to a centrifugal force of 1000 times that of gravity for a definite period of time, usually half an hour. To determine the moisture equivalent, a small sample of soil is whirled in a centrifuge with a centrifugal force of

1000 times that of gravity. The moisture remaining in the sample is determined. This moisture content when expressed as moisture percentage on over dry basis, gives the value of the moisture equivalent. In medium textured soils, the values of field capacity and moisture equivalent are nearly equal. In sandy soils, the field capacity exceeds the moisture equivalent. In very clayey soils, the field capacity is generally lower than the moisture equivalent.

Permanent wilting percentage: The permanent wilting percentage, also known as permanent wilting point or wilting co-efficient, is the soil moisture content at which plants can no longer obtain enough moisture to meet transpiration requirements; and remain wilted unless water is added to the soil. At the permanent wilting point the films of water around the soil particles are held so tightly that roots in contact with the soil cannot remove the water at a sufficiently rapid rate to prevent wilting of the plant leaves. It is a soil characteristic, as all plants whose root systems thoroughly permeates the soil will wilt at nearly the same soil moisture content when grown in a particular soil in a humid atmosphere.

The moisture tension of a soil at the permanent wilting point ranges from 7 to 32 atmospheres, depending on soil texture, on the kind and condition of the plants, on the amount of soluble salts in the soil solution, and to some extent on the climatic environment. Since this point is reached when a change in tension produces little change in moisture content, there is little difference in moisture percentage regardless of the tension taken as the permanent wilting point. Therefore, 15 atmospheres is the pressure commonly used for this point.

The ***wilting range*** is the range in soil-moisture content through which plants undergo progressive degrees of permanent or irreversible wilting, from wilting of the oldest leaves to complete wilting of all leaves. At the permanent wilting point, which is the top of this range, plant growth ceases. Small amounts of water can be removed from the soil by plants after growth ceases, but apparently the water is absorbed only slowly and is enough only to maintain life until more water is available. The moisture content at which the wilting is complete and the plants die is called the *ultimate wilting*. Although the difference in the amount of water in the soil between the two points may be small, there may be a big difference in tension. At the ultimate wilting point soil-moisture tension may be as high as 60 atmospheres.

The most common method of determining the permanent wilting percentage is to grow indicator plants in containers, usually in small cans, holding about 600 grams of soil. Sunflower plant is commonly used as the indicator plant. The plants are allowed to wilt and are then placed in a chamber with an approximately saturated atmosphere to test them for permanent wilting. The residual soil moisture content in the container is then calculated which is the permanent wilting percentage. The determination of moisture content at 15 atmosphere tension which is the usually assumed value of permanent wilting point can be done by the pressure membrane apparatus (Richard, 1947).

Available water. Soil moisture between field capacity and permanent wilting point is referred to as readily available moisture. It is the moisture available for plant use. In general, fine-textured soils have a wide range of water between field capacity and permanent wilting point than coarse textured soils. In contrast, sandy soils with their larger proportion of non-capillary pore space release most of their water within a narrow range of potential because of the predominance of large pores. Illustrates the three kinds of soil water and the difference in available water between typical sandy loam and silt loam soils. Tablebelow present the range of available water holding capacities of different soil textural groups. For irrigation system design, the total available water is calculated for a soil depth based on the root system of a mature plant of the crop to be grown.

Range of available water holding capacity of soils

Soil type	Per cent moisture, based on dry weight of soil		Depth of available water per until of soil
	Field capacity	Permanent wilting percentage	cm per meter depth of soil
Find sane	3-5	1-3	2-4
Sandy loam	5-15	3-8	4-11
Silt loam	12-18	6-10	6-13
Clay loam	15-30	7-16	10-18
Clay	25-40	12-20	16-30

Movement of water within soils

The movement of water within the soil controls not only the rate of infiltration but also the rate of supply of moisture to plant roots and the rate of underground flow to springs and streams and recharge of ground water. Water in the liquid phase flows through the water filled pore space under the influence of gravity. In the films surrounding soil particles (under unsaturated conditions), it moves under the influence of surface tension forces. Water also diffuses as vapour through the air-filled pore spaces along gradients of decreasing vapour pressure. In all cases, the movement is along gradients of decreasing water potential.

Terminology

Water intake. The movement of irrigation water from the soil surface into and through the soil is called water intake. It is the expression of several factors, including infiltration and percolation.

Percolation. Percolation is the downward movement of water through saturated or nearly saturated soil in response to the force of gravity. Percolation occurs when water is under pressure or when the tension is smaller than about ½ atmosphere. *Percolation rate* is synonymous with infiltration rate with the qualitative provision of saturated or near saturated conditions.

Interflow. Interflow is the lateral seepage of water in a relatively pervious soil above a less pervious layer. Such water usually reappears on the surface of the soil at a lower elevation.

Seepage. Seepage is the infiltration (vertically) downward and lateral movements of water into soil or substrata from a source of supply such as a reservoir or irrigation canal. Such water may reappear at the surface as wet spots or seeps or may percolate to join the ground water or may join the subsurface flow to springs or streams. Seepage rate depends on the wetted perimeter of the reservoir or the canal and the capacity of the soil to conduct water both vertically and laterally.

Permeability (1) *Qualitative*. It is the characteristic of a pervious medium relating to the readiness with which it transmits fluids.

(2) *Quantitative*. The specific property governing the rate or readiness with which a porous medium transmits fluids under standard conditions. According to this definition, equations used for expressing flow, which take into account the properties of the fluid, should give the same soil permeability value for all fluids which do not alter the medium.

The term *intrinsic permeability* is used as a permeability factor independent of the fluid. It must, however, be remembered that the factors which tend to change the permeability of the soil matrix to water will influence this value and prevent its use unless they can be measured or evaluated separately.

Hydraulic conductivity. Hydraulic conductivity is the proportionality factor *k* in Darcy's law ($v=ki$, in which *v* is the effective flow velocity and *i* is the hydraulic gradient). It is, therefore, the effective flow velocity at unit hydraulic gradient and has the dimensions of velocity (LT^{-1}). The values of *k* depend on the properties of the fluid with the porous medium, such as swelling of a soil. A soil that has high porosity and coarse open texture has a high hydraulic conductivity value. For two soils of the same 'total' porosity, the soil with small pores has lower conductivity than the soil with large pores because of the resistance to flow in small pores. A soil with pores of many sizes conducts water faster if the large pores form a continuous path through the profile. In fine-textured soils, hydraulic conductivity depends almost entirely on structural pores. In some soils, particles are cemented together to form nearly impermeable layers commonly called *hardpans.* In other soils, very finely divided or colloidal material expands on absorbing water to form an impervious gelatinous mass that restricts the movement of water.

Hydraulic head. Hydraulic head is the elevation with respect to a standard datum at which water stands in a riser pipe or manometer connected to the point in question in the soil. This will include elevation head, pressure head, and also the velocity head, if the terminal opening of the sensing element is pointed upstream. For non-turbulent flow of water in soil the velocity head is negligible. In unsaturated soil a porous cup must be used for establishing hydraulic contact between the soil water and water in a manometer. Hydraulic head has the dimensions of length (*L*).

Hydraulic gradient Hydraulic gradient is the rate of change of piezometric or hydraulic head with distance. Hydraulic gradient of ground water records the head consumed by friction in the flow in unit distance since in ground water flow the velocity heads are generally negligible.

Hydraulic equilibrium of water in soil It is the condition for zero flow rate of liquid or film water in the soil. This condition is satisfied when the pressure gradient force is just equal and opposite to the gravity force.

Movement of water under saturated conditions

Poiseuille's law forms the basis for a number of different equations which have been developed for determining the hydraulic conductivity of the soil for knowledge of its pore-size distribution. Pore size is of outstanding significance, as its fourth power is proportional to the rate of saturated flow. This indicates that saturated flow under otherwise identical conditions decreases as the pore size decreases. Generally the rate of flow in soils of various textures is in the following sequence.

Sand > loam > clay

Moisture movement under unsaturated conditions

As drainage proceeds in a soil and the larger pores are emptied of water the contribution of the hydraulic head or the gravitational component to total potential becomes progressively less important and the contribution of the matric potential ψ_m becomes more important. The effect of pressure is generally negligible because of the continuous nature of the air space. The solute potential (osmotic potential) ψ_s does not affect the potential gradient unless there is unusual concentration of slat at some point in the soil. The negligible effect of solute potential is due to the fact that both solutes and water are moving. Thus, in moisture moment under unsaturated conditions, the potential ψ (Equation 7.28) is the sum of the matric potential ψ_m and, to some extent the gravitational potential $\psi_{g.}$ In horizontal movement, only ψ_m applies. Under conditions of downward movement, capillary and gravitational potentials act together. In upward capillary movement ψ_m and ψ_g oppose one another. For unsaturated flow (Equation 7.28) may be rewritten as:

$$v = - k \frac{\Delta (\psi_m + \psi_g)}{\Delta^I}$$

The direction of *I* is the path of greatest change in ($\psi_m + \psi_g$).

Under unsaturated conditions Darcy's law (Equation 7.28) is still applied but with some modifications and qualifications. It is applicable to unsaturated flow if *k* is regarded as a function of water content, i.e. *k* (0) in which 0 is the soil moisture content. As the soil moisture content and soil moisture potential decreases, the hydraulic conductivity decreases very rapidly, so that ψ_{soil} is – 15 bars, *k* is only 10^{-3} of the value at saturation. According to Philip (1957 a), the rapid decrease in conductivity occurs because the larger pores are emptied first, which greatly decreases the cross-section available for liquid flow. When the continuity of the films is broken, liquid flow no longer occurs.

In unsaturated soil moisture movement, also called capillary movement, *k* (Equation 7.28) is often termed as *capillary conductivity,* though the term hydraulic conductivity is also frequently used. The unsaturated conductivity is a function of soil moisture content as well as number, size and continuity of soil pores. At moisture contents below field capacity, the capillary conductivity is so low that capillary movement is of little or no significance in relation to plant growth. Many investigations have shown that capillary rise from a free water table can be an important source of moisture for plants only when free water is within 60 or 90 cm of the root zone.

Movement of unsaturated flow ceases in sand at a lower tension than in finer textured soils, as the water films lose continuity sooner between the larger particles. The wetter the soil, the greater is the conductivity for water. In the 'moist range', the range of unsaturated flow in soils of various textures is in the following order:

Sand < loam < clay

It may be noticed that this is the reverse of the order encountered in saturated flow. However, in the 'wet range' the unsaturated conductivity occurs in the same or similar order as saturated conductivity.

Water vapour movement

Movement of soil water in unsaturated soils involves both liquid and vapour phases. Although vapour transfer is insignificant in high soil water contents, it increases as void space increases. At a soil moisture potential of about-15 pars, the continuity of the liquid films is broken and water moves only in the form of vapour. Diffusion of water vapour is caused by a vapour pressure gradient as the driving force. The vapour pressure of soil moisture increases with the increase in soil moisture content and temperature, it decreases with the increase in soluble salt content.

Water vapour movement is significant only in the 'moist range'. In the 'wet range' vapour movement is negligible because there are few continuous open pores. In the 'dry range' water movement exists, but there is so little water in the soil that the rate of movement is very small.

Water vapour movement goes on within the soil and also between soil and atmosphere, for example, evaporation, condensation and adsorption. The rate of diffusion of water vapour through the soil is proportional to the square of the effective porosity, regardless of pore sizes.

The finger the soil pores, the higher is the moisture tension under which maximum water vapour movement occurs. In a coarse textured soil pores become free of liquid water at relatively low tensions and when the soil dries out there is little moisture left for vapour transfer. But a fine textured soil retains substantial amounts of moisture even at high tensions, thus permitting vapour transfer. It is interesting to note that maximum water vapour movement in soils vapour movement is of greatest importance for the growth and survival of plants.

LEC. 15. MOISTURE EXTRACTION PATTERN OF CROPS- SOIL MOISTURE STRESS - PLANT WATER STRESS -EFFECTS ON CROP GROWTH

Water as a Plant Component

The factors influencing the water relations of plants, and thus their growth and yield responses, may be grouped into the following

I. Soil factors – soil moisture content, texture, structure, density, salinity, fertility, aeration, temperature and drainage.
II. Plant factors – type of crop, density and depth of rooting, rate of root growth, aerodynamic roughness of the crop, drought tolerance and varietal effects.
III. Weather factors – sunshine, temperature, humidity, wind and rainfall.
IV. Miscellaneous factors – soil volume and plant spacing, soil fertility, and crop and soil management

The metabolic activity of cells and plants is closely related to their water content. Growth of plants is controlled by the rates of cell division and enlargement and by the supply of organic and inorganic compounds required for the synthesis of new protoplasm and cell walls. A decreasing water content is accompanied by a loss of cell turgor* and wilting, cessation of cell enlargement, closure of stomata reduction of photosynthesis and interference with many basic metabolic processes. Eventually, continued dehydration causes disorganization of the protoplasm and death of most organisms. The relation of water content to physiological processes is shown strikingly in seeds, where respiration and other physiological activities increase manifold as the water content increases. In photosynthesis, water is as important a reagent as carbondioixde. An essential function of water in plants is as the solvent in which gases, minerals, and other solutes enter plant cells and move from cell to cell and tissue to tissue within the plant. The permeability of most cell walls and membranes to water results in a continuous liquid phase extending throughout the plant in which translocation of solutes occurs. Water is a reactant or reagent in many physiological processes including photosynthesis and hydrolytic processes such as the hydrolysis of starch to sugar. Water is essential to maintain sufficient turgidity for growth of cells and maintenance of the form and position of leaves and new shoots.

The total quantity of water required for the essential physiological functions of the plant is usually less than five per cent of all the water absorbed. Most of the water entering the plant is lost in transpiration, directly contributing little to its growth. However, failure to replace the water lost by transpiration results in the loss of turgidity, cessation of growth, and eventual death of the plant from dehydration.

The following are the main areas of water-plant relationship: (1) water absorption, (2) water conduction and translocation, and (3) water loss or transpiration.

In determining the importance of water in crop productivity we have to understand clearly all the three processes – absorption, translocation and transpiration. We will have to analyse the effect of these processes on plant growth and crop yield in order to recognize the steps which are needed to regulate and modify the cropping systems with a view to obtain the maximum water use efficiency.

Amount of water in plants: The amounts of water varies in different plant parts. The apical portions of the root and stem contain 90 per cent or more water. Leaves and young fruits are other organs which are rich in water. When the organs mature, their water content decreases. The woods of large trees may contain about 50-60 per cent moisture whereas the stems of wheat, barley and sorghum contain about 60-70 per cent water which at harvest time may decline to 5-10 per cent. Freshly harvested grains of most crops contain 10-15 pr cent of water. Indeed, it is the moisture content of these grains which determines their storage life, viability and germinability.

Absorption of water in soil-plant-atmosphere system. The root system is extremely variable in different crop plants. The variability exists in rooting depth, root length and horizontal distribution of roots. These are further influenced by environmental factors and the genetic constitution. Nevertheless, both the properties of soil and the roots determine the water uptake by roots. The roots of cereals, apparently, occupy more surface area of the soil than other crops. For example, it has been shown that cereal roots extend to 200-4000 cm/cm^2 of soil surface area as against 15-200 cm/cm^2 for non-graminaceous plants.

It is desirable to consider water absorption in the total soil-plant-atmosphere system instead of the roots alone. In this system, one can partition the system in such a manner so that the involvement of different plant parts is taken into account. The flow rate of water in this system is given by the following equation:

$$\text{Flow rate} = \frac{\Psi_{soil} - \Psi_{root\ surface}}{r_{soil}} = \frac{\Psi_{root\ surface} - \Psi_{xylem}}{r_{root}}$$

$$= \frac{\Psi_{xylem} - \Psi_{leaf}}{r_{xylam}} = \frac{\Psi_{leaf} - \Psi_{air}}{r_{leaf} + r_{rleaf}}$$

in which, Ψ is the water potential at various sites of the system and r is the corresponding resistance.

Water absorption by roots is dependent on the supply of water at the root surface. The two main phenomena concerned with this are the movement of water to the root surface and the growth of roots into the soil mass. As the soil dries out from a saturated state, the rate of water movement in the soil decreases rapidly. The water movement in the soil drier than field capacity controls the distance in the soil from which roots can extract water. Thus, under the conditions where the water extracted by roots is not frequently replaced by rain or irrigation, it is important that the root system must expand continuously or else have already occupied a large enough volume of soil to provide the plant with sufficient water to replace the transpiration losses. Hence, all the factors which affect root growth or the occupation by roots of a large enough soil volume, will also affect the absorption of water by plants.

The actual entry of water into the roots is affected by the extent of the absorbing zone of the roots, the permeability of the root cortex to water movement and the water potential at the root surface. The movement of water through the root and conducting elements of the laves xylem to the leaves is initiated and largely controlled by the transpiration from the leaves in response to the water potential gradient extending from the soil water, through the plant to the atmosphere. The water moves from the xylem strands of the leaf across the mesophyll tissue and through the cell walls bordering the sub-stomatal cavities where the liquid vapourizes and diffuses out of the leaves through the stomatal openings. Transpiration, though an energy-controlled process, is modified by the soil, plant and atmospheric factors which govern the potential gradients in the various parts of the water path to the leaf surface.

Moisture stress and plant response

As mentioned previously, plant-water relations consist of a group of interrelated and interdependent processes. Thus, the internal water balance or degree of turgidity of a plant depends on the relative rates of water absorption and water loss, and is affected by the complex of atmospheric, soil and plant factors that modify the rates of absorption and transpiration.

Water moves in response to a potential gradient. When the plant roots are in equilibrium with the soil water potential, and the soil water potential gradients are near zero, a base level of leaf turgor or plant water potential is reached. Under the conditions of low evaporation demand during the night and early morning (prior to sunrise) the values of water potential are often at or near this level. An increase in the rate of transpiration, coincident with the increase in evaporation, during the day, causes a decrease in the turgor pressure of the upper leaves and the development of water potential gradients through the plant from the evaporating surface of the leaves to the absorbing surface of the roots. Conditions are often such that the rate of water loss exceeds the rate of water absorption, causing an internal water deficit to develop in the plant. It is this internal water deficit, through its influence on many of the physiological processes in the plant that is directly responsible for the growth and yield of a crop under the prevailing conditions.

The yield of a crop is the integrated result of a number of physiological processes. Water stress can after photosynthesis and respiration. It can also affect growth and reproduction. Reduction in leaf area, cell size and inter-cellular volume are common under water stress. Dehydration of protoplasm may be responsible for decreasing several physiological processes. Water stress produces important changes in carbohydrate and nitrogen metabolism of plants. Water stress at certain critical stages of plant growth causes more injury than at other stages. For example, irrigation at the crown root initiation stage has been shown to be essential for increased yield of wheat crop.

Moisture extraction pattern

The moisture extraction pattern reveals about how the moisture is extracted and how much quantity is extracted at different depth level in the root zone. The moisture extraction patter shows the relative amount of moisture extracted from different depths within the crop root zone.

The moisture extraction pattern of plant growing in a uniform soil without a restrictive layer and with adequate supply of available soil moisture throughout the zone is shown in figure.

It is seen from the figure that about 40% of the total moisture is extracted form the first quarter of the root zone, 30% form second quarter, 20% from the third quarter and 10% from last further quarter.

This indicates that in most of the crops the effective root zone will be available in the 1st quarter and it does not mean that the last quarter will not need any water. Hence soil moisture measurements at different depths in the root zone has to be taken.

a) To estimate the soil moisture status and
b) To work out the irrigation quantity to be applied

Rooting characteristics and moisture extraction pattern

The root system is extremely variable in different crop plants.

The variability exists in rooting depth, root length and horizontal distribution of roots. These are further influenced by environmental factors and the genetic constitution.

The roots of cereals apparently occupy more surface area of the soil then other crops. For example, it has been proved that cereals' roots extend to 200-400 cm m^2 of soil surface area as against 15-200 cm m^2 for most graminaceous plants.

The amount of soil moisture that is available to the plant is determined by the moisture characteristics of the soil depth and the density of the roots. The moisture characteristics of soil like FC and PWP cannot be altered so easily and greater possibilities lie in changing the rooting characteristics of plants system to go deeper and denser and more proliferation to tap water from deeper layers of soil as well as from the larger surface area.

Plants vary genetically in their rooting characteristics (Figure) Vegetable crops like onion, potato, carrot etc., have very sparse rooting system and unable to use all the soil water in the root.

Rice, Grasses, sorghum, maize, sugarcane have very fibrous dense root system which can extract much water from soil. Millets, groundnut, grams are moderately deep rooted.

Maize, sorghum, lucerne, cotton and perennial plants have deep root system and can utilize effectively the moisture stored in root zone as well as in the unexploited deeper zones. Crops which have dense and deep root system like cotton, sorghum, red gram tolerate high reduction of soil water content. Shallow rooted crops like rice, potato, tomato tolerate low level of soil water reduction. Moderately deep rooted crops like millets, groundnut, grams tolerate medium level of soil water reduction.

The root growth of the crop plants is affected by

1. Genetic nature
2. High water table
3. Shallow nature of soil and permeability of soil layer
4. Soil fertility
5. Salt status of soil

Effective root zone depth

It is depth in which active root proliferation occurs and where maximum water absorption is taking place. It is not necessary that entire root depth should be effective.

LEC. 16. CROP WATER REQUIREMENT - POTENTIAL EVAPOTRANSPIRATION (PET) AND CONSUMPTIVE USE- FACTORS AFFECTING CROP WATER REQUIREMENT - CRITICAL STAGES – WATER REQUIREMENT OF DIFFERENT CROPS

Crop water requirement

Crop water requirement is the water required by the plants for its survival, growth, development and to produce economic parts. This requirement is applied either naturally by precipitation or artificially by irrigation. Hence the crop water requirement includes all losses like:

a) Transpiration loss through leaves (T)
b) Evaporation loss through soil surface in cropped area (E)
c) Amount of weather used by plants (WP) for its metabolic activities which is estimated as less than 1% of the total water absorption. These three components cannot be separated so easily. Hence the ET loss is taken as crop water use or crop water consumptive use.
d) Other application losses are conveyance loss, percolation loss, runoff loss, etc., (WL).
e) The water required for special purposes (WSP) like puddling operation, ploughing operation, land preparation, leaching, requirement, for the purpose of weeding, for dissolving fertilizer and chemical, etc.

Hence the water requirement is symbolically represented as:

$$WR = T + E + WP + WL + WSP$$

(The other application losses and special purposes are mostly indented for wet land cultivation. Hence for irrigated dry land crop the ET loss alone is accounted for crop water requirement).

The estimations of the water requirement of crop are one of the basic needs for crop planning on the farm and for the planning of any irrigation project.

Water requirement may be defined as the quantity of water required by a crop or diversified pattern of crop in a given period of time for its normal growth under field conditions at a place.

Water requirement includes the losses due to ET or CU and losses during the application of irrigation water and the quantity of water required for special purposes or operations such as land preparation, transplanting, leaching etc., Hence it may be formulated as follows

WR = ET or Cu + application loss + water for special needs.

It can also be stated based on “Demand” and “supply source” as follows

$$WR = IR + ER + S$$

Where,

IR	-	Irrigation requirement
ER	-	Effective rainfall
S	-	Contribution from ground water table.

Hence the idea about crop water requirement is essential for farm planning with respect to total quantity of water needed and its efficient use for various cropping schemes of the farm or project area. This crop water requirement is also needed to decide the stream size and design the canal capacity.

The combined loss of evaporation and transpiration from a cropped field is termed as evapotranspiration which is otherwise known as consumptive use and denoted as ET and this is a part of water requirement.

$$CU = E + T + WP$$

Therefore,

$$WR = CU + WL + WSP$$

The crop water requirement can also be defined as water required meeting the evapotranspiration demand of the crop and special needs in case of wet land crop and which also includes other application losses both in the case of wet land and garden land crops. This is also known as crop water demand.

The crop water requirement varies from place to place, from crop to crop and depends on agro-ecological variation and crop characters. The following features which mainly influence the crop water requirement are:

1) Crop factors
   - a) Variety
   - b) Growth stages
   - c) Duration
   - d) Plant population
   - e) Crop growing season
2) Soil factors
   - a) Structure
   - b) Texture
   - c) Depth
   - d) Topography
   - e) Soil chemical composition
3) Climatic factors
   - a) Temperature
   - b) Sunshine hours
   - c) Relative humidity
   - d) Wind velocity
   - e) Rainfall
4) Agronomic management factors
   - a) Irrigation methods used
   - b) Frequency of irrigation and its efficiency
   - c) Tillage and other cultural operations like weeding, mulching etc / intercropping etc

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

Irrigation requirement

The field irrigation requirement of crops refers to water requirement of crops exclusive of effective rainfall and contribution from soil profile and it may be given as follows

$$IR \quad - \quad WR – (ER + S)$$

IR	-	Irrigation requirement
WR	-	Water requirement
ER	-	Effective rainfall
S	-	Soil moisture contribution

Irrigation requirement depends upon the

a) Irrigation need of individual crop based on area of crop
b) Losses in the farm water distribution system etc.

All the quantities are usually expressed in terms of water depth per unit of land area (ha/cm) or unit of depth (cm).

Net irrigation requirement

It is the actual quantity of water required in terms of depth to bring the soil to field capacity level to meet the ET demand of the crop.

It is the water applied by irrigation alone in terms of depth to bring the field to field capacity level. To work out the net irrigation requirement, ground water contribution and other gains in soil moisture are to be excluded. It is the amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity, which in turn meet the ET effective root zone to field capacity, which in turn meet the ET demand of the crop. It is the difference between the F.C and the soil moisture content in the root zone before starting irrigation.

$$d = \sum_{i=i}^{n} \frac{Mfci - Mbi}{100} \times A_i \times D_i$$

d	=	Net irrigation water to be applied (cm)
Mfci	=	FC in i^{th} layer (%)
Mbi	=	Moisture content before irrigation in i^{th} layer (%)
Ai	=	Bulk density (g/cc)
Di	=	depth (cm)
n	=	number of soil layer

Gross irrigation requirement

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

$$\text{Gross irrigation} = \frac{\text{Net irrigation requirement}}{\text{Field efficiency of system}} \times 100$$

Irrigation frequency

Irrigation frequency is the interval between two consecutive irrigations during crop periods. Irrigation frequency is the number of days between irrigation during crop periods without rainfall. It depends upon the rate of uptake of water by plants and soil moisture supply capacity to plant and soil moisture available in the root zone. Hence it is a function of crop, soil and climate. Normally, irrigation should be given at about 50 per cent and not over 60 per cent depletion of the available moisture from the effective root zone in which most of the roots are concentrated.

In designing irrigation system the irrigation frequency to be used, is the time (days) between two irrigation in the period of highest consumptive use of crop growth, i.e. peak consumptive use of crop.

Design frequency (days)

$$= \frac{\text{F C – moisture content of the root zone prior to starting irrigation}}{\text{Peak period consumptive use rate of crop}}$$

Irrigation period

Irrigation period is the number of days that can be allowed for applying one irrigation to a given design area during peak consumptive use period of the crop

Irrigation period

$$= \frac{\text{Net amount of moisture in soil at start of irrigation (FC-PWP)}}{\text{Peak period consumptive use of the crop}}$$

Critical stages for irrigation:

The stage at which the water stress causes severe yield reduction is also known as **critical stage of water requirement**. It is also known as **moisture sensitive period**. Moisture stress due to restricted supply of water during the moisture sensitive period or critical stage will irrevocably reduce the yield. Provision of adequate water and fertilizer at other growth stage will not even help in recovering the yield loss due to stress at critical periods.

It general the mid season stage is most sensitive to water shortage because the shortage during this period will be reflected significantly on yield. For most of the crops the least sensitive stages are ripening and harvesting except for vegetables like Lettuce, Cabbage etc., which need water upto harvesting.

Under scarce condition, in an irrigation project or in a farm, if mono cropping is followed with staggered sowing or planting, it is better to schedule irrigation to crop which has reached mid season stage since it is the most critical stage.

The sensitive stages vary from crop to crop as given below.

Sensitive stage of different crops cereals and millets

Crop	-	Critical stages / Sensitive stages
Rice	-	Panicle initiation critical staps. heading and flowering
Sorghum	-	Flowering and grain formation
Maize	-	Just prior to tasseling and grain filling
Cumbu	-	Heading and flowering
Ragi	-	Primordial initiation and flowering
Wheat	-	Crown root initiation, tillering and booting

Oil seeds		
Groundnut	-	Flowering peg initiation and penetration and pod development
Sesame	-	Blooming to maturity
Sunflower	-	Two weeks before and after flowering
Soybean	-	Blooming and seed formation
Safflower	-	From rosette to flowering
Castor	-	Full growing period
Cash crop		
Cotton	-	Flowering and Boll formation
Sugarcane	-	Maximum vegetative stage
Tobacco	-	Immediately after transplanting
Vegetables		
Onion	-	Bulb formation to maturity
Tomato	-	Flowering and fruit setting
Chillies	-	Flowering
Cabbage	-	Head formation to maturity
Legumes		
Alfalfa	-	Immediately after cutting for hay crop and flowering for seed crop
Beans	-	Flowering and pod setting
Peas	-	Flowering and pod formation
Others		
Coconut	-	Nursery stage root enlargement
Potato	-	Tuber initiation and maturity
Banana	-	Throughout the growth
Citrus	-	Flowering, fruit setting and enlargement
Mango	-	Flowering
Coffee	-	Flowering and fruit development

At critical stages, favourable water level should be ensured through timely irrigations

Water requirement for different crops: *Irrigation schedules for field crops*

Rice

Total water requirement is 1100-1250

The daily consumptive use of rice varies from 6-10 mm and total water is ranges from 1100 to 1250 mm depending upon the agro climatic situation. Of the total water required for the crop, 3% or 40 mm is used for the nursery, 16% or 200 mm for the land preparation i.e. puddling and 81% or 1000 mm for field irrigation of the crop.

The growth of rice plant in relation to water management can be divided into four periods viz.,. Seedling, vegetative, reproductive and ripening. Less water is consumed during seedling stage. At the time of transplanting, shallow depth of 2 cm is adequate and maintained upto 7 days and there after 5 cm of submergence is necessary to facilitate development of new roots. The same water level is required for tiller production during the vegetative phase. At the beginning of the maximum tillering stage the entire water in the field can be drained and left as such for one or two days which is termed as mid season drainage. This mid season drainage may improve the respiratory functions of the roots, stimulate vigorous growth of roots and checks the development of non-effective tillers. Any stress during the vegetative phase may affect the root growth and reduce the leaf area.

During flowering phase 5 cm submergence should be maintained because it is a critical stage of water requirement. Stress during this phase will impair all yield components and cause severe reduction in yield. Excess water than 5 cm is also not necessary especially at booting stage which may lead to delay in heading.

Water requirement during ripening phase is less and water is not necessary after yellow ripening. Water can be gradually drained from the field 15-21 days ahead of harvest of crop. Whenever 5 cm submergence is recommended the irrigation management may be done by irrigating to 5 cm submergence at saturation or one or two days after the disappearance of ponded water. This will result in 30% saving of irrigation water compared to the continuous submergence.

Groundnut

Total water requirement 500-550 mm

Evapotranspiration is low during the first 35 days after sowing and last 35 days before harvest and reaches a peak requirement between peg penetration and pod development stages. After the sowing irrigation the second irrigation can be scheduled 25 days after sowing i.e. 4 or 6 days after first hand hoeing and thereafter irrigation interval of 15 days is maintained upto peak flowering. During the critical stages the interval may be 7 or 10 days depending upon the soil and climate. During maturity period the interval is 15 days.

Finger millet

Total water requirement: 350 mm

Finger millet is a drought tolerant crop. Pre-planting irrigation at 7 or 8 cm is given. Third day after transplantation life irrigation with small quantity of water is sufficient for uniform establishment. Water is then withheld for 10-15 days after the establishment of seedling for healthy and vigorous growth. Subsequently three irrigations are essential at primordial initiation, flowering and grain filling stages.

Sugarcane

Total water requirement: 1800-2200 mm

Formative phase (120 days from planting) is the critical period for water demand. To ensure uniform emergence and optimum number of tillers per unit area lesser quantity of water at more frequencies is preferable. The response for applied water is more during this critical phase during which the crop needs higher quantity of water comparing, the other two phases. Water requirement, number of irrigations etc., are higher during this period. As there is no secondary thickening of stem, elongation of stem as sink for storage of sugar it is desirable to maintain optimum level of moisture during grand growth period. Response for water is less in this stage and this will be still less in the ripening stage. During the ripening phase as harvest time approaches soil moisture content should be allowed to decrease gradually so that growth of cane is checked and sucrose content is increased.

Maize

Total water requirement: 500 – 600 mm

The water requirement of maize is higher but it is very efficient in water use. Growth stages of maize crop are sowing, four leaf stage, knee high, grand growth, tasseling, silking early dough and late dough stages. Crop uniformly requires water in all these stages. Of this, tasseling, silking and early dough stages are critical periods.

Cotton

Total water requirement: 550 – 600 mm

Cotton is sensitive to soil moisture conditions. Little water is used by plant with early part of the season and more water is lost through evaporation than transpiration. As the plant grows, the use of water increases from 3 mm / day reaching a peak of 10 mm a day when the plant is loaded with flowers and boll. Water used during the emergence and early plant growth is only 10% of the total requirement. Ample moisture during flowering and boll development stages is essential. In the early stage as well as at the end the crop requires less water. water requirement remains high till the boll development stage. If excess water is given in the stages other than critical stages it encourages the vegetative growth because it is a indeterminate plant thereby boll setting may be decreased. Irrigation is continued until the first boll of the last flush opens, and then irrigation is stopped.

Sorghum

Total water requirement: 350-500 mm

The critical periods of water requirement are booting, flowering and dough stages. The crop will be irrigated immediately after sowing. Next irritation is given 15 days sowing to encourage development of a strong secondary root system. irrigation prior to heading and ten days after heading are essential for successful crop production.

Pulses

Total water requirement – 200-450 mm

Mostly the pulse are grown under rainfed condition. Some pulse crops like Redgram, Blackgram, Greengram are grown in summer season as irrigated crop which need 3 to 4 irrigation at critical stags like germination, flowering and pod formation.

Water requirement of crops

S.No.	Corps	Duration in days	Water requirement (mm)	No. of irrigations
1.	Rice	135	1250	18
2.	Groundnut	105	550	10
3.	Sorghum	100	350	6
4.	Maize	110	500	8
5.	Sugarcane	365	2000	24
6.	Ragi	100	350	6
7.	Cotton	165	550	11
8.	Pulses	65	350	4

Lec 17. MID -TERM EXAMINATION

LEC. 18 & 19. METHODS OF IRRIGATION - SUITABILITY, ADVANTAGES AND LIMITATIONS

Water application methods are grouped as:

1. Flooding
2. Applying it beneath the soil surface
3. Spraying it under pressure
4. Applying in drops

Irrigation methods

I. Surface
II. Sub-surface
III. Pressurized irrigation

Surface is grouped as Border, Check basin and Furrow irrigations. Border is again classified in to two as straight and contour. Check basins may be of rectangular, contour or ring, whereas furrow irrigation is classified as deep furrow and corrugated furrows. These may be again straight or contour according to direction and leveled and graded as per their elevation

I. Surface irrigation

1. Border irrigation

- The land is divided into number of long parallel strips called borders.
- These borders are separated by low ridges.
- The border strip has a uniform gentle slope in the direction of irrigation.
- Each strip is irrigated independently by turning the water in the upper end.
- The water spreads and flows down the strip in a sheet confined by the border ridges.

Suitability : To soils having moderately low to moderately high infiltration rates. It is not used in coarse sandy soils that have very high infiltration rates and also in heavy soils having very low infiltration rate. Suitable to irrigate all close growing crops like wheat, barley, fodder crops and legumes and not suitable for rice.

Advantages

1. Border ridges can be constructed with simple farm implements like bullock drawn "A" frame ridger or bund former.
2. Labour requirement in irrigation is reduced as compared to conventional check basin method.
3. Uniform distribution of water and high water application efficiencies are possible.
4. Large irrigation streams can be efficiently used.
5. Adequate surface drainage is provided if outlets are available.

Width of border strip: It varies from 3-15 m

Border length

Slope	Soil	Length
0.25 - 0.60%	Sandy and sandy loam	60-120 m
0.20 - 0.40%	Medium loam soil	100-180 m
0.05 – 0.20%	Clay loam and clay soil	150-300 m

2. Check basin irrigation

- It is the most common method.
- Here the field is divided into smaller unit areas so that each has a nearly level surface.
- Bunds or ridges are constructed around the area forming basins within which the irrigation water can be controlled.

- The water applied to a desired depth can be retained until it infiltrates into the soil.
- The size of the basin varies from $10m^2$ to $25\ m^2$ depending upon soil type , topography, stream size and crop.

Adaptability

- ✓ Small gentle and uniform land slopes
- ✓ Soils having moderate to slow infiltration rates.
- ✓ Adapted to grain and fodder crops in heavy soils.
- ✓ Suitable to permeable soils.

Advantages

1. Check basins are useful when leaching is required to remove salts from the soil profile.
2. Rainfall can be conserved and soil erosion is reduced by retaining large part of rain
3. High water application and distribution efficiency.

Limitations

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

Furrow irrigation

- ⇒ Used in the irrigation of row crops.
- ⇒ The furrows are formed between crop rows.
- ⇒ The dimension of furrows depend on the crop grown, equipment used and soil type.
- ⇒ Water is applied by small running streams in furrows between the crop rows.
- ⇒ Water infiltrates into soil and spreads laterally to wet the area between the furrows.
- ⇒ In heavy soils furrows can be used to dispose the excess water.

Adaptability

1. Wide spaced row crops including vegetables.
2. Suitable for maize, sorghum, sugarcane, cotton, tobacco, groundnut, potatoes
3. Suitable to most soils except sand.

Advantages

1. Water in furrows contacts only one half to one fifth of the land surface.
2. Labour requirement for land preparation and irrigation is reduced.
3. Compared to check basins there is less wastage of land in field ditches.

Types of furrow irrigation

Based on alignment of furrows : 1. Straight furrows 2. Contour furrows
Based on size and spacing : 1. Deep furrows 2. Corrugations

Based on irrigation:

A. **All furrow irrigation:** Water is applied evenly in all the furrows and are called furrow system or uniform furrow system.
B. **Alternate furrow irrigation:** It is not an irrigation layout but a technique for water saving. Water is applied in alternate furrows for eg. During first irrigation if the even numbers of furrows are irrigated, during next irrigation, the odd number of furrows will be irrigated.

C. **Skip furrow irrigation:** They are normally adopted during the period of water scarcity and to accommodate intercrops. In the skip furrow irrigation, a set of furrows are completely skipped out from irrigation permanently. The skipped furrow will be utilized for raising intercrop. The system ensures water saving of 30-35 per cent. By this method, the available water is economically used without much field reduction.

D. **Surge irrigation:** Surge irrigation is the application of water in to the furrows intermittently in a series of relatively short ON and OFF times of irrigation cycle. It has been found that intermittent application of water reduces the infiltration tare over surges thereby the water front advances quickly. Hence, reduced net irrigation water requirement. This also results in more uniform soil moisture distribution and storage in the crop root zone compared to continuous flow. The irrigation efficiency is in between 85 and 90%.

II. Sub-surface irrigation

- In subsurface irrigation, water is applied beneath the ground by creating and maintaining an artificial water table at some depth, usually 30-75 cm below the ground surface.
- Moisture moves upwards towards the land surface through capillary action
- Water is applied through underground field trenches laid 15-30 m apart.
- Open ditches are preferred because they are relatively cheaper and suitable to all types of soil.
- The irrigation water should be of good quality to prevent soil salinity.

Advantages

1. Minimum water requirement for raising crops
2. Minimum evaporation and deep percolation losses
3. No wastage of land
7. No interference to movement of farm machinery
8. Cultivation operations can be carried out without concern for the irrigation period.

Disadvantages

1. Requires a special combination of natural conditions.
2. There is danger of water logging
3. Possibility of choking of the pipes lay underground.
4. High cost.

DRIP IRRIGATION SYSTEM

- Drip or trickle irrigation is one of the latest methods of irrigation.
- It is suitable for water scarcity and salt affected soils.
- Water is applied in the root zone of the crop

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

(Major inorganic salts, hardeners, suspended solids, total dissolved solids, biological oxygen demand, chemical oxygen demand, organic, and organic matter, micro-organisms, iron, dissolved oxygen, H2S, iron bacteria, sulphur reducing bacteria etc have to be tested)

Components

- A drip irrigation system consists of a pump or overhead tank, main line, sub-mains, laterals and emitters.
- The mainline delivers water to the sub-mains and the sub-mains into the laterals.
- The emitters which are attached to the laterals distribute water for irrigation.

- The mains, sub-mains and laterals are usually made of black PVC (poly vinyl chloride) tubing. The emitters are also made of PVC material
- The other components include pressure regulator, filters, valves, water meter, fertilizer application components, etc.,

Pump

The pump creates the pressure necessary to force water through the components of the system including the fertilizer tank, filter unit, mainline, lateral and the emitters and drippers. Centrifugal pump operated by engines or electric motors are commonly used. The laterals may be designed to operate under pressures as low as 0.15 to 0.2 kg/cm^2 and as large as 1 to 1.75 kg/cm^2. The water coming out of the emitters is almost at atmospheric pressure.

Chemical tank

A tank may be provided at the head of the drip irrigation systems for applying fertilizers, herbicides and other chemicals in solution directly to the field along with irrigation water.

Filter

It is an essential part of drip irrigation system. It prevents the blockage of pipes and drippers/emitters. The filter system consists of valves and a pressure gauge for regulation and control.

Emitters

Drip nozzles commonly called drippers or emitters are provided at regular intervals on the laterals. They allow water to emit at very low rates usually in trickles. The amount of water dripping out of each emitters in a unit time will depend mainly upon the pressure and size of the opening. The discharge rate of emitters usually ranges from 2 to 10 litres per hour.

Micro-tubes are also used in a drip lateral. They are used mainly in the following ways (1) as emitters (2) as connectors, (3) as pressure regulators

Advantages

1. Water saving - losses due to deep percolation, surface runoff and transmission are avoided. Evaporation losses occurring in sprinkler irrigation do not occur in drip irrigation.
2. Uniform water distribution
3. Application rates can be adjusted by using different size of drippers
4. Suitable for wide spaced row crops, particularly coconut and other horticultural tree crops
5. Soil erosion is reduced
6. Better weed control
7. Land saving
8. Less labour cost

Disadvantages

1. High initial cost
2. Drippers are susceptible to blockage
3. Interferes with farm operations and movement of implements and machineries
4. Frequent maintenance
5. Trees grown may develop shallow confined root zones resulting in poor anchorage.

LAYOUT OF SPRINKLER IRRIGATION SYSTEM

- The sprinkler (overhead or pressure) irrigation system conveys water to the field through pipes (aluminium or PVC) under pressure with a system of nozzles.
- This system is designed to distribute the required depth of water uniformly, which is not possible in surface irrigation.
- Water is applied at a rate less than the infiltration rate of the soil hence the runoff from irrigation is avoided.

A sprinkler system usually consists of the following parts.

1. A pumping unit
2. Debris removal equipment
3. Pressure gauge / water-meter
4. Pipelines (mains – sub-mains and laterals)
5. Couplers
6. Raiser pipes
7. Sprinklers
8. Other accessories such as valves, bends, plugs, etc.

Pumping unit

A high speed centrifugal or turbine pump can be installed for operating the system for individual farm holdings. The pumping plants usually consist of a centrifugal or a turbine type pump, a driving unit, a suction line and a foot valve.

Pipe lines

Pipelines are generally of two types. They are main and lateral. Main pipelines carry water from the pumping plant to many parts of the field. In some cases sub main lines are provided to take water from the mains to laterals. The lateral pipelines carry the water from the main or sub main pipe to the sprinklers. The pipelines may be either permanent, semi permanent or portable.

Couplers

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

Sprinklers

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

Other accessories / fittings

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

Types of sprinkler system

On the basis of arrangement for spraying irrigation water

1. Rotating head (or) revolving sprinkler system
2. Perforated pipe system

Based on the portability

1. Portable system: It has portable mainlines and laterals and a portable pumping unit

2. Semi portable system: A semi portable system is similar to a fully portable system except that the location of the water source and pumping plant are fixed.

3. Semi permanent system: A semi permanent system has portable lateral lines, permanent main lines and sub mains and a stationery water source and pumping plant. The mainlines and sub-mains are usually buried, with risers for nozzles located at suitable intervals.

4. Solid set system: A solid set system has enough laterals to eliminate their movement. The laterals are placed in the field early in the crop season and remain for the season.

5. Permanent system: It consists of permanently laid mains, sub-mains and laterals and a stationary water source and pumping plant. Mains, sub-mains and laterals are usually buried below plough depth. Sprinklers are permanently located on each riser.

Advantages

1. Water saving to an extent of 35-40% compared to surface irrigation methods.
2. Saving in fertilizers - even distribution and avoids wastage.
3. Suitable for undulating topography (sloppy lands)
4. Reduces erosion
5. Suitable for coarse textured soils (sandy soils)
6. Frost control - protect crops against frost and high temperature
7. Drainage problems eliminated
8. Saving in land
9. Fertilisers and other chemicals can be applied through irrigation water

Disadvantages

1. High initial cost
2. Efficiency is affected by wind
3. Higher evaporation losses in spraying water
4. Not suitable for tall crops like sugarcane
5. Not suitable for heavy clay soils
6. Poor quality water can not be used (Sensitivity of crop to saline water and clogging of nozzles)

Steps to be taken for reducing the salt deposits on leaves and fruits during sprinkler irrigation

- Irrigate at night
- Increase the speed of the sprinkler rotation
- Decrease the frequency of irrigation

LEC. 20. WATER BUDGETING AND ITS IMPORTANCE - IRRIGATION SCHEDULING - APPROACHES

Water budgeting:

Allocation of the water receipt including anticipated within the crop period and its detailed account of expenditure for efficient and profitable farm management is called as water budgeting.

Water budgeting may be for an irrigation system planned by irrigation engineers; may be for a canal or for an area (block) or may be for a farm according to the need and plan by responsible persons who plan the irrigation efficiency.

Importance of water budgeting:

- Efficient utilization of available recourse (water) for bringing more area under irrigation.
- To increase the productivity of a region / farm.
- To increase cropping intensity of a region / farm
- To tide over some dry-spells
- To reduce excess irrigation and losses caused thereby
- To avoid run off losses

Irrigation scheduling

Irrigation scheduling is defined as frequency with which water is to be applied based on needs of the crop and nature of the soil.

Irrigation scheduling is nothing but number of irrigations and their frequency required to meet the crop water requirement.

Irrigation scheduling may be defined as scientific management techniques of allocating irrigation water based on the individual crop water requirement (ETc) under different soil and climatic condition, with an aim to achieve maximum crop production per unit of water applied over a unit area in unit time.

Based on the above definition, the concept made is.

"If we provide irrigation facility the agricultural production and productivity will go up automatically"

Irrigation scheduling is a decision making process repeated many times in each year involving when to irrigate and how much of water to apply? Both criteria influence the quantity and quality of the crop. It indicates how much of irrigation water to be used and how often it has to be given.

Effect of application of right amount and excess amount of water

Excess irrigation is harmful because

a) It wastes water below root zone
b) It results in loss of fertilizer nutrients
c) It causes water stagnation and salinity
d) It causes poor aeration
e) Ultimately it damages the crops

However, Irrigation scheduling has its own meaning and importance according to the nature of the work.

For irrigation Engineers

Irrigation scheduling is important to cover more area with available quantity of water or to satisfy the whole command from head to tail reach in the canal or river system.

For soil scientists

It is important that the field should not be over irrigated or under irrigated as both will spoil the chemical and physical equilibrium of the soil.

For Agronomists

It is very much important to get higher yield per unit quantity of water in normal situations and to protect the crop to get as much as possible yield under drought situation by means on supplying water in optimum ratio and minimizing all field losses.

Importance of irrigation scheduling

How much and how often water has to be given depends on the irrigation requirement of the crop.

Irrigation requirement (IR) = Crop water requirement (CWR) – Effective rainfall (ERF)

It can be expressed either in mm/day/ or mm/month

If the crop water requirement of a particular crop is 6 mm per day, it means every day we have to give 6 mm of water to the crop. Practically it is not possible since it is time consuming and laborious. Hence, it is necessary to schedule the water supply by means of some time intervals and quantity. For example the water requirement of 6 mm/day can be scheduled as 24 mm/for every 4 days or 30 mm/for every 5 days or 36 mm/for every 6 days depending upon the soil type and climatic conditions prevailing in that particular place. While doing so we must be very cautions that the interval should not allow the crop to suffer for want of water.

Practical considerations in irrigation scheduling

Before scheduling irrigation in a farm or field or a command, the following criteria should be taken care for efficient scheduling

1. Crop factors

a) Sensitiveness to water shortage
b) Critical stages of the crop
c) Rooting depth
d) Economic value of the crop

2. Water delivery system

a) Canal irrigation or tank irrigation (It is a public distribution system where scheduling is arranged based on the decision made by public based on the resource availability).
b) Well irrigation (individual decision is final)

3. Types of soil

a) Sandy – needs short frequency of irrigation and less quantity of water
b) Clay – needs long frequency of irrigation and more quantity of water

4. Salinity hazard

To maintain favorable salt balance, excess water application may be required rather than ET requirement of the crop to leach the excess salt through deep percolation

5. Irrigation methods

a) Basin method allows more infiltration through more wetting surface which in turn needs more water and long interval in irrigation frequency
b) Furrow method allows less infiltration due to less wetting surface which needs less water and short interval in irrigation frequency.
c) Sprinkler method needs less water and more frequency
d) Drip method needs less water and more frequency

6. Irrigation interval

The extension of irrigation interval does not always save water. The interval has to be optimized based on the agroclimatic situation.

7. Minimum spreadable depth

We cannot reduce the depth based on the water requirement of the crop alone. The depth should be fixed based on the soil type, rooting nature of the crop and irrigation method followed. The minimum depth should be so as to achieve uniformity of application and to get uniform distribution over the entire field.

Theoretical approaches of irrigation scheduling

I Direct approach

a) Depth interval and yield approach
b) Soil moisture deficit and optimum moisture regime approach
c) Sensitive crop approach
d) Plant observation method

II Indirect or predictive approach

a) Critical stage or Phenological stage approach
b) Meteorological or climatological approach

III Mathematical approach

a) Estimation method approach
b) Simple calculation method

IV system as a whole approach

a) Rotational water supply schedule

I. Direct approach

A) Depth interval and yield approach

In this method, different depths of irrigation water at different time intervals fixed arbitrarily are tried without considering the soil and weather characters.

The irrigation treatment which gives the maximum yield with minimum depth and extended interval is chosen as the best irrigation schedule. Earlier workers have adopted this practice to work out the duty of water for different crops in many irrigation projects. It is the rough irrigation schedule. Hence may irrigation projects which have adopted this practice have failed to achieve the full efficiency?

Disadvantages

- Rainfall is not taken into account
- Ground water contribution is not taken into account
- Soil parameters are not taken for calculating irrigation requirement and hence this approach is not in use.

B) Soil moisture deficit and optimum moisture regime approach

This approach considers soil moisture content in the root zone of the crop for fixing the schedule. When the soil moisture reaches a pre fixed value, may be 40% of Available Soil Moisture (ASM) or 50% ASM or 60% ASM, irrigation is given. The degree of depletion is measured through percentage of availability by using gravimetric, tensiometer, resistance block, neutron probe, etc.,

Disadvantages

- Soil moisture alone is taken into account
- Hence it cannot be taken for all type of soil in particular region
- It varies from soil to soil

C) Sensitive crop approach

The crops which are grown for their fresh leaves or fruits are more sensitive to water shortage than the crops which are grown for their dry seeds or fruits. Based on their sensitivity the crops can be indexed as below.

Sensitivity

Low	Low to Medium	Medium to high	High
Cassava	Alfalfa	Beans	Banana
Millets	Cotton	Citrus	Cabbage
Redgram	Maize	Soybean	Fresh Green
	Groundnut	Wheat	Vegetables
			Rice
			Sugarcane
			Tomato

D) Plant observation method

Normally in field condition farmers use to adopt this practice for scheduling irrigation. The day to day changes in plant physical character like colour of the plant, erect nature of plant leaves, wilting symptoms, etc., are closely and carefully observed on the whole and not for individual plant and then time of irrigation is fixed according to the crop symptoms. It needs more skill and experience about the crop as well as local circumstances like field condition, the rainy days of that tract etc.,

Disadvantage

- No accuracy in finding the crop water need
- Sometimes sensitive symptoms are evident only after reaching almost the wilting point. So yield loss will occur.

i) Indicator plant technique

As we have seen already some crops like sunflower, tomato are highly sensitive to water stress which will show stress symptom earlier than other stress tolerating crops. Hence, to know the stress symptoms earlier such sensitive crops are planted in random in the field and based on the stress symptoms noticed in such plants, scheduling of irrigation can be made. This technique is called indicator plant technique.

ii) Micro plot technique or indicator plot technique

In this method a one cubic foot micro plot is made of with coarse textured soil to have more infiltration less water holding capacity and more evaporation than the actual main field. Normally the field soil is mixed with sand in 1:2 ratio and filled in the micro plots made in the field. The seed of the same crop and variety is grown in micro plot with all similar cultural practices as that of the main crop. The crops in micro plot show early stress symptoms than that of main field. Based on this scheduling of irrigation can be made.

II Predictive approach of indirect approach

A) Critical stage or phonological stage approach

The growth period of an annual crop can be divided into four growth stages

Initial stage : from sowing to 10% ground cover

Crop development stage	: 10 to 70% ground cover
Mid season stage	: flowering to grain setting stage
Late season stage	: ripening and harvesting stage

B) Meteorological approach

The basic principles employed with this approach are estimation of daily potential evapo-transpiration rates. Hence it requires knowledge on

a) Short term evapo-transpiration rates at various stages of plant development
b) Soil water retention characteristics
c) Permissible soil water deficit in respect to evaporative demand
d) Effective rooting depth of the crop grown

The irrigation scheduling is based on the cumulative pan evaporation and irrigation depth.

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

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

For example, for ten days cumulative pan evaporation at the rate of 10 mm per day equal to 100 mm (CPE). Irrigation depth to be given is 50 mm. Therefore IW/CPE ratio is

$$IW/CPE \quad \frac{50 \text{ mm (depth)}}{100 \text{ mm (CPE)}} = 0.5$$

Like this many ratio have to be tried and find the best yield performing rabi which can be adopted for scheduling irrigation.

The irrigation depth (IW) for different crops are fixed based on the soil and climatic condition. The ratio of IW / CPE which gives relatively best yield is fixed for each crop by experiment with different rations.

The irrigation depth (IW) divided by the ratio (R) will give the cumulative pan evaporation value at which irrigation is to be made.

For example the irrigation depth (IW) needed is 50 mm and the ratio (R) to be tried is 0.5.

Therefore the cumulative pan evaporation value needed to irrigated the field is

IW / R 50 / 0.5 = 100 mm

If the 100 mm of CPE is attained in 10 days (pan evaporation @ 10 mm per day), once in 10 days irrigation is to be given.

Advantages

Gives best correlation compared to other formulae where climatic parameters and soil parameters (depth) are considered.

Disadvantages

This approach is subject to marked influence by the selecting pan site.

For example

USWB class A open pan evaporimeter reading from June to December amounted to
130 cm when pan is sited on grass field, 150 cm when pan is sited on dry land with fetch of grass, 176 cm when pan is sited on dry land without fetch of grass

Pan readings generally over estimated ET during early stage and maturity stage

III Mathematical approach

A) Estimation method approach

It is nothing but scientific prediction mainly based on he climate and soil type. Calculated crop water need and estimated root depth are taken into account in this.

a. Soil type

Soil type are classified as follows

Sandy / shallow	-	Low depth of water and more frequency
Loamy soil	-	Moderate depth water and less frequency
Clay soil	-	More depth of water and less frequency

b. Climate

Climates are classified based on **reference ET** as follows:

Reference ET

4 – 5 mm/day – Low
6 – 7 mm/day – Medium
8 – 9 mm/day – High

Reference ET (mm/day) for different climatic zones

	Mean daily temp		
Climatic zone	15^0C Low	15 – 25^0C Medium	> 25^0C High
Desert/arid	4-6	7-8	9-10
Semiarid	4-5	6-7	8-9
Sub humid	3-4	5-6	7-8
Humid	1-2	3-4	5-6

The above table is based on the crop water needs during peak period. It is also assumed that there is no rainfall or little occurs during the growing season. Based on this method estimated irrigation schedule is given below for major field crops.

Estimated irrigation schedule for major field crops in peak periods

Intervals in days												
	Sandy				**Loamy**				**Clay**			
Climate	**1**	**2**	**3***	**Depth**	**1**	**2**	**3***	**Depth**	**1**	**2**	**3***	**Depth**
Banana	5	3	2	25	7	5	4	40	10	7	5	55
Cotton	9	6	5	40	11	8	6	55	14	10	7	70
Sorghum	8	6	4	40	11	8	6	55	14	10	7	70
G.nut	6	4	3	25	7	5	4	35	11	8	6	50
Maize	8	6	4	40	11	8	6	55	14	10	7	70
Peas	6	4	3	30	8	6	4	40	10	7	5	50
Soybean	8	6	4	40	11	8	6	55	14	10	7	70
Sugarcane	8	6	4	40	10	7	5	55	13	9	7	70
Sunflower	8	6	4	40	11	8	6	55	14	10	7	70
Wheat	8	6	4	40	11	8	6	55	14	10	7	70
Tomato	6	4	3	30	8	6	4	40	10	7	5	50

1* - Low temperature of 15^0C
2* - medium temperature of 15-25^0C
3*- high temperature of >25^0C

Adjustment in this method for Non peak periods

a) In early growth stages

The irrigation could be adjusted with little water and same frequency. But same water and less frequency are not advisable.

b) In late growth stage

Less frequency with same amount of water is advisable in this period.

c) In rainy days

The table schedule is to be adjusted when there is contribution from rainfall during crop growth period. This can be adjusted by giving longer interval (high frequency) with little water.

d) For irrigation practice and soil characteristics

For example, if a maize crop is grown on a clayey soil in a moderately warm climate, according to the table the intervals is 10 days and the depth is 70 mm per application. But based on the irrigation method practiced and soil type, the soil is unable to hold 70mm of water per application. The soil could hold only 50 mm/application. In this situation instead of giving 70 mm for every 10 days, it is possible to give 63 mm for every 9 days or 56 mm for every 8 days or 49 mm for every 7 days or 42 mm for every 6 days. The 49 mm for every 7 days is the approximate interval for local situation. Hence this method of intervals for irrigation can be adopted.

B) Simple Calculation Method

It is based on the estimated depth of irrigation application and calculated irrigation need of the crop over growing season. Hence the influence of climate especially temperature and rainfall is taken for consideration. Hence, it is more accurate than that of the estimated method.

It involves four steps

a) Estimate the net and gross irrigation depth (d) in mm.
b) Calculate the irrigation water need (mm) over total growing season
c) Calculate the number of irrigation over total growing season
d) Calculate the irrigation interval

Estimation net and gross irrigation

The net irrigation depth is calculated based on the irrigation depth. This may vary with local irrigation method and practice and soil type. If local data are not available the table given below can be used which will be approximate for most of the field crops. The root depth can be measured locally and adjusted.

Approximate net irrigation depth (mm)

	Rooting depth		
Soil type	**Shallow**	**Medium**	**Deep**
Sandy	15	30	40
Loamy	20	40	60
Clay	30	50	70

Root depth of different field crops are Given below

Shallow 30 – 60 cm

Rice, rabi, onion, potato, pineapple, cabbage.

Medium 50 – 100 cm

Banana, bean, coconut, groundnut, peas, soybean, sunflower, tobacco, tomato, cumbu, pulses

Deep 90-150 cm

Citrus, grapes, wheat, cotton, maize, wheat, sorghum, soybean

We know very well that all the water applied in the field cannot be used by the plants. There is some water loss through deep percolation, run off etc., To include this unavoidable water loss the field application efficiency (eaf) can be used. The gross irrigation depth includes the water loss through deep percolation and run off.

$$\text{Gross irrigation (d)} = \frac{100 \times \text{net irrigation depth}}{\text{Field application efficiency}}$$

$$= \frac{100 \times \text{n.d (cm)}}{\text{eaf (\%)}}$$

If reliable data for field application efficiency are not available the efficiency rate given below can be used which are more approximate.

For surface method = 60%
Sprinkler method = 75%
Drip method = 90%

According to the table, the depth is 40 mm for tomato grown on a loamy soil. If furrow irrigation is used, field application efficiency is 60% and therefore gross irrigation depth is

$$\text{Gross irrigation depth} \qquad d = \frac{100 \times 40}{60} = 67 \text{ mm}$$

b) Calculation of irrigation water need for total growing season

Tomato crop is planted in February 7th and harvested in June 30th

Water needs mm/month

February	March	April	May	June	Total
67	110	166	195	180	718

The water need is calculated based of ET value of the crop during that period

c) Calculate the number of irrigation over total growing period

$$\text{Number of irrigation} = \frac{\text{Total water need}}{\text{Depth}}$$

$$= \frac{718}{40} = 18$$

$$\textbf{d). Irrigation interval} = \frac{\text{Duration (days)}}{\text{Number of irrigation}}$$

$$= \frac{143}{18} = 7.94 = 8.0$$

Conclusion

Irrigation schedule for tomato
Net d = 40 mm
Gross d = 65 mm
Interval = 8 days

Water requirement for peak season

April	May	June	Total
166	195	180	541

Depth (d) = 40 mm

$$\text{Number of irrigation} = \frac{WR = 541}{d = 40}$$

= 13.5 approximately 14 irrigations

$$\text{Irrigation interval} = \frac{\text{Duration}}{\text{No. of irrigation}} = \frac{91 \text{ days}}{14} = 6.5 \text{ days} = 7.0$$

Water requirement for early growth period

February	March	Total
67	110	117

$$\text{No. of irrigation} = \frac{177}{40}$$

= 4.4

Approximately = 4 irrigation

$$\text{Irrigation interval} = \frac{52}{4} = 13 \text{ days interval}$$

This interval is too long and the rooting depth is also very shallow during this period. Hence adjustment can be made by reducing the irrigation depth as follows

i.e., instead of 40 mm depth 30 mm depth can be tried

$$\frac{177}{30} = 5.9 = 6 = \frac{52 \text{ days}}{6} = 8.67 = 9.0$$

9 days is irrigation interval can be adopted.

IV. System as a whole approach

A) Rotational water supply

R.W.S is one of the techniques in irrigation water distribution management. It aims at equi-distribution of irrigation water irrespective of location of the land in the command area by enforcing irrigation time schedules.

Each 10 ha block is divided into 3 to 4 sub units (irrigation groups) According to the availability of irrigation water, stabilized field channels and group-wise irrigation requirement, time schedules are evolved. The irrigation will be done strictly in accordance with the group-wise time schedules by the block committees. Within the group, the time is to be shared by the farmers themselves.

LEC. 21. WATER USE EFFICIENCY (WUE) & INDICES

An efficient irrigation system implies effective transfer of water from the source to the filed with minimum possible loss. The objective of the efficiency concept is to identify the nature of water loss and to decide the type of improvements in the system. Evaluation of performance in terms of efficiency is prerequisite for proper use of irrigation water.

1. Irrigation Efficiency

It is defined as the ratio of water output to the water input, i.e., the ratio or percentage of the irrigation water consumed by the crop of an irrigated farm, field or project to the water delivered from the source.

$$E_i = \frac{W_c}{W_r} \times 100$$

where,

E_i = irrigation efficiency (%)

W_c = irrigation water consumed by crop during its growth period in an irrigation project.

W_r = water delivered from canals during the growth period of crops.

In most irrigation projects, the irrigation efficiency ranges between 12 to 34 %.

2. Water Conveyance Efficiency

It is a measure of efficiency of water conveyance system from canal network to watercourses and field channels. It is the ratio of water delivered infields at the outlet head to that diverted into the canal system from the river or reservoir. Water losses occur in conveyance from the point of diversion till it reaches the farmer's fields which can be evaluated by water conveyance efficiency, as under:

$$E_c = \frac{W_t}{W_f} \times 100$$

where,

E_c = water conveyance efficiency, per cent

W_f= water delivered to the farm by conveyance system (at field supply channel)

W_t = water introduced into the conveyance system from the point of diversion

Water conveyance efficiency is generally low; about 21% losses occur in earthen watercourses only.

3. Water Application Efficiency

It is a measure of efficiency of water application in the field. It is the ratio of volume of water that is stored in the root zone of crops and ultimately consumed by transpiration or evaporation or both to the volume of water actually delivered at the field. Alternatively, it may be defined as the percentage of water applied that can be accounted for as increase in soil moisture in soils as occupied by the principal rooting system of the crop. It is also termed as farm efficiency as it takes into account water lost in application at the farm. We have

$$E_a = \frac{W_s}{W_f} \times 100$$

where,

E_a = water application efficiency, per cent

W_s = irrigation water stored in the root zone of farm soil

W_f = irrigation water delivered to the farm (at field supply channel)

In general, water application efficiency decreases as the amount of water during each irrigation increases. Water losses due to inefficient application of water in the field vary from 28 to 50 %. Common sources of loss of irrigation water during application are represented thus:

Rf = surface runoff from the farm
Df = deep percolation below the farm root zone soil

Neglecting evaporation losses during application, we have

$$Wf = Ws + Df + Rf$$

$$Ec = Wf - \frac{(Df + Rf)}{Wf} \times 100$$

4. Water Use Efficiency

Having conveyed water to the point of use and having applied it, the next efficiency concept of concern is the efficiency of water use. It is expressed in kg/ha cm. The proportion of water delivered and beneficially used on the project can be calculated using the following formula

$$Eu = \frac{Wu}{Wd} \times 100$$

where,

Eu = water use efficiency, per cent
Wu = water beneficially used
Wd = water delivered

Water use efficiency is also defined as (i) **crop water use efficiency and (ii) field water efficiency.**

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

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

where,

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

CWUE is otherwise called consumptive water use efficiency. It is the ratio of crop yield (Y) to the sum of the amount of water taken up and used for crop growth (G), evaporated directly from the soil surface (E) and transpired through foliage (T) or consumptive use (Cu)

$$\mathbf{CWUE = \frac{Y}{G + E + T}}$$

where,

$$\mathbf{(G + E + T) = Cu}$$

In other words ET is Cu since water used for crop growth is negligible.

$$CWUE = \frac{Y}{CU}$$

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

(b) Field Water Use Efficiency:

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

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

where,

FWUE = field water use efficiency

WR = water requirement

This is the ratio of crop yield to the amount of water used in the field (WR) including growth (G), direct evaporation from the soil surface (E), transpiration (T) and deep percolation loss (D).

$$FWUE = \frac{Y}{G + E + T + D}$$

$$G + E + T + D = WR$$

It is expressed in kg/ha/mm (or) kg/ha/cm

Deep percolation is important for rice crop. For other crops seepage is important.

Of the two indices defined, the crop water use efficiency is more of research value whereas the field water use efficiency has grater practical importance for planners and farmers.

5. Water Storage Efficiency:

It is defined as the ratio of the water stored in the root depth by irrigation to the water needed in the root depth to bring it to the field capacity. Also termed as water storage factor.

$$Es = \frac{Ws}{Ww} \times 100$$

where,

Es = water storage efficiency, per cent

Ws = water stored in the root zone during the irrigation

Ww = water needed in the root zone prior to irrigation, i.e., field capacity available moisture.

6. Water Distribution Efficiency

Expression for distribution efficiency to evaluate the extent to which the water is uniformly distributed is as follows:

$$Ed = \frac{(1-d)}{D} \times 100$$

$$= \frac{(1 - \text{Average deviation})}{\text{Average depth applied}} \times 100$$

where,

Ed = water distribution efficiency, per cent

d = average numerical deviation in depth of water stored from average depth stored during irrigation

D = average depth of water stored along the run during irrigation

A water distribution efficiency of 80% means that 10% of water was applied in excess and consequently 10% was deficient in comparison to the average depth of application.

7. Consumptive Use Efficiency

It is defined as the ratio of consumptive water use by the crop of irrigated farm or project and the irrigation water stored in the root zone of the soil on the farm or the project area. After irrigation water is stored in the soil, it may not be available for use by the crop because water may evaporate from the ground surface or continuously move downward beyond the root zone as it may happen in wide furrow spacing. The loss of water by deep penetration and by surface evaporation following irrigation is evaluated from the following expression:

$$Ecu = \frac{Wcu}{Wd} \times 100$$

where,

Ecu = consumptive use efficiency, per cent
Wcu = normal consumptive use of water
Wd = net amount of water depleted from root zone soil

Consumptive use efficiency is useful in explaining the difference in crop response from different methods of irrigation.

Exercise

1. Work out the irrigation efficiency from the following data.
   Water conveyance and delivery loss = 40%
   Deep percolation and surface runoff in farms = 30%
   Water stored in soil lost by evaporation = 20%

2. A borewell fitted with 7.5 HP motor discharges water at the rate of 12 lit/sec. Water received at the main field. Channel was measured as 8.5 lit/sec. Workout the conveyance efficiency.
3. Work out the water use efficiency for the following crops using the data given in the table.

Crop	Yield (kg/ha)	ET (mm)	WR (mm)
Rice	6,200	500	1,200
Groundnut	800	320	500
Sugarcane	110,000	1,260	2,050

LEC. 22. AGRONOMIC PRACTICES FOR USE OF PROBLEM WATER - SALINE, EFFLUENT, SEWAGE WATER

Quality of irrigation water

Whatever may be the source of irrigation water viz., river, canal, tank, open well or tube well, some soluble salts are always dissolved in it. The main soluble constituent in water are Ca, Mg, Na and K as cations and chloride, sulphate bicarbonate and carbonate as anions. However ions of other elements such as lithium, silicon, bromine, iodine, copper, cobalt, fluorine, boron, titanium, vanadium, barium, arsenic, antimony, beryllium, chromium, manganese, lead, selenium phosphate and organic matter are also present. Among the soluble constituents, calcium, sodium, sulphate, bicarbonate and boron are important in determining the quality of irrigation water and its suitability for irrigation purposes. However other factors such as soil texture, permeability, drainage, type of crop etc., are equally important in determining the suitability of irrigation water. The following are the most common problems that result from using poor quality water.

1. Salinity

If the total quantity of salts in the irrigation water is high, the salts will accumulate in the crop root zone and affect the crop growth and yield. Excess salt condition reduces uptake of water due to high concentration of soil solution.

2. Permeability

Some specific salts reduce the rate of infiltration in to the soil profile

3. Toxicity

When certain constituents of water are taken up by plans which accumulates in large quantities and results in plant toxicity and reduces yield.

4. Miscellaneous

Excessive Nitrogen in irrigation water causes excessive vegetative growth and leads to lodging and delayed crop maturity. White deposits on fruits or leaves may occur due to sprinkler irrigation with high bicarbonate water.

Classification of irrigation water quality

Quality of water	EC (m.mhos / cm)	pH	Na (%)	Cl (me/l)	SAR
Excellent	0.5	6.5 – 7.5	30	2.5	1.0
Good	0.5 – 1.5	7.5 – 8.0	30 – 60	2.5 – 5.0	1.0 – 2.0
Fair	1.5 – 3.0	8.0 – 8.5	60 – 75	5.0 – 7.5	2.0 – 4.0
Poor	3.0 – 5.0	8.5 – 9.0	75 – 90	7.5 – 10.	4.0 – 8.0
Very poor	5.0 – 6.0	9.0 – 10.	80 – 90	10.0 – 12.5	8.0 – 15.0
Unsuitable	>6.0	> 10	>90	>12.5	>15

(SAR – Sodium Adsorption ratio)

Factors affecting suitability of waters for irrigation

The suitability of particular water for irrigation is governed by the following factors.

1. Chemical composition of water (TSS, pH; CO_3, HCO_3, Cl, So_4, Ca, Mg, Na, and B)
2. Total concentration of soluble salts or salinity (EC)
3. Concentration of sodium ions, in proportion to calcium and magnesium or sodicity (SAR);
4. Trace element boron may be toxic to plant growth, if present in limits beyond permissible

5. The effect of salt on crop growth is of osmotic nature. If excessive quantities of soluble salts accumulate in the root zone the crop has extra difficult in extracting enough water from salty solution, thereby affecting the yields adversely.
6. Besides this, total salinity depends of the extent to which exchangeable sodium percentage (ESP) of soil increase as a result of adsorption of sodium from water. This increase depends on sodium percentage.
7. Soil characteristics like structure, texture, organic matter, nature of clay minerals, topography etc.
8. Plant characteristics like tolerance of plant varies with different stages of growth. The germinating and seedling stages are usually the most sensitive to salinity.
9. Climatic factors can modify plant response to salinity. Tolerance to saline water irrigation is often greater in winter than in the summer. Rainfall is the most significant factor for the leaching of salts from the plant root zone. Temperature also plays a vital role.
10. Management practices also play great role. Wherever saline water is used for irrigation, adoption of management practices which allow minimum salt accumulation in the root zone of the soil is necessary.

The primary parameters that have to be considered to ensure effective irrigation management for salt control are the water requirement of crop and quality of irrigation water. Correct irrigation should restore any soil water deficit, to control salt levels.

Points to be considered for the management and use of poor quality water

1. Application of greater amounts of organic matter such as FYM, compost etc., to the soil to improve permeability and structure.
2. Increasing the proportion of calcium, through addition of gypsum ($CaSO_4$) to the irrigation water in the channel, by keeping pebbles mixed pure gypsum bundles in the irrigation tank.
3. Mixing of good quality water with poor water in proper proportions so that both the sources of water are effectively used to maximum advantage.
4. Periodical application of organic matter and raising as well as incorporation of green manure crops in the soil.
5. Irrigating the land with small quantities of water at frequent intervals instead of large quantity at a time.
6. Application of fertilizer may be increased slightly more than the normally required and preferably ammonium sulphate for nitrogen, super phosphate and Di Ammonium Phosphate (DAP) for phosphorus application
7. Drainage facilities must be improved
8. Raising of salt tolerant crops such as cotton, ragi, sugar beet, paddy, groundnut, sorghum, corn, sunflower, chillies, tobacco, onion, tomato, garden beans, amaranthus and lucerne.

Use of poor quality water

Besides the salinity and alkalinity hazard of water, some industrial effluents and sewage water are also problem water that can be reused by proper treatment. The complex growth of industries and urbanization (Urban development) leads to massive increase in waste water in the form of sewage and effluent. Waste water supplies not only nutrient but also some toxic elements such as total solids of chloride, carbonate, bicarbonate, sulphate, sodium chromium, calcium magnesium, etc., in high concentration. Besides this the effluent or waste water creates

BOD (Bio chemical Oxygen Demand) These waste water when used for irrigation leads to surface and sub surface source of pollution due to horizontal and vertical seepage.

Projected waste-water Utilization

It is estimated that 287,000 million m^3 of waste water can be reusable during 2000 A.D. Hence this waste water can be properly treated as follows

- ❖ Dilute with good quality water in the ratio of 50:50 or 75:25
- ❖ Alternate irrigation with waste water and good quality water
- ❖ Treat the effluent water through fill and draw tanks, lime tank, equalization tank, settling tank, sludge removal tank, aerobic and anaerobic treatment tanks etc.,

WATER MANAGEMENT FOR PROBLEM SOILS

When rocks and minerals under go weathering process large quantities of soluble salts are formed. In humid regions these salts are washed down to the ground water and to the sea. But in arid and semi arid regions they accumulate in the soil. Excessive irrigation and poor water management are the two chief causes of water logging and salt accumulation. An accumulation of salts in soil leads to unfavourable soil water-air relationship and effect the crop production.

The following are the main causes which leads to development of salty soils (salinity or alkalinity)

1. Arid climate

About 25% of earth surface is arid in which salt accumulation is a common problem. In India about 25 million hectare is salt affected with different degree of degradation.

2. High subsoil water table

When the water table is with in capillary range, the water containing soluble salts rises to surface. When the water evaporates the salts are deposited as encrustation. It is estimated that in Punjab annually about 50,000 acres becomes saline because of raising water table.

3. Poor drainage

Due to poor drainage accumulation of water leads to water logging condition which leads to salt accumulation.

4. Quality of irrigation water

Irrigation water containing more than permissible quantities of soluble salts with sodium carbonate and bicarbonates make the soil salty.

5. Inundation with sea water

In coastal area, periodical inundation of land by sea water during high tides makes soil salty. Besides deep bore wells are also the reason for saline soils.

6. Nature of parent rock minerals

The saline nature of parent rock minerals leads to salt accumulation

7. Seepage form canals

The continuous seepage leads to salt accumulation.

Classification of problem soils

The soil problems can also be divided into

a) Chemical b) Physical

Soil Chemical Problem

The salt affected soils can be classified based on their ESP, pH and EC as follows

	ESP (%)	EC mhos/cm	pH
Saline	< 15	> 4	< 8.5
Saline alkali	> 15	> 4	> 8.5
Alkali/sodic	> 15	< 4	> 8.5

Reclamation of Saline soil

Leaching or flushing with good quality of water provided there will not be water logged condition i.e. good drainage system should be there to flush water.

Reclamation of Alkali soil

By converting exchangeable sodium into soluble salts by adding the following amendments.

1. Calcium chloride
2. Calcium sulphate (Gypsum)
3. Sulphuric acid
4. Ferrous sulphate
5. Aluminum sulphate

Reclamation of Saline alkali soil

The reclamation of these soils is similar to that of alkali soils. First step is to remove the exchangeable sodium and then the excess salts and sodium are to be leached out.

Commonly salt affected soils are referred as problem soils as indicated above. Further, based on pH value it can also be grouped as acid soils where the pH value is less than 7.

Management practices for chemical problems of soil

Reclamation of saline and alkali soils are not complete unless proper remedial measures are under taken to restore the soil fertility and structure of the soil. The following are the important management practices to overcome there problems.

- The saline soil can be easily improved with leaching of salts by using of god quality water and by providing good drainage systems.
- Application of gypsum would improve the permeability of soil by making good soil aggregates
- In acidic soils, lime application should be adequate and excessive leaching should be avoided
- Salt resistant or saline resistant species should be selected for cultivation
- Application of amendments viz gypsum and press mud is found to suppress the sodium and chromium content in plant and soil.
- Growing resistant crops like ragi cotton, barley and rice can be advocated.
- Growing green manure crops like sunnhemp, daincha and kolinji can be advocated.
- Growing resistant varieties like CoC 771 in sugarcane Co 43 in rice may be made.
- Adoption of drip irrigation for possible crop is also recommended to over come soil physical and chemical problems.
- Liberal application of FYM
- Application of green manure
- Excess phosphorous and application
- Proper drainage to keep the soil without adverse effect to plant systems.

Soil physical problems

Very coarse, very clayey texture, shallow depth and encrustation in soil surface are the possible physical problems. Too frequent irrigation in clayey soils with very high water retention results in poor drainage, water logging and crop damage. Excess irrigation or heavy rain create hardening of soil surface in red latritic soils with high Fe and Al hydroxides and low organic matter. This leads to poor germination, restriction of shoot and development and slow entry of water into the soil profile.

Water management practices for physical problem of soil

- In light soils shallow depth of water with more frequency should be adopted.
- To increase the infiltration rate of clay type soil, breeding of soil by mixing with coarse textured soil or tank silt at the rate of 50 tones per hectare is advocated.
- Organic wastes like crop residue, farm waste, coir pith, filter cake, etc., at the rate of 20 tones per hectare once in every year can be applied.
- Poorly drained clay soils can be improved by providing tile drains and trenches intermittently.
- To make the soil more permeable and to overcome poor drainage, addition of organic wastes or sandy soil at the rate of 20 tones per ha or 50 tones per ha respectively is advocated.
- Tank silt or heavy soil application is the only way to increase soil depth and water holding capacity. Besides growth shallow rooted crop is advisable.
- The encrustation problem could be alleviated by incorporating organic matter and adding montmorilonite clay containing silt.

LEC. 23. COMMAND AREA DEVELOPMENT- CONTINGENT CROP PLAN IN MAJOR IRRIGATION PROJECTS OF TAMIL NADU - DRAINAGE – IMPORTANCE AND METHODS

Command Area Development

Due to ill distribution, erratic and uncertain nature of rainfall over the year and variations is year to year cause management difficulties in predicting the quantity and scheduling irrigation in command areas. Irrigated agriculture plays a vital role in our food production and therefore a well regulated irrigation system is highly essential to reduce the loss of water and to increase irrigation efficiencies.

To achieve this maximum possible irrigation efficiencies, there are two approaches viz.,

1. Modernization of conveyance system down below the reservoirs upto government controlled outlet. This work involves mainly the construction and maintenance of head sluices, main canals, branch canals, and distributaries (Modernization of Supplier's Side or System Level Development Works)
2. Modernization below the government controlled outlets upto the drains. (Modernization of user's side or Farm level development works) This works are otherwise known as On-Farm Development works (OFD).

Conveyance and distribution system

Reservoir
Main canal
Branch canal
Minor
Distributory
Sluice / outlet
Field channel
Distribution boxes
Turnout
Checks

On-Farm Development Works (OFD)

On-Farm Development works include lining of field irrigation channels and infrastructural facilities like bed regulators, diversion and distribution boxes, turnouts and drop structures to regulate and convey the irrigation water from government controlled outlets to individual land holdings.

This type of work mainly aims to reduce conveyance and application losses, to minimize water logging condition and to conserve water

Thus the OFD works are more helpful in achieving the objective of the modernization of irrigation systems.

But their execution involves lot of problems due to the following reasons

- The OFD works are to be executed in the farmers fields
- The number of farmers involved are more
- The influence of Socio-economic constraints

In Tamil Nadu, the OFD works are undertaken by the State Agricultural Engineering Department

The OFD Strategy

The 10 ha. block outlets are the last government outlets having regulating shutter arrangements only at the sluices of branch canals. Each sluice serves 1 to 12 blocks through the lined distributory. The OFD works are planned duly considering the entire command area under each sluice and the irrigation problems and conflicts in each block are analysed so as to design the preventive and curative measures. The common problems prevailing in command area and the appropriate OFD measures proposed are furnished below in nutshell.

Problems

a) Absence of adequate field channel network causing wastage of irrigation in field to field irrigation.
b) Interfering with the distributory (carrying water down to other 10 ha blocks) by adjoining head reach farmers in each block.
c) Leakage and lateral seepage of water from earthen channels. Running at the edge of higher level lands causing “water logging” in the adjoining low lying fields.
d) Difficulties in irrigating the higher level fields through earthen channels at zero gradient.
e) In the locations the water need to be diverted in different wastage of land and water.
f) Earthen channels with erosive slopes
g) Structural deficiencies essential structures such as channel crossing, small culverts road crossings, with siphon arrangements etc., are to be constructed wherever necessary.

OFT measures to overcome the problems

a) Provision of proper earthen field channel net work to have earthen canal from the source upto each holding
b) Provision of higher level field channels (mostly lined) parallel to the distributory in the upper part of each block for feeding to the adjoining lands without the necessity for interfering with the distributory. By this arrangement the share of lower blocks is fully allowed without any enchroachement.
c) This problem is solved by lining such portion of the earthen channels.
d) Such earthen channels are lined at zero gradient
e) Construction of diversion boxes with leading channels in all the required directions.
f) Bed dams are constructed to stabilize the slope and drop structures are constructed at the point of sudden drop in bed levels.
g) Essential structures such as channel crossing, small culverts, road crossing, with siphon arrangements, etc. are constructed wherever necessary.

The above details are furnished just to show only some of the problems and relevant OFD measures. But the OFD works are carried out with the “systems approach” to provide engineering solutions for the problems in the command area with the objective of improving the irrigation water use efficiency.

Irrigation management under limited water supply

As any scarce resource needs management for its optimal utility. The irrigation water also needs management to obtain optimum crop production with the available water resources. Water management is practiced in two stages. (viz)

1. Water distribution management and
2. Water utilization management. The later is the crop water management at field level.

Rotational Water Supply (RWS)

RWS is one of the techniques is irrigation water distribution management. It aims at equi-distribution of irrigation water irrespective of location of the land in the command area by enforcing irrigation time schedules.

Each 10 ha. block is divided into 3 to 4 sub units (irrigation groups) According to the availability of irrigation water, stabilized field channels and group-wise irrigation requirement, time schedules are evolved. The irrigation will be done strictly in accordance with the group-wise time schedules by the block committee. Within the group, the time is to be shared by the farmers within the group by themselves.

WATER LOGGING AND FIELD DRAINAGE

For optimum growth and yield of field crops, proper balance between soil air and soil moisture is quite essential. Except rice many of the cultivated plants cannot withstand excess water in the soil. The ideal condition is that moisture and air occupy the pore spaces in equal proportions. When the soil contains excess water than that can be accommodated in the pore spaces it is said the field is water logged.

Causes of water logging

1. Excessive use of water when the water is available in abundance or cheaply due to the belief that more water contributes better yield.
2. Improper selection of irrigation methods
3. Percolation and seepage from lands canals and reservoir located at nearby elevated places
4. Improper lay out and lack of outlets
5. Presence of impervious layer with profile impeding percolation
6. Upward rise of water from shallow ground water table or aquifer.

Effects of water logging

Direct effects

Replacement of soil air which is the main source of oxygen for the roots as well as soil microbes.

Due to high amount of CO_2 in soil air high CO_2 concentration under water logged condition will kill plant roots.

Sometimes superficial root system or air space in root system will develop.

Due to poor aeration intake of water and nutrient will be reduced.

Indirect effects

Nutrients are made un-available due to leaching

Toxic elements will be formed under anaerobic condition

Composition of organic matter under anaerobic condition results in production of organic acids like butyric acid which is toxic to plants.

Reduces the availability of N, Mn, Fe, Cu, Zn, mb,

Reduces soil temperature

Reduces the activity of beneficial microbes

Destruct soil structure

Difficult for cultural operations

Incidence of pest, disease and weeds

Changes for some elements in water logged condition

Elements	Normal form	Reduced form water logged soil
Carbon	Carbon di oxide	Methane (H4) complex aldehyde
Nitrogen	Nitrate No_3	Nitrogen (N) and NH_2 amides, ammonia
Sulphur	Sulphate So_4	Hydrogen sulphide (H_2S)

Drainage

It is the process of removal of excess water as free or gravitational water from the surface and the sub surface of farm lands with a view to avoid water logging and creates favourable soil conditions for optimum plant growth.

Need for drainage

It is generally assumed that in arid region drainage is not necessary and water logging is not a problem. Even in arid region due to over irrigation and seepage from reservoirs canals etc., drainage becomes necessary.

Irrigation and drainage are complementary practices in arid region to have optimum soil water balance.

In humid region drainage is of greater necessity mainly due to heavy precipitation.

Drainage is required under the following condition

a) High water table
b) Water ponding on the surface for longer periods
c) Excessive soil moisture content above F.C, not draining easily as in clay soil
d) Areas of salinity and alkalinity where annual evaporation exceeds rainfall and capillary rise of ground water occurs
e) Humid region with continuous of intermittent heavy rainfall
f) Flat land with fine texture soil
g) Low lying flat areas surrounded by hills

Characteristics of good drainage system

1. It should be permanent
2. It must have adequate capacity to drain the area completely
3. There should be minimum interference with cultural operated
4. There should be minimum loss of cultivable area
5. It should intercept or collect water and remove it quickly within shorter period

Methods of drainage

There are two methods
1. Surface method
2. Sub surface method

Surface drainage

This is designed primarily to remove excess water from the surface of soil profile. This can be done by developing slope in the land so that excess water drains by gravity.

It is suitable for

(i) Slowly permeable clay and shallow soil
(ii) Regions of high intensity rainfall
(iii) To fields where adequate out lets are not available
(iv) The land with less than 1.5% slope

It can be made by

a) Land smoothing
b) Making field ditches

The surface drainage can be further classified as

a) Life drainage
b) Gravity drainage
c) Field surface drainage
d) Ditch drainage

Lift drainage

To drain from low lying area or areas having water due to embankment, life drainage is used. Water to be drained is lifted normally by opened devices unscoops or by pumping or by mechanical means. This method is costly, cumbersome and time consuming but effective and efficient to drain standing water over the soil surface.

Gravity drainage

Water is allowed to drain from the areas under higher elevation to lower reaches through the regulated gravity flow through the out let of various types. This system is practiced in wet land rice with gentle to moderate slope.

This method is less costly, easy and effective however the area to be drained should be leveled smooth and slightly elevated from the drainage source.

Field surface drainage

The excess water received from the rain or irrigation is drained through this method. The irrigated basins or furrows are connected with the drainage under lower elevation which is connected to the main out let and to the farm pond used for water harvesting. If the slope of the land is sufficient to drain excess water from the individual plot, this drain water may be collected and stored locally in reservoir for recycling for life saving irrigation. This drainage method is cheap and effective but there is possibility of soil erosion and distribution of weed seeds along the flow of drainage water.

Ditch drainage

Ditches of different dimension are constructed at distances to drain the excess water accumulated on the surface and inside the soil upto the depth of ditch. Such ditches may be interceptors or relief drains. This method is adopted in nurseries, seed beds and rainfed crops. This is an effective and efficient method but requires smoothening of surface and construction of ditches. This involves cost and wastage of crop lands. Shifting of soil, restriction for the movement of farm machineries reconstruction and renovation of ditches during the crop duration and harvesting of crops and the problems in this method. In flat land, bed or parallel field ditches may be constructed. The collector ditches should be across the field ditches.

Advantages	**Disadvantages**
Low initial cost	Low efficiency
Easy for inspection	Loss of cultivable land
Effective in low	Interference to cultural operation
Permeability area	High maintenance cost

Sub surface drainage system

Sub surface drains are under ground artificial channels through which excess water may flow to a suitable outlet. The purpose is to lower the ground water level below the root zone of the crop. The movement of water into sub surface drains is influenced by

1. The hydraulic conductivity of soil
2. Depth of drain below ground surface
3. The horizontal distance between individual drains

Underground drainage is mostly needed to the

Medium textured soil

High value crop

High soil productivity

The are four types of sub surface drainage

1. Tile drainage
2. Mole drainage
3. Vertical drainage
4. Well Drainage / or Drainage wells

Advantage of sub surface

1. There is no loss of cultivable land
2. No interference for field operation
3. Maintenance cost is less
4. Effectively drains sub soil and creates better soil environments

Disadvantage

1. Initial cost is high
2. It requires constant attention
3. It is effective for soils having low permeability

1. Title drainage

This consist of continuous line of tiles laid at a specific depth and grade so that the excess water enters through the tiles and flow out by gravity. Laterals collect water from soil and drain into sub main and then to main and finally to the out let. Tile drains are made with clay and concrete, Tiles should be strong enough to withstand the pressure and also resistant to erosive action of chemicals in soil water.

2. Mole drainage

Mole drains are unlined circular earthen channels formed within the soil by a mole plough. The mole plough has a long blade like shank to which a cylindical bullet nosed plug is attached known as mole. As the plough is drawn through the soil the mole forms the cavity to a set depth. Mole drainage is not effective in the loose soil since the channels produced by the mole will collapse. This is also not suitable for heavy plastic soil where mole seals the soil to the movement of water.

3. Vertical drainage

Vertical drainage is the disposal of drainage water through well into porous layers of earth. Such a layer must be capable of taking large volume of water rapidly. Such layers are found in river bed.

4. Drainage wells

The wells are used for the drainage of agricultural lands especially in irrigated areas.

Systems of drainage

There are five systems of drainage

1. Random 2. Herringbone 3. Grid iron 4. Interceptor

1. Random

This is used where the wet area are scattered and isolated from each other. The lines are laid more or less at random to drain these wet areas. The main is located in the largest natural depression while the submains and laterals extend to the individual wet areas.

2. Herring bone

In this system the main are in a narrow depression and the laterals enter the main from both side at an angle of 45^0 like the bones of a fish.

3. Gridiron

The gridiron is similar to herringbone but the laterals enter the main only from one side at right angles. It is adopted in flat regularly shaped fields. This is an efficient drainage system.

4. Interceptor

Ditches of different dimension are constructed at distance to drain the excess water accumulated on the surface and inside the soil upto the depth of ditch. Such ditches may be interceptors or relief drains. This method is adopted in nurseries, seed beds and rainfed crops. This is an effective and efficient method but requires smoothening of surface and construction of ditches. This involves cost and wastage of crop lands. Shifting of soil, restriction for the movement of farm machineries reconstruction and renovation of ditches during the crop duration and harvesting of crops are the problems in this method. In flat land, bed or parallel field ditches may be constructed. The collector ditches should be across the field ditches.

LEC 24: DRY FARMING – DEFINITION – DRY FARMING AND RAINFED FARMING - SIGNIFICANCE OF DRY FARMING IN INDIAN AGRICULTURE - INDICES OF ARIDITY.

Growing of crops entirely under rainfed conditions is known as dryland agriculture. Depending on the amount of rainfall received, dryland agriculture can he grouped into three categories;

Dry farming is cultivation of crops in regions with annual rainfall less than 750 mm. Crop failure is most common due to prolonged dry spells during the crop period. These are arid regions with a growing season (period of adequate soil moisture) less than 75 days. Moisture conservation practices are necessary for crop production.

Dryland farming is cultivation of crops in regions with annual rainfall more than 750 mm. In spite of prolonged dry spells crop failure is relatively less frequent. These are semiarid tracts with a growing period between 75 and 120 days. Moisture conservation practices are necessary for crop production. However, adequate drainage is required especially for Vertisols.

Rainfed farming is crop production in regions with annual rainfall more than 1150 mm. Crops are not subjected to soil moisture stress during the crop period. Emphasis is often on disposal of excess water. These are humid regions with growing period more than 120 days.

Dry farming and dryland farming	Rainfed agriculture
Emphasis is on soil and water conservation, sustainable crop yields and limited fertilizer use according to soil moisture availability	Emphasis is on disposal of excess water, maximum crop yield, high levels of inputs and control of water erosion

United Nations Economic and Social Commission for Asia and the Pacific distinguished dry land agriculture mainly into two categories: dryland and rainfed farming. The distinguishing features of these two types of farming are given below.

Dryland vs. rainfed farming

Constituent	Dryland farming	Rainfed farming
Rainfall (mm)	<800	>800
Moisture availability to the crop	Shortage	Enough
Growing season (days)	<200	>200
Growing regions	Arid and semiarid as well as uplands of sub-humid and humid region	Humid and sub-humid region
Cropping system	Single crop or intercropping	Intercropping or double cropping
Constraints	Wind and water erosion	Water erosion

Significance of Dry farming in Indian Agriculture:

1. About 70% of rural population lives in dry farming areas and their livelihood depend on success or failure of the crops
2. Much of the increase in food production in the recent past is estimated to be mainly due to irrigated areas. Since 1950, the extent of irrigated land in the world has increased from 94 million ha to about 220 million ha. During the 1980s, however, the rate of irrigation development has dropped materially and is presently less than 1 per cent per year, whereas the world population is increasing at 1.7 per cent per annum. Irrigated land accounts for 18

per cent of the cultivated land but produces 33 per cent of the food. The cost of irrigation and drainage development of new systems averages over $5,000 per hectare and can be as high as $10,000. Therefore, it is inevitable that in future the additional food has to come mainly from the drylands.

3. With the current pace of irrigation development, it is assumed that the gross irrigated area is likely to increase to 75 X 10^6 ha by the year 2000. This means that more than 55 per cent of the gross cropped area will continue to be farmed under rainfed conditions.
4. In India only 43 m. ha of land out of the cultivated area of 143 m. ha was irrigated by 1986-87, leaving the remaining 100 m. ha as rainfed. According to experts, even when the ultimate irrigation potential is reached, 55 per cent of the net sown area will be still, rainfed.
5. The contribution (production) of rainfed agriculture in India is about 45 per cent of the total food grain, 75 per cent of oilseeds, 90 per cent of pulses and about 70 per cent of cotton.
6. By the end of the 20th century the contribution of drylands will have to be 60 per cent if India is to provide adequate food to 1000 million people. Hence tremendous efforts both in the development and research fronts are essential to achieve this target.
7. More than 90 per cent of the area under sorghum, groundnut, and pulses is rainfed. In case of maize and chickpea, 82 to 85 per cent area is rainfed. Even 78 percent of cotton area is rainfed. In case of rapeseed/mustard, about 65.8 per cent of the area is rainfed. Interestingly, but not surprisingly, 61.7, 44.0, and 35.0 per cent area under rice, barley and wheat, respectively, is rainfed.
8. Although, India is blessed with average annual rainfall of about 1200 mm, slightly above the global mean of 990 mm, the fate of dryland crops oscillates with the quantity, onset, and progress, spatial and temporal distribution of monsoon rains. Of the mean annual rainfall, 30 per cent of the country gets less than 750 mm and 40 per cent between 750 and 1250 mm. Only 20 per cent area is blessed with rainfall between 1250 and 2000 mm, leaving about 10 per cent area with annual rainfall over 2000 mm. A critical appraisal of the existing rain water availability shows that
   - India receives 400 million hectare meters (M ha m) of rain water annually,
   - About 160 M ha m falls on agricultural land,
   - Nearly 24 M ha m is available for harvesting in small scale water harvesting structures,
   - About 186 M ha m goes to rivers as runoff, and
   - Around one-fourth of the total annual rainfall is received before or after cropping season.
9. At present, 3 ha of dryland crop produce cereal grain equivalent to that produced in one ha irrigated crop. There is scope for doubling the average yield of dryland crops. Improvements in the productivity of dryland crops are largely indiscernible. With limited scope for increasing the area under plough, only option left is to increase the productivity with the modern technology and inputs, since the per capita land availability which was 0.28 ha in 1990 is expected to decline 0.19 ha in 2010.
10. The productivity of grains already showed a plateau in irrigated agriculture due to problems related to nutrient exhaustion, salinity build up and raising water table. Therefore, the challenges of the present millennium would be to produce more from less of drylands while ensuring conservation of existing resources. Hence, new strategies would have to be evolved which would make the fragile dryland ecosystems more productive as well as sustainable. In order to achieve evergreen revolution, we shall have to make grey areas (drylands) as green through latest technological innovations.
11. Dryland offers good scope fro development of Agroforestry, Social forestry, Horti-Sylvi-pasture and such other similar systems which will not only supply food, fuel to the village

people and fodder to the cattle but forms a suitable vegetative cover for ecological maintenance.

"Intensive irrigated farming is an imperative for survival; but improved dryland agriculture is essential for equity" – Dr. Gautam, Former DG, ICAR

Development of Dry farming in India:

1920 Scarcity tract development given importance by the Royal Commission on Agriculture
1923 Establishing Dryland Research Station at Manjri(Pune) Tamhane to Kanikar 1926
1933 Research Stations established at Bijapur and Solapur
1934 Research Stations established at Hagari and Raichur
1935 Research Station established at Rohtak (Punjab)
1942 Bombay Land Development act passed
1944 Monograph on dry farming in India by N.V. Kanitkar (Bombay, Hyderabad, Madras Dry Farming Practices)
1953 Establishing Central Soil Conservation Board
1955 Dry Farming demonstration Centres started
1970 23 Research Centres established under AICRPDA
1972 Establishment of ICRISAT
1976 Establishment of Dryland Operational Research Projects
1983 Starting of 47 model watersheds under ICAR
1984 Initiation of World Bank assisted Watershed Development Programmes in four states. Establishing Dryland Development Board in Karnataka
1985 Birth of Central Research Institute for Dryland Agriculture at Hyderabad
1986 Launching of NWDPRA programmes by Government of India in 15 states.

Indices of Aridity

Aridity refers to a condition of deficiency of water due to either insufficient precipitation or excess water loss over supply. The term "arid" is derived from a Latin word, "arere" which means 'dry'.

Assessment of the degree of aridity of a place is necessary to serve as a base for the application of technology, for the interpretation of resource assessment and for transfer of technology. It also useful to analyse the climatic resources and to identify specific climatic constraints for planning agricultural development.

The degree of aridity can be assessed from climatic parameters and plant criteria. More than 50 classification of agro-climate was made by many scientists. Some important indices related to aridity are given below.

1. Thornthwaite and Mather (1955)

The classification of Thornthwaite (1948) was modified for the Moisture Index (Im) and is give below

$$Im = 100 [(P-PE)/PE]$$

Where, P = Precipitation, PE = Potential evapo-transpiration

Im Quantity	Climate classification
100 and above	Per humid
20 to 100	Humid
0 to 20	Moist sub humid
-33.3 to 0	Dry sub humid
-66.7 to -33.3	Semi arid
-100 to -66.7	Arid

2. Troll (1965)

Based on thermal and hygric variables and number of humid months, climate is classified and said to be of agricultural use. Humid month is one having mean rainfall exceeding the mean Potential evapo transpiration.

Humid months	Climate classification
12.0 to 9.5	Tropical rainforest
9.5 to 7.0	Humid Savannah
7.0 to 4.5	Dry Savannah (Wet – dry SAT)
4.5 to 2.0	Thorn Savannah (Dry SAT)
2.0 to 1.0	Semi desert (Arid)
1.0 to 0.0	Desert (Arid)

3. Papadakis (1961)

Moisture Index (H) based on precipitation, soil moisture storage and PET was developed.

$$H = [P + W] / E$$

Where

P = Monthly precipitation
E = Monthly PET
W = Water stored from previous rainfall

H value	Climate
Less than 0.25	Arid
0.25 to 0.50	Dry
0.50 to 0.75	Intermediate
0.75 to 1.00	Intermediate humid
1.00 to 2.00	Humid
More than 2.00	Wet

4. Hargreaves (1971)

Moisture Availability Index (MAI) is used for the classification. It is the ratio of dependable precipitation to potential evapo transpiration. It is a measure of adequacy of precipitation in supplying crop water demand.

$$\text{MAI} \quad \frac{\text{Dependable precipitation (75\% probable rainfall)}}{\text{Potential evapo transpiration}}$$

MAI	Climate classification
0.0 to 0.33 during all months	Very arid
More than 0.34 for 1-2 months	Arid
More than 0.34 for 3-4 consecutive months	Semi arid

5. Steiner et al (1988)

After careful consideration of several definitions, Steiner et al. (1988) consider aridity index concept of the United Nations Conference on Desertification based on the balance between precipitation (P) and evapo-transpiration (ETP) to be appropriate for wide scale adoption. According to this definition the areas with P/ETP ratio between 0.03 and 0.20 are arid and areas with the ratio between 0.2 and 0.5 are semi-arid.

6. FAO classification

Another 'influential' definition is based on 'growing period concept' of the FAO. Areas having a growing period between 1 and 74 days are classified as arid and those with a growing period between 75 and 119 days are semi-arid. (Growing period is the number of days during a year when precipitation exceeds half the potential evapotranspiration, plus a period to use an assumed 100 mm of water from excess precipitation (or less, if not available) stored in the soil profile.)

7. ICAR classification of agroclimatic zones

ICAR while establishing the dryland centers in different agroclimatic zones of the country in 1970, used the simple formula of Thornthwaite (1955) for estimating the moisture index.

Moisture Index = 100 [(P-PE)/PE]

Thornthwaite and Mathur (1955) gave only six classification while the ICAR had eight moisture indices with eight moisture belt indicating eight zones in India. The scale adopted in defining climatic zones in terms of moisture indices are;

Zone	Moisture Index	Moisture belt
1	< -80	Extremely dry
2	-60 to -80	Semi dry
3	-40 to -60	Dry
4	-20 to -40	Slightly dry
5	0 to -20	Slightly moist
6	0 to +50	Moist
7	+50 to +100	Wet
8	> +100	Extremely wet

Drought – definition, types and effect of drought on crop production

Low rainfall or failure of monsoon rains is a recurring feature in India. This has been responsible for droughts and famines. The word drought generally denotes scarcity of water in a region. Though, aridity and drought are due to insufficient water, aridity is a permanent climatic feature and is the culmination of a number of long term processes. However, drought is a temporary condition that occurs for a short period due to deficient precipitation for vegetation, river flow, water supply and human consumption. Drought is due to anomaly in atmospheric circulation.

Particulars	Aridity	Drought
Duration	Permanent feature	Temporary condition of scarcity of varying duration
Factors	Culmination of many long term processes considers all climatic features	Caused by deficient rainfall
Aspect described	Description of Climate	Description of Water availability

Definition of drought

There is no universally accepted definition for drought.

a. Early workers defined drought as prolonged period without rainfall.

b. According to Ramdas (1960) drought is a situation when the actual seasonal rainfall is deficient by more than twice the mean deviation.

c. American Meteorological Society defined drought as a period of abnormally dry weather sufficiently prolonged for lack of water to cause a severe hydrological imbalance in the area affected.

d. Prolonged deficiencies of soil moisture adversely affect crop growth indicating incidence of agricultural drought. It is the result of imbalance between soil moisture and evapo-transpiration needs of an area over a fairly long period as to cause damage to standing crops and to reduce the yields.

e. The irrigation commission of India defines drought as a situation occurring in any area where the annual rainfall is less than 75% of normal rainfall.

Classification of drought

Drought can be classified based on duration, nature of users, time of occurrence and using some specific terms. Demarcation between the classifications is not well defined and many a time overlapping of the cause and effect of one on the rest is seen.

1. Based on duration

a. Permanent drought: This is characteristic of the desert climate where sparse vegetation growing is adapted to drought and agriculture is possible only by irrigation during entire crop season.

b. Seasonal drought: This is found in climates with well defined rainy and dry seasons. Most of the arid and semiarid zones fall in this category. Duration of the crop varieties and planting dates should be such that the growing season should fall within rainy season.

c. Contingent drought: This involves an abnormal failure of rainfall. It may occur almost anywhere especially in most parts of humid or sub humid climates. It is usually, brief, irregular and generally affects only a small area.

d. Invisible drought: This can occur even when there is frequent rain in an area. When rainfall is inadequate to meet the evapo-transpiration losses, the result is borderline water deficiency in soil resulting in less than optimum yield. This occurs usually in humid regions.

2. Based on their relevance to the users (National Commission on Agriculture, 1976)

a. Meteorological drought: It is defined as a condition, where the annual precipitation is less than the normal over an area for prolonged period (month, season or year).

b. Atmospheric drought: It is due to low air humidity, frequently accompanied by hot dry winds. It may occur even under conditions of adequate available soil moisture. It refers to a condition when plants show wilting symptoms during the hot part of the day when transpiration exceeds absorption temporarily for a short period. When decreases absorption keeps pace with transpiration and plants revive. (Mid day wilt).

c. Hydrological drought: Meteorological drought, when prolonged results in hydrological drought with depletion of surface water and consequent drying of reservoirs, tanks etc. It results in deficiency of water for all sectors using water. This is based on water balance and how it affects irrigation as a whole for bringing crops to maturity.

d. Agricultural drought: It is the result of soil moisture stress due to imbalance between available soil moisture and evapo-transpiration of a crop. It is usually gradual and progressive. Plants can therefore, adjust at least partly, to the increased soil moisture stress. This situation arises as a consequence of scanty precipitation or its uneven distribution both in space and time. It is also usually referred as soil drought.

Relevant definition of agricultural drought appears to be a period of dryness during the crop season, sufficiently prolonged to adversely effect the yield. The extent of yield loss depends on the crop growth stage and the degree of stress. It does not begin when the rain ceases, but actually commences only when the plant roots are not able to obtain the soil moisture rapidly enough to replace evapo-transpiration losses. Important causes for agricultural drought are

- Inadequate precipitation
- Erratic distribution
- Long dry spells in the monsoon
- Late onset of monsoon
- Early withdrawal of monsoon
- Lack of proper soil and crop management

3. Based on time of occurrence

a. Early season drought: It occurs due to delay in onset of monsoon or due to long dry spells after early sowing

b. Mid season drought: Occurs due to long gaps between two successive rains and stored moisture becoming insufficient during this long dry spell.

c. Late season drought: Occurs due to early cessation of rainfall and crop water stress at maturity stage.

4. Other terms to describe drought

a. Apparent drought: What is drought for one crop may not be drought for another crop; what is drought in red soil may not be drought in black soil.

b. Physiological drought: Refers to a condition where crops are unable to absorb water from soil even when water is available, due to the high osmotic pressure of soil solution due to increased soil concentration, as in saline and alkaline soils. It is not due to deficit of water supply.

Periodicity of drought

The Indian Meteorological Department examined the incidence of drought for the period from 1871 to 1967, utilizing the monthly rainfall of 306 stations in the country. It was seen that during 1877, 1899, 1918 and 1972 more than 40 per cent of the total area experienced drought. General observation on the periodicity of drought in respect of different meteorological subdivisions of India is given below.

Meteorological subdivisions	Period of recurrence of drought
Assam	Very rare, once in 15 years
W Bengal, MP, Konkan, Coastal AP, Kerala, Bihar, Orissa	Once in 5 years
South interior Karnataka, Eastern UP, Gujarat, Vidharbha, Rajasthan, Western UP, TN, Kashmir, Rayalaseema and Telangana	Once in 3 years
Western Rajasthan	Once in 2.5 years

Usual Drought period in different parts of India

Beginning of drought

- Droughts do not occur in Assam, South Kerala and eastern part of West Bengal.
- Severe drought begins on 1 October in the northwest arid zone and even much earlier in the western part.
- In the southern arid zone and adjoining interior portion of Maharashtra State, the severe drought begins by the end of November.
- In most of the central portion of the country to the east of the line joining Delhi, Udaipur and Baroda, the commencement is only in the month of Februrary or later. This is due to high water holding capacity of the black soil region.
- In the western coastal region of Maharashtra and Karnataka states, the rainfall is very high. In spite of this, severe drought begins by December-January, probably because of the lower water holding capacity of the soil.
- Severe drought commences only after April in Gwalior, Guna, Jabalpur, Pendra, and Satna region of Madhya Pradesh.

Closure of drought

a. On the average, severe drought ends outside the regions of east Bihar, Tamil Nadu, Karnataka, and southern Andhra Pradesh only by 1 May. In most of these regions it ends mainly after 15 May.
b. In the arid zone of northwest India, severe drought ends normally during the second fortnight of June, except in the Jaisalmer and Bikaner regions where normally cessation of severe drought is only by the first week of July.

Effect of drought on crop production

c. Water relations – Alters the water status by its influence on absorption, translocation and transpiration. The lag in absorption behind transpiration results in loss of turgor as a result of increase in the atmospheric dryness.
d. Photosynthesis – Photosynthesis is reduced by moisture stress due to reduction in Photosynthetic rate, chlorophyll content, leaf area and increase in assimilates saturation in leaves (due to lack of translocation).
e. Respiration – Increase with mild drought but more serve drought lowers water content and respiration.
f. Anatomical changes – Decrease in size of the cells and inter cellular spaces, thicker cell wall greater development of mechanical tissue. Stomata per unit leaf tend to increase.
g. Metabolic reaction – All most all metabolic reactions are affected by water deficits.
h. Hormonal Relationships altered – The activity of growth promoting hormones like cytokinin, gibberlic acid and indole acetic acid decreases and growth regulating hormone like abscisic acid, ethylene, betain etc. increases.
i. Nutrition – The fixation, uptake and assimilation of nitrogen is affected. Since dry matter production is considerably reduced the uptake of NPK is reduced.
j. Growth and Development – Decrease in growth of leaves, stems and fruits. Maturity is delayed if drought occurs before flowering while it advances if drought occurs after flowering.
k. Reproduction and grain growth – Drought at flowering and grain development determines the number of fruits and individual grain weight, respectively. Panicle initiation in cereals is

critical while drought at anthesis may lead to drying of pollen. Drought at grain development reduces yield while vegetative and grain filling stages are less sensitive to moisture stress.

l. Yield – The effect on yield depends hugely on what proportion of the total dry matter is considered as useful material to be harvested. If it is aerial and underground parts effect of drought is as sensitive as total growth. When the yield consists of seeds as in cereals, moisture stress at flowering is detrimental. When the yield is fibre or chemicals where economic product is a small fraction of total dry matter moderate stress on growth does not have adverse effect on yields.

LEC 25: DRY FARMING REGIONS – CLIMATIC CHARACTERISTICS – RAINFALL: INTENSITY, DISTRIBUTION, RELIABILITY, ABERRATIONS

Arid regions of world

The following are the five arid zones in the world

1. North African Eurasian – Sahara and Tar desert
2. North American desert – Arizona in USA
3. South American desert – Peru
4. South African desert – Namibia
5. Australian desert – Central Australia

The climate of arid region is characterized by very low rainfall, usually less than 200 mm per year, occurring in a very short period. Rainless dry spells, may at times, stretch for more than a year. Depending on temperature regimes and location from equator, the arid regions are classified into Arid Tropics with mean annual temperature exceeding 18 ºC and Arid Temperate regions with mean annual temperature less than 18 ºC.

Semi arid regions of world

Depending on distance from equator and temperature regimes, semi arid regions are divided into Semi Arid Tropics, usually termed as SAT regions and semi arid temperate regions.

a. Semi arid tropics.

This region lies between 10º and 30º north and south latitudes. It is spread over 48 countries in four continents of Asia, Australia, America and Africa. It covers many parts in Africa, India, Pakistan and North Eastern Burma in Asia, Northern Australia and Mexico, Paraguay, Bolivia and Venezuela in South America. The total area of SAT is estimated to be 18.9 million square kilometers. West Africa accounts for 24% of semi arid tropics, East Africa 18%, South Africa 20%, Latin America 17%, Australia 10% and South Asia 11%.

A semi arid climate is essentially a mixed climate in which a fairly moist or rainy season alternates with a completely dry season. Hence, the climate is described as alternating wet and dry climate. Rainfall occurs during 2 to 7 months of the year. When number of wet months is 2.0 to 4.5, it is described as dry SAT and when rainy months ranges from 4.5 to 7.0 it is called as wet SAT. Rainfall quantity ranges from 400 to 750 mm per year, with a variability of 20-30%. But, the onset, closure and duration of rainy season exhibits wide variability between years. Distribution of rainfall within the season also exhibits wide fluctuations between years. A greater portion of rainfall is received in high intensity over a short duration, leading to run off. Mean annual temperature is more than 18 ºC and during most months PET is higher than precipitation. Soil moisture inadequacy is the major constraint for cropping.

b. Semi arid temperate region of the world

This occurs in Russia, North Western China, USA and Canada. Though annual rainfall is low, PET also is low during many months. Mean annual temperature is less than 18 ºC. Maximum temperature during summer is 33 ºC while minimum temperature may reach -26 ºC during winter months. Temperature rather than moisture is the critical limiting factor for crop production.

Arid and Semi arid regions of India

Total area under arid and semiarid regions in India extends over 135.8 million hectares

Climate	Area (m ha)	Regions
Arid Tropics	31.7	Rajasthan, Gujarat, Punjab, Haryana, Parts of Karnataka and Andhra
Arid Temperate	7.0	Jammu and Kashmir
Semiarid Tropics	95.7	Maharastra, Karnataka, Andhra, Rajasthan, Tamilnadu, Gujarat, Punjab, Haryana, Uttarprades, Madyapradesh
Semiarid Temperate	1.4	Jammu and Kashmir

Temperature in arid and semiarid temperate region is maximum at 32 ºC in July and minimum at -14 ºC in January – February. Temperature in arid and semiarid tropics is maximum at 40-42 ºC in May and minimum varies from 3-5 ºC in Punjab and Haryana and 18-24 ºC in Tamilnadu.

Distribution of arid and Semi arid regions of India

State	Arid		Semiarid	
	Area (Sq km)	Per cent to total area in India	Area (Sq km)	Per cent to total area in India
A. Tropics				
Rajasthan	196150	61	121020	13
Gujarat	62180	20	90520	9
Punjab	14510	5	31770	3
Haryana	12840	4	26880	3
Uttarpradesh	-	-	64230	7
Madhyapradesh	-	-	59470	6
Maharastra	1290	0.4	189580	19
Karnataka	8570	3	139360	15
Andhrapradesh	21550	7	138670	15
Tamil Nadu	-		95250	10
All India	317090		956750	
b. Temperate				
Jammu & Kashmir	70300		13780	

The words “Arid” and “Semiarid” must be understood differentially from dry farming. All the dry farming areas are located in arid and semi arid regions only. But not all the arid and semiarid regions come under dry farming areas. When irrigation facilities are available, irrigated farming is practiced extensively in arid and semiarid regions also. Eg. Punjab, Haryana. Similarly the two words arid / semiarid and tropical / temperate must be understood correctly. Arid or semiarid refers to moisture regimes where as tropical or temperate refers to thermal (temperature) regime of an area.

Climate	Moisture regime	Thermal regime	Constraints for cropping
Arid Tropics	Dry	Above 18 ºC	Moisture
Arid Temperate	Dry	Below 18 ºC	Moisture and Temperature
Semiarid tropics	Wet-Dry	Above 18 ºC	Moisture
Semiarid temperat	Wet-Dry	Below 18 ºC	Temperature

DRY FARMING REGIONS OF INDIA

Region	States	Places	Rainfall	Monsoon	Climate	Soils	Crops/cropping systems
Jhansi	Uttarpradesh	Jhansi, Hamirpur Banda Lalitpur, Jalaun	930	Jun-Sep (196)	Semi arid	Red black	Sorghum-safflower / mustard cowpea / urd / moong,-gram safflower rice-soybean-gram safflower
Rajkot	Gujarat	Rajkot Surendranagar; Jamnagar, Junagadh Bhavanagar, Amreli	625	Jun-Sep (134)	Arid	Medium black	Sorghum / bajra / cotton green gram / black gram redgram / cluster bean / groundnut / sesamum / castor-safflower / sunflower/ green gram / mustard.
Akola	Maharashtra Andhra Pradesh	Akola, Amravati, Wardha, Yeotmal Parbhani, Buldana, Khandesh, Adilabad, Nizambad	830	Jun-Sep (196)	Semi arid	Medium and deep black	Green gram / sorghum/ safflower / sunflower/ cotton + green gram / groundnut-sorghum + green gram / black gram / redgram groundnut + sunflower
Sholapur	Maharashtra	Solapur, Ahmednagar, Nasik, Pune, Satara, Sangli, Dhule, Bhir, Osmanabad, Jalgaon, Buldhana	722	May-Oct (68)	Semi arid	Black	Pear millet-Gram / Black gram-sorghum / Pearl millet + Redgram / Horsegram / Redgram + setaria / Groundnut / sunflower /Castor-Horsegram
Indore	Madhya Pradesh	Indore, Ratlan Ujjain Dewar, Dhar, Khargaon Khandura,	990	May-Sep (196)	Semi arid	Medium deep black	Maize-gram / safflower sorghum + soybean-gram safflower-maize + groundnut sorghum + redgram
Rewa	Madhya Pradesh	SidluRewa Satna Shadol Panna Jabalpur Damoh Chattarpur, Tikamgarh	1080	Jun-Sep (196)	Sub humid	Medium black mixed red and black	Sorghum +Redgram-gram/rice- wheat /gram Black grim Green gram-wheat/ rice-lentil
Bijapur	Maharashtra Karnataka	Bijapur, Gulbarga Belgraum, Raichur	680	May-Oct (105)	Semi arid	Medium and deep black	Green gram-sorghum / safflower-groundnut/ pearl millet + redgram. Bengal gram+ safflower / cotton

Udaipur	Rajasthan	Uddipur, Chittorgarh Bhilwara, Ajmer, Banswara, Dungarpur	635	Jun-Sep (196)	Semi arid	Medium black	Sorghum maize-safflower mustard / pearl millet / pearl millet +cowpea –mustard / Sorghum-mustard. Redgram / green gram / groundnut / Sunflower-wheat / mustard.
Bellary	Karnataka Andhra	Chellakere Chitradurga Bellary, Raichur,, Anantapur, Kurnool, Mahboobnagar	500	Sep-Oct (105)	Semi arid	Medium and deep black	Sorghum / safflower / gram sorghum + lablab
Kovilpatti	TamilNadu	Tiruneiveli, Thoothukudi	730	Sep-Dec (135)	Semi arid	Deep black	Sorghum + cowpea / Pearl millet / Setaria / kudiraivali / black gram / green gram / Redgram / lablab/ cowpea / cotton +black gram Sunflower / Senna
Agra	Uttar Pradesh	Agra Aligarh Mathura, Etah Manipuri	710	Jun-Sep (187)	Semi arid	Deep alluvial sandy loam	Pearl millet / black gram / green gram / redgram / cluster bean / groundnut safflower / mustard / pearl millet+ redgram / black gram / greengram / groundnut + castor
Anantapur	Andhra	Anantapur, Karnool, Chithoor	570	May-Oct (120)	Arid	Red loam	Pearl millet / sorghum / setaria/ castor / Redgram / gmundnut / mesta / groundnut+ Redgram / castor / pearl millet+ Redgram / castor
Hyderabad	Andhra	Rangareddy Nalgonda,, Medak Karimnagar,, Mahboobnagar, Warangal	770	Jun-Oct (208)	Semi arid	Shallow red sandy loam	Sorghum / pearl millet / castor/ redgram / ragi / setaria / niger / horsegram / sorghum / maize + red gram-safflower

Regions of Tamil Nadu

Region	Taluk / District	Annual rainfall (mm)	Monsoon	Climate	Soils	Crops/ cropping systems
Northwest	Dhammpmi Dt., Taluks of Omalur,	844	Jun - Oct	Semiarid	Red	Groundnut + Redgram / Castor – Horsegram
	Attur, Rasipuram Sankagiri in Salem Dt. Perambahu Taluk	842	Jun - Oct	Semiarid	Red	Cowpea - sorghum / Sorghum + lablab redgram
	Parts of Tirupattur and Vellore Taluks	900	Jun - Oct	Semiarid	Red	Ragi / pearl millet / Samai- horsegram
Western	Palladam, Kangeyam Dharapuram Udumalpet Coimbatore taluks of Coimbatore and Periyar Districts	711 717	Sep - Nov	Semiarid	Red black	Cotton/ sorghum/ pear millet / bengal gram / coriander / sorghum + lablab./ red gram
East central	Parts of Tiruchi, Pudukkottai, Madurai and Dindugul Dts.	840 918 876	Sep - Nov	Semiarid	Black Red Red	Cotton / sorghum / pearl millet / sesamum sorghum / pulses / pearl millet / groundnut +red gram/castor
Southern	Tirunelveli Dt.	940	Oct - Dec	Semiarid	Red	Groundnut / cowpea / sesamum sorghum / pearl millet / pulses castor
	Thoothukudi Dt.	677	Oct- Dec	Semiarid	Black Red	Cotton / chillies / coriander / black gram / sorghum / pearl millet / pulses.
	Virudunagar Dt.	817	Oct - Dec	Semiarid	Black	Cotton / sunflower / maize / sorghum,/ pearl millet / pulses / castor
	Ramanathapuram Dt.	819	Oct- Dec	Semiarid	Black	Rice / cotton / sorghum/ pulses / chillies
	Sivagangai Dt.	910	Oct- Dec	Semiarid	Red	Groundnut / pearl millet / sesamum / cowpea /redgram / castor

Indian Agriculture - Climate

Location

India is located between 8°to 36° North of the equator and between 68° to 96° East longitude. It is a tropical country.

Temperature

The tropic of cancer, which passes through the middle of the country, divides it into two distinct climates. The tropical climate in the South where all the 12 months of the year have mean daily temperature exceeding 20°C; and in the North where a sub-tropical climate prevails. In sub-tropics during the winter months, it is cool to cold. Frosts occur sometime during the months of December and January. Some areas in the Northern India have a temperate climate. Here it snows during the winter months and freezing temperatures may extend to two months or more during the year. Three main climatic zones of India based on temperature are shown in the map below.

Rainfall

Rainfall in India varies considerably. In some parts of the Thar desert, located in Western Rajasthan, the annual rainfall is as low as 100 mm; while in the East, the annual rainfall may be as high as 10,000 mm or more. In some areas it may rain for a month or two during the year, in others as many as 11 months may be rainy.

Monsoon

India is a monsoonal country. In the tropical and sub-tropical regions, almost 80% of the total annually rainfall is received during the monsoon rainy season. There are two types of monsoons received in India. During the main rainy season extending from June/July to September/October, the rains we receive are called as South-West monsoons. They are called thus, because the rainy season sets in first in the South of India and rains progress gradually towards the West of the country.

Onset of monsoon

At Trivandrum in Kerala State, the monsoon breaks around June 1; at Hyderabad in Andhra Pradesh around June 5; at Bombay around June 10; and at Jaipur or Jodhpur towards end of June or early July. The normal dates of onset are just averages, in actual terms there may be a week or 10 days delay or earliness. These are just guide dates for agricultural operations or crop calendars. The actual dates vary from year to year.

NE monsoons occur due to cyclonic disturbances in the Bay of Bengal. Their normal date of onset is between November 1 and November 15. These rains withdraw by about end of January and occur in areas located below 10°N latitude in India.

Rainfall distribution

The rainy season extends to about 2 to 4 months across most of agricultural regions in Northern and North-West India; it extends to 5 months in Peninsular India (eg. Hyderabad), and is of a much longer duration in some Southern areas (eg. Bangalore or Trivandrum).

Rainfall climatology

Study of rainfall over a long period is called rainfall climatology. It reveals general pattern of rainfall of a particular place. It helps in understanding the amount, intensity, distribution and other rainfall characteristics. Rainfall analysis also helps in classification of climate. Suitable and efficient cropping systems can be developed by understanding the rainfall pattern. Rainfall analysis helps in taking decisions on time of sowing, scheduling of irrigation, time of harvesting etc. Rainfall analysis is necessary for designing farm ponds, tanks or irrigation projects. Amount, distribution and intensity of rainfall are the important aspects of rainfall that have considerable influence on crop production.

Precipitation is water in liquid or solid forms, falling to the earth. It always precedes condensation or sublimation or a combination of the two and is primarily associated with raising air. In the same way that isotherms and isobars are used to show temperature and pressure distribution respectively, isohyets for rainfall distribution. An isohyets is a line connecting points with equal values of rainfall.

Change of state from water vapour to liquid water is condensation. When moist air comes in contact with cool surfaces, it may be cooled to the point where its capacity to hold water vapour is exceeded by the actual amount in the air. Part of the water vapour then condenses into liquid form on the cool surface, produce dew. When this happens, the latent heat of vaporization, in this process, called the latent heat of condensation is released. At temperatures below freezing, water may bypass the liquid form in its change of state. When dry air with a temperature well below freezing comes in contact with ice, molecules of ice (H_2O) pass directly into the vapour state by the processes of sublimation.

Forms of precipitation

Condensation forms of fog, dew and frost are not considered to be precipitation. The common precipitation forms are rain, drizzle, snow, sleet and hail. Of these, drizzle and light snow are the only forms likely to fall from clouds having little or no vertical development. Fog results when atmospheric water vapour condenses to water droplets or ice crystals, become visible and will have their base in contact with ground.

Types of rainfall based on distribution

In India, all areas located between 20° North of equator to 40° North, the rainfall is unimodal and almost all of the annual rainfall is received due to South-West monsoons. In South India, the areas located below 10° North, the rainfall is bimodal or it has two peaks – one peak during the South-West rainy season and the second peak in NE monsoon.

Rainfall Quantity

Generally, yield levels are determined by the amount of precipitation above the basic minimum required to enable the crop to achieve maturity. Though rainfall has major influence on yield of crops, yields are not always directly proportional to the amount of precipitation. Rainfall may also be in excess of the optimum and thereby cause reduced yields which may appear paradoxical to semi-arid climates. When the rainfall is concentrated in 4-5 months of the year, there may be periods when the rate of precipitation exceeds the intake rate of soil. As a result, considerable runoff occurs, plant nutrients are leached out of the root zone and crops are adversely affected by anaerobic conditions (Germination, establishment etc), especially if the excess precipitation occurs during the cool season. It may uproot and wash away young seedlings, causes lodging of grown up crops and affect pollination and seed setting.

Based on the average rainfall over years, the receipt of rainfall during a year is classified by IMD as below.

-19 to +19%	=	Normal
+20 to +59%	=	Excess
> + 59%	=	Wet
-20 to –59%	=	Deficit
<-60%	=	Scanty

Rain fall analysis - refer practical schedule

Intensity of Rainfall

Intensity of rainfall mainly influences erosion of soil. Study of rainfall intensity helps in probable period of floods, filling of irrigation tanks etc. If the intensity of rainfall exceeds rate of infiltration of soil, runoff starts. High intensity rainfall causes soil erosion. The runoff from hills and mountain slopes is collected in tanks. The relationship between intensity of rainfall and runoff is given below.

Less than 12.5 mm	-	Runoff is rare
12.5 to 25.0 mm	-	Runoff in 35% occasions
25.0 to 50.0 mm	-	Runoff in 80% occasions
Above 50.0 mm	-	Runoff in 100% occasions

Distribution of Rainfall

The amount of rainfall received at periodic intervals like weeks, months, seasons etc. indicates distribution. In addition, distribution of rainfall can be known by the length of dry spells, wet spells and rainy days. Distribution of rainfall is more important than total rainfall. It can be illustrated with following example taking rainfall related indices of Hyderabad and Sholapur.

Index	Hyderabad	Sholapur
Annual rainfall (mm)	764	742
Seasonal rainfall (mm)	580	556
Coefficient of variation (%)	26	28
Potential evapo-transpiration (mm)	1757	1802
Growing season	130	148
Soil	Vertisol	Vertisol

It is apparent from the data that annual rainfall is fairly similar at both locations as is seasonal rainfall. The rainfall is equally variable and the potential evapo-transpiration is fairly similar at the two locations. The growing season is slightly less at Hyderabad compared to Sholapur. From the above, one could probably anticipate that the production potentials are quite similar. However, rainy season crops are successful at Hyderabad and the annual yields range from 5,000 to 7,000 kg/ha while at Sholapur rainy season crops are risky and annual yields range from 1,000 to 2,000 kg/ha. Low grain yields at Sholapur are mainly due to discontinuous rainfall or long breaks in rainfall during the crop period.

Dependability/reliability of Rainfall

Another important character of rainfall is its dependability. Rainfall in dry farming regions is characterized by high variability and less reliability. The variability occurs in quantity of rainfall, onset and closure of rainy seasons, duration of rainfall and distribution within rainy season. The spatial variability refers to the variability of rainfall between two locations and the temporal variability refers to the variations over time i.e. between years, between seasons and within season. Variability of rainfall is the greatest hazard to crop production in the dry farming regions.

The dependability can be estimated by 75 per cent probability rainfall and by coefficient of variation. It indicates that there is 75 per cent probability of receiving a particular amount of rainfall in three years out of four years. It can be estimated by arranging the amount of rainfall present at the three-fourth's place in the descending order line is the 75 per cent probability rainfall.

Example:

Annual rainfall during different years		Rainfall arranged in descending order	
Years	Amount (mm)	Amount (mm)	Ascending order
1950	850	1020	1
1951	950	950	2
1952	1020	870	3
1953	625	850	4
1954	750	750	5
1955	550	725	6
1956	650	650	7
1957	475	*631*	*8*
1958	631	625	9
1959	725	550	10
1960	870	525	11
1962	525	475	12

Out of 12 years, 631 mm and above rainfall was received in eight years and it is the 75 per cent probability rainfall.

Coefficient of Variation (CV%) . By calculating coefficient of variation, the variation in rainfall can be quantified. If the CV is more, it means that variation in rainfall from year to year or season to season is more. If the CV is less, the variation in rainfall is less and it is more dependable.

$$\text{Coefficient of variation} \quad \frac{\text{Standard deviation}}{\text{Mean}} \times 100$$

$$SD = \sqrt{\frac{\sum x^2 - (\sum x)^2 / n}{n-1}}$$

Dependability of rainfall based on CV

Period	Dependable	Not dependable
Annual	25%	> 25%
Seasonal	50%	> 50%
Monthly	100%	> 100%
Weekly	150%	> 150%
Daily	250%	> 250%

Rainfall Aberrations

a. Deficit in the quantity of rainfall adversely affects crops growth through inadequate supply of moisture. It leads to lower yield and even complete crop failure.
b. High intensity rainfall causes runoff and soil erosion. It reduces the storage-of rainfall in the soil.
c. Erratic distribution leads to long dry spells during crop growth and cause moisture stress.
d. High variability in the onset of rainy season affects time of sowing. Delayed onset also affects crop choice.

e. Early withdrawal or cessation of rainfall before the normal time of closure will lead to moisture stress at maturity and reduce crop yield.

f. Dry spells during rainy season affect crop growth depending on length of dry spell, sage of occurrence and soil type. Dry spells over 3 weeks are usually harmful.

Dry spell after sowing	Germination and establishment affected.
At vegetative stage	Stem elongation, leaf area expansion and dry matter accumulation affected.
At flowering	Very critical for pollination and grain setting affected.
At ripening	Affects grain development and yield.

Effect of rainfall on crop production

- Primary source of water for the earth is precipitation
- About 40 % of food produced depended on rainfall
- The choice of crop and variety depends on rainfall
- The crops depend on rainfall for their moisture need. Though rivers, tanks and well can supplement the rainfall, these sources also depends on the rains ultimately.
- Deficient rains limits crop growth and heavy rains are even more harmful.
- Occurrence of drought and famines are mainly due to inadequate rainfall over a continuous period of time.

LEC: 26 SOIL MOISTURE CONSTRAINTS AND THEIR MANAGEMENT IN DRYLANDS – TILLAGE – CONTROL OF WATER AND WIND EROSION – MECHANICAL, AGRONOMIC AND VEGETATIVE METHODS.

Factors of affecting crop production in dry farming regions:

Most of the cropping in the arid and semi arid regions continues to be under rainfed conditions. A majority of the farmers are small farmers with meager resources. The poor resources base permits only low input subsistence farming with low and unstable crop yields. The low productivity of agriculture in dry farming regions is due to the cumulative effect of many constraints for crop production. The constraints can be broadly grouped in to

a. Climatic constraints,
b. Soil related constraints,
c. Cultivation practices and
d. Socio economic & political constraints.

<u>a. Climatic constraints</u>

1. Vagaries of monsoon
   (i) Variable Rainfall: Annual rainfall varies greatly from year to year and naturally its coefficient of variation. Generally, higher the rainfall less is the coefficient of variation. In other words, crop failures due to uncertain rains are more frequent in regions with lesser rainfall.
   (ii) Intensity and Distribution: In general, more than 50 per cent of total rainfall is usually received in 3 to 5 rainy days. Such intensive rainfall results in substantial loss of water due to surface runoff. This process also accelerates soil erosion. Distribution of rainfall during the crop growing season is more important than total rainfall in dryland agriculture.
   (iii) Late Onset of Monsoon: If the onset of monsoon is delayed crops/varieties recommended to the region cannot be sown in time. Delayed sowing lead to uneconomical crop yields.
   (iv) Early Withdrawal of Monsoon: This situation is equally or more dangerous than late onset of monsoon. Rainy season crops will be subjected to terminal stress leading to poor yields. Similarly, post-rainy season crops fail due to inadequate available soil moisture, especially during reproductive and maturity phases.
   (v) Prolonged Dry Spells: Breaks of monsoon for 7-10 days may not be a serious concern. Breaks of more than 15 days duration especially at critical stages for soil moisture stress leads to reduction in yield. Drought due to break in monsoon may adversely affect the crops in shallow soils than in deep soils.
2. High atmospheric temperature
3. Low relative humidity
4. Hot dry winds
5. High atmospheric water demand (potential evapo-transpiration) exceeding precipitation during most part of the year.

<u>b. Soil Constraints</u>

1. Inadequate soil moisture availability
2. Poor organic matter content
3. Poor soil fertility
4. Soil deterioration due to erosion (wind, water)

c. Cultivation practices

The existing management practices adopted by the farmers are evolved based on long term experience by the farmers. The analysis of traditional system revealed that on one hand the traditional system suffers due to the fact that yield levels are low and unstable while on the other hand it has strong points due to which it has stood the test of time.

The traditional management practices are listed below;

- Ploughing with country plough which is replaced by tractor, ploughing just prior to sowing
- Ploughing along the slope
- Broadcasting seeds/gorru sowing / sowing behind the country plough leading to poor as well as uneven plants stand
- Selection of traditional varieties
- Monsoon sowing
- Choice of crop based on rain fall
- Application FYM in limited quantity
- Hand weeding
- Mixed cropping
- Use of conventional system of harvesting
- Traditional storage system

*Among the traditional management practices the fallowing practices are technically sound and can be practiced. (*Strength)

√ Monsoon sowing: This still holds good for crops like maize, red gram, bajra and karunganni cotton

√ Choice of crop based on rain fall: Farmers take up coriander for late onset of monsoon. This traditional practice has been experimentally proved to be correct.

√ Hand weeding: It has proved to be as effective as herbicide application in terms of weed control and yield.

√ Mixed cropping: Farmers adopt many mixed cropping systems based on their experience. Groundnut and red gram are sown in 6:1 ratio. Co 19 sorghum black gram, green gram, Lab-Lab (mochai) are broadcasted. Cotton + black gram is sown in 6:1 ratio or black gram is sown in border. Even though the yield is less there is some stability in yield due to mixed cropping and it is an insurance against risk of complete failure.

√ Traditional system of harvesting processing consumes more labour, but it can be followed because of no loss in grain during the process of harvest.

√ Traditional storage is based on sound practical knowledge as well as it involves low cost technology

√ In certain pockets pre monsoon sowing or early sowing of crops are taken.

√ Inter cultivation with plough in between crop rows is one of the best *insitu* soil moisture conservation techniques.

Weakness in traditional system

☒ Most management practices are not aimed at soil moisture conservation.

☒ Traditional system does not build up nutrient status in the soil; on the contrary it depletes the fertility status.

☒ Genotypes /varieties used are poor yielders.

- ☒ Spatial and temporal variations are not effectively utilized in the mixed cropping adopted by the farmers. This results in no yield advantage.
- ☒ One of the most serious limitations due to traditional management practices is low plant population per unit area which ultimately reduces yield.
- ☒ Run off is neither collected nor used efficiently.

Scope for improvement in productivity of crops

1. Compilation of results of dry farming crop production during 1970's in the area covered by dryfarming stations started during middle of 1930's indicated 2-5 times increased crop production is possible
2. With introduction of Dryland Agricultural Research Projects in 1970s experiment evidence indicate that there is scope to push the production of dryland crops by nearly 3 to 4 times of farmers level.
3. Salvation not from technology alone and a concentrated multidiociphinary multiagency approach is necessary.

d. Socio-economic constraints – may be studied in extension

Inadequate soil moisture availability is the major constraint in dry farming. All the above factors directly and indirectly affect the soil moisture. Availability of soil moisture to crops is affected by rainfall behaviour as well as by various soil properties.

a) Shallow soils, degraded soils, eroded soils, gravelly soils and coarse textured soils have poor water holding capacity and hence can not store much of rainfall.
b) Wind and water erosion remove the finer soil particles and expose the hard, impermeable subsoil causing less infiltration and less water storage-
c) Crusting of soil surface after rainfall reduces infiltration and storage of rainfall, due to high run off.
d) Compaction in surface and sub soil hardpans and poor soil structure affect infiltration and water storage.
e) Poor organic matter content adversely affects soil physical properties related to moisture storage.

METHODS OF SOIL MOISTURE MAINTENANCE

They are grouped as follows:

a) By adapting proper tillage
b) Control of run off water and soil erosion
c) Recycling of rain water
d) Reducing loss soil moisture by mulching and anti-transpirants
e) By increased rain fall use efficiency

A. Tillage in relation to soil moisture conservation

Tillage may be described as the Practice of modifying the state of the soil in order to provide conditions favourable to crop growth, (Cuplin, 1986). The objectives of tillage in drylands are;

(1) Develop desired soil structure for a seed bed which allows rapid infiltration and good retention of rainfall.
(2) Minimize soil erosion by following practices as contour tillage, tillage across the slope etc.
(3) Control weeds and remove unwanted crop plants.
(4) Manage crop residues, through mixing of trash is desirable for achieving good tilth and decomposition of residues. However, the retention of trash on top layers is also useful in

reducing erosion. On the other hand, complete coverage of residues sometimes necessitates control of insects or to prevent interference with precision planting operations.

(5) Obtain specific soil configurations for *in*- situ moisture conservation, drainage, planting etc.

(6) Incorporate and mix manures, fertilizers, pesticides or soil amendments into the soil.

(7) Accomplish segregation by moving soil from one layer to another, removal of rocks or root harvesting.

Hence, attention must be paid to the depth of tillage, time of tillage, direction of tillage and intensity of tillage.

a) Depth of tillage - depends on soil type, crop and time of tillage

Deep tillage of 25-30 cm is beneficial for deep heavy clay soils to improve permeability and to close cracks formed while drying. In soils with hard pans, deep tillage once in 2-3 years with chisel plough upto 35-45 cm depth at 60-120 cm interval will increase effective depth for rooting and moisture storage. Deep tillage is preferable for cotton, redgram and other deep rooted crops. It is not to be recommended for shallow, gravelly, light textured soils.

Medium deep tillage of 15-20 cm depth is generally sufficient for most soils and crops. It is recommended for medium deep soils, shallow rooted crops, soils with pan free horizon and for stubble incorporation.

Shallow tillage upto 10cm is followed in light textured soils, and shallow soils and in soils highly susceptible to erosion. In soils prone for surface crusting, shallow surface stirring or shallow harrowing is useful.

Depth of tillage and crop yield

Crop	Yield q ha^{-1}	
	Shallow tillage	Deep tillage
Pigeon pea	9.0	11.7
Pearl millet	12.0	15.4
Groundnut	4.2	5.4
Maize	24.3	47.8

As depth of tillage increases, soil moisture storage from rainfall also increases from about 7-8 % with shallow tillage to 9-10% with medium deep tillage and 11-12% with deep tillage.

b) Time of tillage

Early completion of tillage is often helpful to enable sowing immediately after rainfall and before the soil dries up. Summer tillage or off-season tillage done with preseason rainfall causes more conservation of moisture and also enables early and timely sowing. It is particularly useful for pre-monsoon sowing.

Effect of summer tillage on crop yield

Tillage	Sorghum yield q ha^{-1}		
	Normal rainfall	Above normal rainfall	Below normal rainfall
No summer tillage	9.1	14.6	4.9
Summer tillage	14.3	19.3	12.4

c) Direction of tillage

For moisture conservation, ploughing across slope or along contour is very effective. Plough furrows check the velocity of runoff, promote more infiltration when water stagnates in the depressions caused by plough furrows and improves soil moisture storage.

d) Intensity of tillage

It refers to the number of times tillage is done. Frequent ploughing in shallow light textured soils will pulverize the soils into fine dust and increase the susceptibility to erosion. In heavy soils, leaving the land in a rough and cloddy stage prior to sowing is useful for more depression storage.

The concept of minimal tillage is also practiced in dry lands. Here tillage is confined to seeding zone only and the inter-space is not tilled. It not only saves time, energy and cost but also helps moisture conservation. The practice of "set line cultivation" adopted in some dry regions is an example of minimum tillage. Here the seed row space is fixed and season after season, tillage is done only in this seeding strip. The intervening strip is not tilled.

Modern concept of Tillage

In dry lands, rainfall is received simultaneously over a large area. In order to ensure timely sowing before soil dries up, the interval between land preparations and sowing must be narrowed down. This calls for completion of tillage over a large area in quick time. Dependence on bullock power and traditional wooden plough may not help in this regard. Use of more efficient tillage implements and mechanization of tillage operations are warranted.

Tillage in drylands also encompasses land shaping for insitu soil moisture conservation. Implements that can carryout tillage and land shaping in one single operation will help in saving time and cost. If land preparation, land shaping and sowing can be done in one single operation it can save considerable time. This is termed as once over tillage, plough planting or conservation tillage. Suitable tractor drawn machinery like a broad bed former cum seeder, Basin lister cum seeder which can complete the land shaping and sowing simultaneously can be used.

a) minimum/optimum/reduced tillage
b) conservation/mulch tillage
c) zero tillage

Minimum/optimum/reduced tillage

The objectives of these systems include (a) reducing energy input and labour requirement for crop production (b) conserving soil moisture and reducing erosion (c) providing optimum seedbed rather than homogenising the entire soil surface, and (d) keeping field compaction to minimum.

Conservation/mulch tillage

The objectives are to achieve soil and water conservation and energy conservation through reduced tillage operations. Both systems usually leave crop residue on the surface and each operation is planned to maintain continuous soil coverage by residue or growing plants. The conservation tillage practices may advance some of the goals of alternative farming such as increasing organic matter in soil and reducing soil erosion, but some conservation tillage practices may increase the need for pesticides. Conservation tillage changes soil properties in ways that affect plant growth, and reduce water runoff from fields. The mulched soil is cooler and soil surface under the residue is moist, as a result many conservation tillage systems have been successful.

Zero tillage or no-till system

In the crop residue is usually shredded and planting is done without pre tillage. No till planting has problem of adequate weed control.

Soil deterioration due to erosion (wind and water)

Detachment and transport of soil and soil material caused by water and wind are widely prevalent in dry farming regions. Erosion takes place in both red soils and black soils.

B. Effect of runoff and erosion on soil moisture retention

- Runoff leads to wastage of rainfall.
- Under unchecked conditions, even up to 40% of rainfall may be lost as runoff.
- Even when moisture conservation practices are adopted, about 10-20% of rainfall may be lost as runoff because of high intensity rainfall.
- Erosion removes top soil and exposes hard impermeable sub soil, increasing the chances of more run off.
- Erosion adversely affects soil physical properties such as loss of structure reduced infiltration, soil depth and soil moisture storage capacity.
- Loss of top soil through erosion leads to loss of plant nutrients and poor soil fertility.

Soil and water are the most critical basic resources, which must be conserved as effectively as possible. No phenomenon is more destructive than soil erosion through which fertile topsoil and rain water are lost. Soil and water conservation is the only known way to protect the lands from degradation and conserving rainwater for improving the productivity of dry land crops.

Soil erosion

Soil erosion is the process of detachment of soil particles from the topsoil and transportation of the detached soil particles by wind and/or water. The detaching agents are falling rain drop, channel flow and wind. The transporting agents are flowing water, rain splash and wind.

Out of 328 mha of India's geographical area 175 m ha (53.3%) subject to soil erosion and alll kind of land degradation. Out of which 104.6 m ha are cultivable.

Recent estimates indicate that about 5,333mt (16.35 t/ha) of soil is detached annually. 29% carried away by rivers to the sea.10% deposited in reservoirs resulting 1-2% loss of storage capacity.

Types of erosion

Geological erosion: It is said to be in equilibrium with the soil forming process. It takes place under natural vegetative cover completely undisturbed by biotic factors. This long time slow process has developed the present topographic features like stream channels, valleys, etc. through weather abnormalities such as intense rainfall and biotic interference.

Accelerated erosion: It is due to disturbance in natural equilibrium by the activities of man and animals through land mismanagement, destruction of forests, overgrazing, etc. Soil loss through erosion is more than the soil formed due to soil forming process.

Water erosion:

Water and wind are the main agencies responsible for soil erosion. Loss of soil from land surface by water, including runoff from melted snow and ice is usually referred to as water erosion.

The major erosive agents in water erosion are impacting raindrops and runoff water flowing over the soil surface. Erosion and sedimentation embody the processes of detachment, transportation and deposition of soil particles. Detachment is dislodging of soil particles from soil mass by the erosive agents. Transportation is movement of detached soil particles (sediment) from their original location. The sediment moves along the stream and part of it may eventually reach the ocean. Some sediment is usually deposited at the base of the slopes, reservoirs and flood plains along the way.

Forms of water erosion

Sheet, Rill, gully, ravine, landslide and stream bank erosion.

Factors affecting water erosion

a) Rainfall - amount, intensity, duration & distribution
b) Soils - primary particle size, distribution, OM, structure, Fe & Al oxides, initial moisture content
c) Topography - nature and length of slope
d) Soil surface cover - plant canopy or mulches
e) Biotic interference – disturbance of natural balance

Losses due to erosion

- Loss of fertile top soil
- Loss of rain water
- Nutrient losses
- Silting up of reservoirs
- Damage to forests
- Reduced ground water potential
- Damage to reservoirs and irrigation channels
- Adverse effect on public health

Wind erosion

Erosion of soil by the action of wind is known as wind erosion. It is a serious problem on lands devoid of vegetation. It is more common in arid and semiarid region. It is essentially a dry weather phenomenon stimulated by soil moisture deficiency. The process of wind erosion consists of three phases: initiation of movement, transportation and deposition. About 33 M ha in India is affected by wind erosion. This includes 23.9 M ha of desert and about 6.5 M ha of coastal sands.

Transportation of soil particles by wind takes place in three ways

Saltation - movement of soil particles by a short series of bounces along the ground surface

Suspension - movement of fine dust particles, smaller than 0.1mm dia floating in the air

Surface creep - Rolling and sliding of soil particles along the ground surface due to impact of particles descending and hitting during saltation is called surface creep

Factors affecting wind erosion

1. Soil clodiness
2. Surface roughness
3. Water stable aggregates and surface crust (Mechanical stability)
4. Wind and soil moisture (surface is dry or slightly moist)
5. Field length
6. Vegetative cover
7. Organic matter (cementing)
8. Topography
9. Soil type (sand erodes easily)

Losses due to wind erosion

a. Fertile top soil is lost
b. Fertile soils are converted into unproductive sandy soils drifting sand
c. Yield losses due to abrasive action of wind driven soil particles, especially on broad leaved crops

Water erosion control

Water erosion can be minimized by preventing the detachment of soil particles and their transportation. Principles of water erosion control are;

- Maintenance of soil infiltration capacity
- Soil protection from rainfall
- Control of surface runoff
- Safe disposal of surface runoff

Control measures are grouped in to three Agronomic, mechanical and forestry measures

Agronomic – Choice of crops, land preparation, contour cultivation, strip cropping, mulching, application of manures and fertilizers and appropriate cropping systems

Mechanical – Contour bunding, Graded bunding, Bench terracing, Contour trenching, Gully control, vegetative barriers

Forestry – Perennial trees and grasses

Wind erosion control

Greatest damage by wind erosion occurs during summer months in dry regions, where soil surface is bare and wind velocity is at its peak. Basic principles of wind erosion control are:

- Reducing wind velocity at ground surface, sufficient to prevent it being able to pickup soil particles
- Increasing the size of soil aggregates or covering the soil with a non-erodable surface
- Trapping the saltating soil particles
- Keeping the soil moist so that soil particles moving by saltation loose their momentum at the surface

Practices such as stubble mulching and minimum tillage, cover crops, strip-cropping, crop rotation, wind barriers and shelterbelts and mulches can be practiced to minimize wind erosion.

C. INSITU MOISTURE CONSERVATION TECHNIQUES

- Storage of rainfall in soil at the place where it falls is termed as "insitu" soil moisture conservation.
- It aims at increasing infiltration of rainfall into the soil and reducing runoff loss of rainwater.
- Insitu soil moisture conservation can be accomplished through.
    - Cultural /agronomic methods
    - Mechanical methods
    - Agrostological / biological methods

Extent of soil moisture storage from rainfall is influenced quantity and intensity of rainfall, slope, soil properties such as texture, structure, depth, surface characters, presence of sub soil hard pans, rate of infiltration and permeability, water holding capacity, vegetative cover, etc.

INSITU MOISTURE CONSERVATION

Cultural/ agronomical	Mechanical	Agrostological
Addition of organic matter Summer ploughing, mulching cultivation, strip cropping	Basin listing, Bunding, Ridges and furrows, Tie ridging, Random tie ridging, Broad bed furrow, Dead furrow, Furrows after crop establishment	Pasture, Strip cropping with grasses, Ley farming, Vegetative barriers

1. Cultural /Agronomical methods
   i) Addition of organic matter: By improving soil physical properties and WHC
   ii) Off season/summer tillage: Plough furrows can hold water in the depressions and thereby increase the infiltration. When done across the slope, the plough furrows check runoff, reduce the velocity of runoff water and improve storage. Summer tillage is a traditional practice helps in the storage of pre-sowing rainfall. When ploughing is done along contour it is termed as contour ploughing and is more helpful for in situ moisture conservation. Summer ploughing also helps in control of perennial weeds, pest control and enables early sowing with onset of rains. Experimental results at Kovilpatti indicated that summer ploughing with disc plough had increased infiltration rate to 5.8 mm per hour over fallow field where infiltration was only 2.9 mm per hour.

   iii) Contour farming: Ploughing along the contour and sowing reduce soil erosion and reduce runoff. Jowar sown in the black soils on contour line restricts the run off to 13.7% of the total rainfall and soil loss to 2.4 t/ha/year
   iv) Cover crops: Erosion reduced if the land surface is fully covered with foliage (Eg.)
   - Black gram, green gram, Groundnut
   - Fodder grasses like *Cenchrus ciliaris*, *Cenchrus glaucus*, Dinanath grass, Marvel grass. Both contour cropping and cover cropping can be practiced when the slope is less than 2 per cent.

   v) Mixed cropping
   vi) Inter cropping
   vii) Mulching
   viii) Strip cropping: Strip intercropping involves erosion resistant crops and erosion permitting crops in alternate strips of 2-3 m width across slope and along the contour. Erosion resistant crops include grasses and legumes with rapid canopy development. (e.g) *Cenchrus glaucus* + *Stylosanthes hamata*

2. Mechanical methods of soil moisture conservation

The basic principle involved

- ✧ shaping the land surface manually or with implements in such a way as to reduce the velocity of runoff,
- ✧ to allow more time for rainfall to stand on soil surface and
- ✧ to facilitate more infiltration of rainfall into soil layers

Choice of any particular method under a given situation is influenced by rainfall characters soil type, crops, sowing methods and slope of land.

i) Basin listing: Formation of small depressions (basins) of 10-15 cm depth and 10-15 cm width at regular intervals using an implement called basinlister. The small basins collect rainfall and improve its storage. It is usually done before sowing. It is suitable for all soil types and crops.

ii) Bunding: Formation of narrow based or broad based bunds across slope at suitable intervals depending on slope of field. The bunds check the free flow of runoff water, impound the rainwater in the inter-bund space, increase its infiltration and improve soil moisture storage. Leveling of inter-bund space is essential to ensure uniform spread of water and avoid water stagnation in patches. It can be classified into three types

Contour bunding

Bunds of 1 m basal width, 0.5 m top width and 0.5 m height are formed along the contour. The distance between two contour bunds depends on slope. The inter-bund surface is leveled and used for cropping. It is suitable for deep red soils with slope less than 1 %. It is not suitable for heavy black soils with low infiltration where bunds tend to develop cracks on drying. Contour bunds are permanent structures and requires technical assistance and heavy investment.

Graded/ field bunding

Bunds of 30-45 cm basal width, and 15-20 cm height are formed across slope at suitable intervals of 20-30 m depending on slope. The inter-bund area is leveled and cropped. It is suitable for medium deep to deep red soils with slopes upto 1%. It is not suitable for black soils due to susceptibility to cracking and breaching. Bunds can be maintained for 2-3 seasons with reshaping as and when required.

Compartmental bunding

Small bunds of 15 cm width and 15 cm height are formed in both directions (along and across slope) to divide the field into small basins or compartments of 40 sq m size (8 x 5 m). It is suitable for red soils and black soils with a slope of 0.5 to 1%. The bunds can be formed before sowing or immediately after sowing with local wooden plough. It is highly suitable for broadcast sown crops. CRIDA has recommended this method as the best insitu soil moisture conservation measure for Kovilpatti. Maize, sunflower, sorghum perform well in this type of bunding.

iii) Ridges and furrows

Furrows of 30-45 cm width and 15-20 cm height are formed across slope. The furrows guide runoff water safely when rainfall intensity is high and avoid water stagnation. They collect and store water when rainfall intensity is less. It is suitable for medium deep to deep black soils and deep red soils. It can be practised in wide row spaced crops like cotton, maize, chillies, tomato etc. It is not suitable for shallow red soils, shallow black soils and sandy/ gravelly soils. It is not suitable for broadcast sown crops and for crops sown at closer row spacing less than 30 cm. Since furrows are formed usually before sowing, sowing by dibbling or planting alone is possible.

Tie ridging is a modification of the above system of ridges and furrows where in the ridges are connected or tied by a small bund at 2-3 m interval along the furrows.

Random tie ridging is another modification where discontinuous furrows of 20-25 cm width, 45-60 cm length and 15 cm depth are formed between clumps or hills of crops at the time of weeding.

Yet another modification of ridges and furrows method is the practice of sowing in lines on flat beds and formation of furrows between crop rows at 25 - 30 days after sowing. This enables sowing behind plough or through seed drill.

iv) Broad bed furrow (BBF)

Here beds of 1.5 m width, 15 cm height and convenient length are formed, separated by furrows of 30 cm width and 15 cm depth. Crops are sown on the beds at required intervals. It is suitable for heavy black soils and deep red soils. The furrows have a gradient of 0.6%. Broad bed furrow has many advantages over other methods.

- ☺ It can accommodate a wide range of crop geometry i.e close as well as wide row spacing.
- ☺ It is suitable for both sole cropping and intercropping systems.
- ☺ Furrows serve to safely guide runoff water in the early part of rainy season and store rain water in the later stages.
- ☺ Sowing can be done with seed drills.
- ☺ It can be formed by bullock drawn or tractor drawn implements. Bed former cum seed drill enables BBF formation and sowing simultaneously, thus reducing the delay between rainfall receipt and sowing.

v) Dead furrow

At the time of sowing or immediately after sowing, deep furrows of 20 cm depth are formed at intervals of 6-8 rows of crops. No crop is raised in the furrow. Sowing and furrowing are done across slope. It can be done with wooden plough in both black and red soils.

3. Agrostological methods

The use of grasses to control soil erosion, reduce run off and improve soil moisture storage constitutes the agrostological method. Grasses with their close canopy cover over soil surface and profuse root system which binds soil particles provide excellent protection against runoff and erosion. The following are the various agrostological methods of insitu moisture conservation.

i) Pastures / grass lands

Raising perennial grasses to establish pastures or grass lands is recommended for shallow gravelly, eroded, degraded soils. Grass canopy intercepts rainfall, reduces splash erosion, checks runoff and improves soil moisture storage from rainfall.

ii) Strip cropping with grasses

Alternate strips of grasses and annual field crops arranged across slope check runoff and erosion and help in increasing moisture storage in soil.

iii) Ley farming

It is the practice of growing fodder grasses and legumes and annual crops in rotation. Grasses and legumes like Cenchrus, stylo are grown for 3-5 years and followed by annual crops like sorghum for 2 year. When the field is under grasses or legumes, soil moisture conservation is improved.

iv) Vegetative barriers

Vegetative barrier consists of one or two rows of perennial grasses established at suitable interval across the slope and along the contour. It serves as a block to free runoff and soil transport. Vettiver, Cenchrus etc are suitable grasses for this purpose.

Vettiver can be planted in rows at intervals of 40 m in 0.5% slope. Plough furrows are opened with disc plough first before commencement of monsoon. 5-8 cm deep holes are formed at 20cm interval and two slips per hole are planted in the beginning of rainy season. The soil around the roots is compacted. Vettiver barriers check runoff and prevent soil erosion. While they retain the soil they allow excess runoff to flow through their canopy without soil loss. It is adapted to drought and requires less care for maintenance. It does not exhibit any border effect on crops in adjacent rows.

- It allows uniform spread of water to lower area in the field resulting in uniform plant stand thus increasing yield of a crop by 10-15%
- Facilitates better storage of soil moisture
- If fodder grasses like *Cenchrus glaucus* or marvel grass are used, fodder can also be harvested and given to the animal
- Vegetative barriers are best suited for black soil. Unlike contour bunding which give way due to development of crack in summer in black soils vegetative barriers do not allow such phenomenon in black soil. Hence the vegetative barriers can be effectively maintained in black soil for 4-5 years
- After 4-5 years, replanting material can also be had from the old barrier by 'quartering'

LEC 27. RECYCLING AND REDUCING LOSS OF SOIL MOISTURE – MULCHING – ANTI-EVAPORANTS AND ANTI-TRANSPIRANTS

C. Recycling of rain water

Runoff is that portion of precipitation which makes its ways towards stream, channel, lake or ocean as surface flow. Mostly runoff refers to surface flow only.

Runoff from rainfall is inevitable and can not be completely arrested. In dry farming areas, rainfall often occurs at high intensity which exceeds the infiltration rate and causes runoff. Also, when quantity of rainfall exceeds the water holding capacity of soils, runoff has to take place. In certain instances, surface characteristics of soils also cause runoff. Usually, under unchecked conditions, about 40% of rainfall may be lost as runoff. Even if moisture conservation practices are adopted, about 10-15 % of rainfall in black soils and about 20 % of rainfall in red soils is lost as runoff.

The amount of such runoff varies with rainfall intensity, soil physical properties, soil surface characters, slope, vegetation cover and cultural practices. Runoff water, if not checked, flows out and is wasted, causing soil erosion. It can be guided, collected and recycled to augment water availability to rainfed crops. The collection, storage and recycling of runoff water constitute the process of water harvesting.

Water harvesting can be viewed from two situations. First is a case of normal rainfall with high intensity on a few rainy days causing runoff. This runoff can be guided and collected in storage structures called farm ponds and reused for supplemental irrigation to crops suffering from moisture stress. This is termed as macro watershed approach or macro catchment water harvesting.

In the second instance, total rainfall is less and soil storage is inadequate for supporting crop growth. Here part of the land is left barren and uncultivated. This is known as donor area and is treated in such a way as to increase runoff from rainfall. The runoff from the donor strip is directed towards the lower adjacent strip to increase soil moisture storage there. This strip is used for raising crops. This is called as micro watershed approach or micro catchment water harvesting.

Water harvesting through farm ponds

The collection of rain water and storing in big farm ponds is not a new concept in Tamil Nadu. It is in vogue since early days in the form of tanks. Farm ponds are small storage structures constructed at the lowest point of a farm to collect and store runoff water. Runoff from various parts of the catchment area is properly guided through grassed water ways into the farm pond. The following points need to be considered while constructing farm ponds.

- Deep heavy soils with low permeability are better suited for farm pond technology than shallow light soils with high permeability. But, ironically, the usefulness of farm pond is more felt in light soils with low water storage capacity.
- Farm pond has to be constructed at the lowest point of the farm to collect runoff water from the entire farm area
- Size of farm pond depends on rainfall quantity, soil type, area of catchment (farm size) and estimated runoff.

Catchments area (ha)	Capacity of farm pond(ha cm)	Size of pond (m)		
		Top	Bottom	Depth
6.50	14.21	27.4	19.8	2.5
6.66	16.13	27.4	18.3	3.05
6.39	20.68	30.5	21.3	3.05
12.14	20.68	30.5	21.3	3.05
12.50	31.46	36.5	27.4	3.05

- Provisions for arresting soil inflow into the pond at the inlet point and a weir, for draining excess water when pond is full have to be made
- Runoff has to be guided to the farm pond through grassed water ways.
- Water loss through seepage and, evaporation has to be checked. Seepage loss, can be reduced by lining the sides and bottom with soil + sand + cement or soil + cowdung + straw, spraying sodium chloride or sodium carbonate on the surface. Evaporation loss can be reduced by floating materials to prevent direct exposure of water surface, changing the shape of the pond to provide more depth rather than surface area (circular instead of rectangular)

Advantages of farm pond

- Harvested water can be used for protective irrigation to crops at critical stages
- Since runoff is properly guided through grassed water ways, erosion is checked
- Earth excavated from ponds can be used for bunding and levelling of fields
- Stored water can be used as drinking water for humans and animals, for spraying operations and for fish rearing.
- High value tree crops can be raised near farm ponds with protective irrigation
- A chain of farm ponds can recharge ground water in the region

Water harvesting under deficit rainfall

The situation here is that the seasonal rainfall quantity .by itself is not sufficient to support a crop till maturity. Therefore, runoff of rainfall from a part of the land left uncultivated is directed to an adjacent strip which alone is used for cropping. In this strip (run-on strip / recipient area), the rainfall falling on its surface is supplemented by runoff directed from the other stiip of land (donor area / runoff strip) and total water supply available is increased to facilitate cropping. This can be accomplished by the following practices.

A portion of the field in the upper reach is left uncultivated. It is shaped or treated to increase runoff. This can be accomplished by covering the surface with Polythene films or by water proofing it by spraying sodium carbonate or water repellant materials like silicone / asphalt or by shaping the land into a sloping, clear, smooth, compact surface to increase runoff. Runoff from this donor strip is guided to a smaller, strip on the lower reach to increases soil storage and to raise crops. The proportion of 'donor area' to cropped area depends on rainfall quantity, duration of rainfall, soil properties and crop characters. In the p cropped area, land is shaped to conserve moisture. Acceptability of this method is however limited in regions where pressure on land does not permit leaving a large area barren for runoff harvesting.

Creating micro relief in cultivated field between seed rows to direct rain water to crop root zone is another approach. Here small alternate strips of land of suitable width are left without cropping. These un-cropped strips are ridged up and compacted or shaped to slope towards seed rows to increase runoff which will flow towards cropped strip. The relative width of runoff strip and cropped strip varies from 2:1 to 4:1 depending on rainfall. Land shaping through raised ridges between crop rows, planting in shallow ditch or trench, formation of slopping beds towards tree trunk, saucer shaped basins around trees, semicircular or crescent shaped basins on the downward slope around trees etc. come under this category. The micro watershed methods discussed above are also termed inter row water harvesting or inter plot water harvesting.

D. Reduction of loss of stored soil moisture

Rainfall infiltrates into the soil and permeates downward and laterally and gets stored in soil profile. Part of it percolates down to ground water. Stored water is absorbed by plants and weeds. It is lost from the soil surface as evaporation and from crop and weed canopy as transpiration. The loss through evaporation from soil and transpiration by weeds can be checked to reduce loss of stored moisture. Excessive transpiration loss from crop plants can also be minimized. ET loss is by latent heat of vapourisation and is governed by energy, vapour pressure gradient and conductivity of medium.

<u>Evapotranspiration can be checked by</u>

- Minimizing the evaporative surface area
- Minimize the energy need to the evaporative site
- Minimize the diffusivity / conductivity of water movement from soil
- Minimize the driving force or potential that is responsible for up ward movement of water

Reduction of evaporation loss

Evaporation happens to maintain soil thermal regime and is governed by

- Soil moisture content
- Vegetative cover on surface
- Soil type
- Temperature gradient between soil and atmosphere
- Atmospheric water demand.

Higher soil moisture content, especially a wet surface soil increases evaporation rate. As the surface soil dries up, continuity of capillary pores is disrupted and moisture movement up wards from deeper layers is reduced.

Soil surface that is exposed to radiation without any vegetative cover offers more scope for evaporation due to over heating. Evaporation loss in a cropped field is more in the early growth stage when canopy cover is less, especially in widely spaced crops and slow growing species. Vegetative cover prevents direct exposure of soil surface to radiation, reduces heating of soil layers and thus checks the necessity for evaporation.

Black soils tend to absorb more heat and may evaporate more water. When cracks are formed during drying, evaporation takes place from the sides of the cracks also. With high temperature, low humidity and dry winds atmospheric water demand increases the rate of evaporation.

Measures to control evaporation loss

Shallow surface tillage: When surface soil is stirred by tillage, the continuity of capillary pores is broken and the rise of water through capillary movement is obstructed. Shallow tillage after summer showers is beneficial in this regard. This process is called dust mulching. Inter tillage between crop rows during early dry spells has a similar effect.

Mulching: Mulching means covering the soil surface with any material such as organic wastes, plastic, Polythene, etc. The organic wastes used for mulching include crop stubbles, straw, coir pith, groundnut shell, husk etc. These wastes at 5-10 t ha^{-1} are spread on the soil surface to a thickness of 5-10 cm. Mulching provides the following benefits.

- Reduces direct impact of rain drops on soil particles and controls splash erosion
- Increases infiltration
- Reduces velocity of runoff water
- Controls erosion.
- Improves soil moisture storage from rainfall.
- Controls evaporation loss
- Suppresses weed growth.
- Influences thermal regime of soil by reducing soil temperature
- Improves microbial activity
- Controls salinity development.
- Can be incorporated as manures later

Mulching	% of rainfall stored in soil
No mulch	16-20
Straw mulch 1.6 t ha^{-1}	19-28
Straw mulch 3.3 t ha^{-1}	22-33
Straw mulch 6.6 t ha^{-1}	28-37
Straw mulch 22.0 t ha^{-1}	66

Vertical mulching is a technique where in trenches of 40 cm wide, 15 cm deep are dug at 2-4 m interval across slope and filled with stubbles or organic wastes to a height of 10 cm above soil surface. Runoff is checked, collected in the shallow trenches and redistributed to adjoining soil layers. Vertical mulch at Agricultural Research Station, Kovilpatti has increased cotton yield over flat bed system. This method can be considered as precursor method to broad bed furrow method.

Live mulching is the term used to describe the covering of soil surface through the plant canopy in intercropping system. (Eg) sorghum + forage cowpea, sorghum + sword bean

Dust mulching refers to the soil condition associated with tillage. When land is ploughed or stirred the surface soil is disturbed and this breaks the continuity of capillary pores from sub soil to surface. As a result, evaporation is checked and soil moisture is conserved. Guntaka (Blade harrow) / Danti/ hand hoe are the implements used for dust mulching.

Stover mulch or straw mulch refers to covering the soil surface with cumbu / sorghum straw, sugarcane trash reduces the evaporation and increases soil moisture efficiency. Similarly mulching with organic waste, crop residues, plastic material can be done.

Stubble mulch is referred to the stirring of the soil with implements that leave considerable part of the vegetative material or crop residues or vegetative litter on the surface as a protection against erosion and for conserving moisture by favouring infiltration and reducing evaporation. Stubble mulch is very effectively done in western countries, where crop residue or by products like straw, stover or haulms are not given to animals as fodder. Special farm implements are available to create minimum disturbance and leave large surface area undisturbed. It also acts as minimum tillage and conservation tillage.

Pebble mulch where small pebbles like stone are placed on the soil surface. This mulching will be successful in dry land fruit tree culture. The pebbles placed on the basins of trees not only reduce evaporation but also facilitate infiltration of rain water into the basin.

Use of anti-evaporanting chemicals: Chemicals like hexadecanol are used as anti-evaporants. When sprayed and mixed with soil surface, hexadecanol is reported to reduce evaporation by 43 %. The treated surface layer dries up fast and creates a diffusional barrier for upward movement of water vapour. It is resistant to microbial activity and degradation. It remains in soil for more than a year. It also increased the soil aggregate stability.

Evaporation from free water surface, farm ponds, lakes etc can be reduced to 80% by wax emulsions, rubber / plastic boats or saw dust.

Shelter belt

In arid and semiarid regions the hot winds dry the surface soil and create vapour pressure gradient and continuous vapourisation takes place. This continuous vapourisation can be arrested by raising shelter belt. It is a practice of growing one of multi rows of trees / shrubs or crop plants across the wind direction either in the field or field boundaries to reduce the wind effect and to reduce the wind velocity.

Shelter belt reduces

- The evaporation
- Increases soil moisture content by 3-5 per cent and this will be useful to alleviate the terminal moisture stress in crops grown in adjoining area. The increase in soil moisture percentage is due to favourable micro climate created by shelter belts
- It can be used as resting place of live stocks in dry lands
- Due to reduction in wind velocity, the pollen drift in orchard crops is minimized, there by pollination percentage is increased and fruit setting is improved.
- Many trees in shelter belt are economically important. After long period of maintenance the trees can be disposed off as timber and raw material for industrial use. Fruit trees grown in shelter belt gives fruits which fetch higher economic returns.
- Wind break is also a form of shelter belt, but only one row of tall trees having good leaf canopy are grown in North - South direction in order to reduce wind velocity and there by reduce soil erosion. Tall trees like eucalyptus, Casuarinas, wood apple are grown as wind breaks. After years of maintenance these trees can be disposed of economically.

Measures to reduce transpiration loss

Though transpiration is necessary and unavoidable evil, excessive transpiration has to be controlled especially when soil moisture stress develops during critical stages of crop growth. The rate of transpiration is governed by

- Soil moisture potential
- Atmospheric water demand
- Plant canopy characters such as leaf area, leaf orientation, stomatal resistance, etc.

Transpiration loss can be reduced by the use of antitranspirants and by some cultural methods also.

Antitranspirants

Antitranspirants are substances or chemicals applied on plant-foliage to control rate of transpiration. The important points to be considered in using antitranspirants are;

a) They should restrict water loss from leaf surface without restricting entry of carbon dioxide for photosynthesis, and

b) Transpiration necessary for cooling of leaf surface should not be completely stopped by the application of antitranspirants leading to rise in leaf temperature.

Based on their mechanism of action, antitranspirants are classified into various types.

b) Stomatal closing type: They cause partial or complete closure of stomata by inducing the guard cells to close. But complete closure of stomata adversely affects gas exchange and photosynthesis. These chemicals may also cause phyto-toxicity and are very expensive too. Eg. Phenyl mercuric acetate (PMA), alkanyl succinic acid (ASA).

c) Film forming type: They cover the stomata by forming a thin film over leaf surface. These substances are nontoxic, non degradable and very easy to apply but they adversely affect photosynthesis. Eg. Paraffin and wax emulsions, folic 2 % power oil 1 %.

d) Reflectant type: When sprayed on leaf surface, the reflectant type antitranspirants increase the leaf albedo or leaf reflectance of sunlight. As a result, heating is reduced, leaf temperature inside is low and need for transpiration is reduced. Eg. Kaolin, lime solution. Spraying kaolin, at 3-6% concentration reduced leaf temperature by 3-4 °C and transpiration by 22-28%. These are less expensive, non phytotoxic and do not interfere with photosynthesis since stomatal closure does not take place. Spraying 5% kaolin to cotton at grand growth stage is very successful.

e) Growth retardant type: Chemicals like cycocel (ccc-chloro choline chloride, chlor mequat) when sprayed on foliage, reduce leaf area and thereby reduce the transpiring area and transpiration.

Cultural methods of transpiration control

a) Weed control: Most weeds have a high transpiration coefficient i.e. amount of water transpired to produce unit quantity of dry matter. Early weed control prevents unwanted transpiration loss through weeds.

b) Shelterbelts: Rows of trees grown across the direction of wind reduce air movement, reduce temperature of air and plant canopy, increase humidity in the protected strips and thereby reduce the atmospheric water demand and control transpiration in the inter space between shelterbelts.

c) Alley cropping: This practice refers to raising perennial shrubs or tall crops as hedge rows up to 1-2 m height at 48 m intervals and raising short statured annual crops in the alleys (inter space between hedge rows). A similar effect on reduction in atmospheric water demand and transpiration as described under shelter belts is caused in alley cropping. This method is also called as hedge row inter cropping. Eg.

Hedge row	Intercrop
Leucaena / Desmanthus	Blackgram / cowpea / sunflower / groundnut
Agathi / castor / Perennial redgram / Casuarina (trained as bush) glyricidia / cowpea	Cotton / blackgram

LEC 28 RAINFALL USE EFFICIENCY – CROPS AND CROPPING SYSTEM – CHOICE OF CROP AND VARIETIES – INTERCROPPING – SEQUENTIAL CROPPING – CROP SUBSTITUTION AND ITS IMPORTANCE – CLIMATOLOGICAL APPROACH FOR CROP PLANNING

E. RAINFALL USE EFFICIENCY

1. Most common definition is WUE = Dry weight produced/ET

Any soil moisture conservation technique which increases the RUE will be considered as the best management technique for that area.

Sorghum	Soil moisture %		Cotton + Black gram	Soil moisture %
Bund	33.0	10.2	BBF	22.7
Graded Bund	31.0	10.3	CB	21.6
Vetiver	35.0	9.0	Tied ridge	20.4
Dead furrow	29.0	8.8	Dead furrow	19.6
			Flat bed	18.7

2. Relationship between yield and RF

RUE = Yield / Rainfall Kg/mm

Eg. Silvipasture = 28 Kg/mm, Cotton = Less than 10 Kg/mm

3. Stanhill, 1986 defined WUE as the ratio of water used (ET) to the water potentially available (Rainfall + stored moisture)

Choice of crops

Traditional cropping pattern in the dry farming areas is dominated by food grains viz Millets and pulses. In a predominantly subsistence type of farming system, such dominance of food crops is natural. The choice of crops for drylands is affected by

- Rainfall quantity and distribution
- Time of onset of rainy season
- Duration of rainy reason
- Soil characters including amount of rain water stored in the soil
- Farmer's requirements

The major focus of research under AICRPDA has been on the identification of most efficient crops for each dry farming region. The criteria for choice of crops comprise the following

- Tolerance to drought
- Fast growth during initial period to withstand harsh environment
- Genetic potential for high yield
- Short or medium duration to escape terminal drought
- Adaptability to wide climatic variations
- Response to fertilizers

Selection of suitable varieties

In most crops of dry farming regions, traditional local varieties still dominate. The preference for these local varieties is based on their pronounced drought tolerance. But they are usually longer in duration susceptible to moisture stress at maturity. They have low yield potential even under favourable rainfall. They do not respond significantly to improved management such as nutrient supply. The criteria now adopted for selection of crop varieties for dry lands include drought tolerance, short or medium duration, high yield potential, response to nutrient supply, high water use efficiency, moderate resistance to pest and diseases. Suitable varieties for all dry land crops have been developed in all the dry farming regions and have proved their high yield potential.

Choice of cropping system

Cropping system refers to the spatial and temporal association of crops in a farming system. Choice of suitable cropping system must aim at maximum and sustainable use of resources especially water and soil. Cropping systems depend on rainfall quantity, length of rainy reason and soil storage capacity. The broad guidelines in choosing a cropping system for dry lands are given below.

Potential cropping system based on rainfall and soil characters

Rainfall (mm)	Soil type	Growing season (weeks)	Profile storage capacity (mm)	Suggested cropping system
350-600	Alfisols, shallow vertisols	20	100	Single rainy season cropping sorghum / maize / soybean
350-600	Deep aridisols, Entisols(alluvium)	20	100	Single cropping sorghum / maize / soybean in kharif / rabi
350-600	Deep vertisols	20	100	Single post rainy season cropping sorghum
600-750	Alfisols, vertisols, entisols	20-30	150	Intercropping 1. Sorghum + Pigeon pea 2. Cotton + Black gram
750-900	Entisols, deep vertisols, deep alfisols, inceptisols	30	200	Double cropping with monitoring 1. Maize – safflower 2. Soybean – chick pea 3. Groundnut – horsegram
> 900	As above	> 30	> 200	Assured double cropping Maize – chick pea Soybean - safflower

Intercropping

Intercropping refers to growing two or more crops in the same field during the same season. Intercropping is widely practiced in dry farming since it offers many advantages as outlined below.

- Intercropping is a risk minimization strategy and provides an insurance against complete crop failure due to rainfall abnormalities. This is made possible through the duration difference between component crops
- It provides more yield and income per unit area per unit time than sole cropping
- Stability in production is achieved
- Multiple products for home consumption as well as for marketing are made available
- When legumes are included in intercropping, soil fertility is enriched
- Intercrop canopy suppresses weed growth
- Some intercrop combinations provide biological control of pests and diseases (eg) cotton + cluster bean cropping system. Intercrop cluster bean reduces jassid incidence in cotton
- Resource use efficiency is increased viz., light, water and nutrients are efficiently used

However, for success in intercropping the competition between component crops must be minimized and the complimentary effects must be maximized. This can be accomplished by the following means

- Choice of suitable component crops differing in duration, rooting pattern, canopy architecture nutrient requirement and occurrence of critical stages
- Selection of genotypes in each component crop
- Optimum population of component crops
- Suitable crop geometry to provide adequate space for intercrops
- Preference for leguminous crops as intercrops

Inter cropping system suitable for drylands

Crops	Geometry	Base crop duration	Intercrop duration
Sorghum + Lablab	6-8:2	100-120	150-180
Sorghum + Redgram	6-8:1	100-120	180
Sorghum + Cowpea	2:1	100-120	80
Cotton + Black gram	2:1	150-185	65-75
Groundnut + Redgram	6-8:1	105	180
Groundnut + Castor	6-8:1	105	150-180
Bengalgram + Coriander	4:1	100	80
Maize + Cowpea	2:1	100-110	75-80
Ragi+ Cowpea + Redgram	6:1:1	100	75 + 180

Double cropping in drylands

Double cropping either by sequential cropping or relay cropping is possible in places with high rainfall (> 900 mm) extended rainy season and high soil moisture storage capacity.

Double cropping by relay cropping

Groundnut / Ragi	+	Redgram	-	Horsegram
(Jun-Sep)		(Jun-Jan)		(Sep-Jan)

Groundnut or ragi is sown with redgram as intercrop in 6:1 proportion in June. After harvest of groundnut in September, horsegram is relay sown in the space between redgram rows.

Double cropping by sequential cropping

Pearl / ragi / samai (May – Sep)	Horsegram (Sep – Jan)
Groundnut / sesamum (May – Sep)	Horsegram (Sep – Jan)
Cowpea / greengram (Jun – Sep)	Sorghum (Oct – Jan)
Sorghum (Jul – Oct)	Chickpea (Oct – Feb)

Efficient double cropping system for drylands of India

Soil type	Region	Water availability (days)	Double cropping system
Vertisols	MP	210-230	Maize – chickpea Soybean – wheat
	Maharastra	190-210	Sorghum – safflower
	Karnataka	130-150	Cowpea – sorghum Greengram – safflower
Inceptisols	UP	200-230 180-200	Rice – Chickpea Pearl millet – chickpea Blackgram – mustard
Oxisols	Bihar	160-180	Maize – chickpea Groundnut – barley
Alfisols	Karnataka	190-220	Cowpea – ragi Soybean – ragi
Alfisols and aridisols		< 120	No double cropping

Crop substitution

It refers to the replacement of an existing low yielding crop with another crop which is better adapted to the prevailing environment and is capable of giving higher yield under similar climatic conditions. For many dry farming regions of India, more suitable crops than existing ones have been identified. However, the acceptance and adoption of the practice of crop substitution by dry land farmers is poor since in most instances the new crops replace food crops.

Region	Traditional crop	q/ha	More suitable crop	q/ha
Agra	Wheat	10.3	Mustard	20.4
Bellary	Cotton	2.0	Sorghum	26.7
Bijapur	Wheat	9.4	Safflower	18.8
Varanasi	Upland rice	28.0	Maize	33.8

In vertisols of Tamil Nadu, sunflower and maize are substituting millets and senna substituting low value pulses.

CLIMATOLOGICAL APPROACH FOR CROP PLANNING

Crops and varieties selected should match the length of growing season during which they are not subjected to soil moisture stress. Climatological analysis helps to identify cultivars suitable for different regions. Feasibility for intercropping, sequence cropping and double cropping can also be known from such analysis. For regions with cropping season less than 20 weeks, single crop during *kharif or rabi* is recommended. Regions with more than 30 weeks and above have no problem for double cropping. In regions with 20-30 weeks cropping season, double cropping may be risky. Such areas are ideal for intercropping.

LENGTH OF EFFECTIVE CROPPING SEASON IN DIFFERENT AREAS (RANDHAWA AND VENKATESWARULU 1979)

Category	Effective cropping season(weeks) in different areas			Potential cropping system
< 20 weeks	Bellary (8) Hissar (17)	Jodhpur(11) Rajkot (17)	Anantapur (13) Bijapur (17)	Sole cropping
20-30 weeks	Jhansi (21) Udaipur (22) Anand (25)	Kovilpatti (21) Solapur (23) Akola (27)	Hyderabad (22) Agra (24)	Intercropping
> 30 weeks	Bhubaneswar (32) Bangalore (36) Rewa (36) Samba (44)	Varanasi (32) Hoshiarpur (35) Ranchi (45)	Indore (36) Dehradun (44)	Sequence cropping

Water balance for different agroclimatic regions has been calculated and water availability periods worked out. Regions with 350-600 mm rainfall having 20 weeks effective growing season are suitable for single cropping in *kharif* (red and shallow black soils) or *rabi* (deep black soils). Intercropping is possible in regions receiving 600-750 mm rainfall and having 20-30 weeks of effective growing season. Areas with more than 750 mm rainfall or with more than 30 weeks are suitable for double cropping.

SUITABLE CROPPING SYSTEMS BASED ON RAINFALL AND WATER AVAILABILITY PERIOD

Rainfall (MM)	Soils	Water availability period (weeks)	Potential cropping system
350-600	Alfisols & Shallow vertisols	20	Single kharif cropping
350-600	Aridisols & Entisols	20	Single cropping either in kharif or rabi
350-600	Deep Vertisols	20	Single rabi cropping
600-750	Alfisols, Vertisols &Entisols	20-30	Intercropping
750-900	Entisols, Deep Vertisols, Alfisols & Inceptisols	>30	Double cropping with monitoring
>900	Entisols, Deep vertisols, Alfisols & Inceptisols	>30	Assured double cropping

LEC 29. ESTABLISHMENT OF OPTIMUM POPULATION – SEED HARDENING – PRE-MONSOON SOWING – TIME, METHOD AND DEPTH OF SOWING – DENSITY AND GEOMETRY

Establishment of optimum population

Poor or suboptimal population is a major reason for low yields in rainfed crops. Establishment of an optimum population depends on

- Seed treatment
- Sowing at optimum soil moisture
- Time of sowing
- Depth of sowing
- Method of sowing
- Crop geometry

a) Seed treatment

Seed treatment is done for many purposes such as protection against pests and diseases, inoculation of bio-fertilizers and inducing drought tolerance.

Seed treatment with insecticides and fungicides is a low cost technology for protection against pests and diseases. In drylands, spraying of chemicals for pest control is difficult due to scarcity of water. Hence a preventive measure through seed treatment is very useful.

Bio-fertilizers like azospirillum, rhizobium and phosphobacterium are applied through seed inoculation as a low cost technology for nutrient supply.

Seed hardening

It is done to induce drought tolerance in emerging seedlings. It is the process of soaking seeds in chemical solution and drying to induce tolerance to drought. Soil moisture stress immediately after sowing affects germination and establishment. Seed hardening enables seedlings to survive this early moisture stress.

During seed hardening, seeds are subjected to partial hydration followed by dehydration before sowing. Seeds are soaked for specified time in chemical solutions of prescribed concentration. Soaked seeds are then dried in shade back to original moisture content. During soaking, seeds imbibe water and germination process is started but not completed. The hardened seeds are thus in a ready state for germination. When sown in moist soils, seeds germinate immediately. Such early germination helps in seedling emergence before surface soil dries up.

The advantages of seed hardening are listed below

- ☺ Ensures early germination by 2-3 days compared to untreated seeds
- ☺ Induces better root development which enables absorption of more moisture
- ☺ Germination and seedling emergence are completed before surface soil dries out
- ☺ Induces drought tolerance by increasing the resistance to protoplasmic dehydration in young seedlings subjected to moisture stress.
- ☺ Low cost technology
- ☺ Hardened seeds can be sown immediately or within 30 days of treatment.
- ☺ Most important requirement for pre-monsoon sowing.

For success in seed hardening, attention must be paid in selection of right chemical, its concentration, time of soaking, volume of solution and drying under shade to original moisture content.

Seed hardening in various crops

Crop	Chemical	Concentration	Soaking time	Volume of solution per kg seed
Rice	Potassium chloride	1 %	Water-10hrs chemical-10hrs	1 litre
Sorghum	Potassium di-hydrogen phosphate	2 %	6 hrs	350ml
	Potassium chloride	1 %	5 hrs	1 litre
Pearl millet	Potassium chloride	2 %	16 hrs	1 litre
	Sodium chloride	3%		
Ragi	Calcium chloride	0.5%	Until visibility of embryo growth	1 litre
Sunflower	Zinc sulphate	2 %	12 hrs	1 litre
Cotton	CCC	1000 ppm	6 hrs	1 litre
	KCl	2%	5 hrs	1.6 litres
	DAP	2%	5 hrs	1.6 litres

Pulses (Black gram / green gram)
Four kilo gram of wood ash is collected, powdered thoroughly to which 30% Acacia gum is added and mixed thoroughly so that wood ash - gum paste is obtained. Eight kg of black gram or green gram seed is spread over the Acacia - wood ash paste and mixed thoroughly so that all the seeds are smeared with the paste. The treated seeds are shade dried for 5 hours and then can be sown.

b) Sowing at optimum soil moisture

An effective rainfall of 20-25 mm which can wet a depth of 10-15 cm is needed for sowing. Moisture stress at or immediately after sowing adversely affects germination and establishment of seedlings. To ensure adequate soil moisture at sowing, sowing has to be done as early as possible after soaking rainfall is received. Sowing methods and implements play a crucial rile in this regard.

c) Time of sowing

Optimum time of sowing is indicated by adequate rainfall to wet seeding depth and continuity of rainfall after sowing. The probable sowing time in a rainfed area is the week which has a rainfall of not less than 20 mm with coefficient of variability less than 100% and the probability of a wet week following wet week. Timely sowing ensures optimal yield besides it may also help pest avoidance. Maharastra kharif sorghum cultivated in 30 lakh hectares and more than 70% is under hybrid prone to shoot fly. If sown at early July, the pest incidence can be avoided.

Pre-monsoon dry seeding

In some regions, where heavy clay soils dominate, sowing after rains is impossible due to high stickiness of soil. Here sowing is done in dry soil, 2-3 weeks before the onset of monsoon (pre-monsoon). Seeds will remain in soil and germinate only on receipt of optimum rainfall.

The advantages of pre-monsoon dry seeding are

- Early sowing
- Uniform germination and good establishment
- Utilization of first rainfall itself for germination instead of for land preparation in post monsoon sowing
- Early maturity before closure of monsoon and avoidance of stress at maturity.

The success of pre-monsoon dry seeding depends on the following

i) It is recommended for bold seeds like cotton and sorghum only and not for all crops.
ii) Time of advance sowing must be fixed based on rainfall analysis for date of onset of monsoon and continuity of rainfall after sowing.
iii) Seeds must be hardened to ensure quick germination and drought tolerance
iv) Seeding depth must be such that seeds will germinate only after receipt of rainfall to wet that depth is received. Surface sowing may lead to germination with less rainfall and death due to subsequent soil drying.
v) Off season tillage is necessary to enable sowing in dry soil before monsoon
vi) Seed damage by soil insects has to be prevented

Examples of pre-monsoon sowing

1. For sorghum in black soils, pre-monsoon dry seeding is recommended 1-2 weeks before onset of monsoon with depth of sowing at 5 cm and seed hardening with 2 per cent potassium di-hydrogen phosphate or potassium chloride.

2. For cotton in black soils, pre-monsoon dry seeding is recommended at 2-4 weeks before commencement of monsoon, with a sowing depth of 5 cm and seed hardening with CCC (500 ppm) or potassium chloride or DAP at 2% level.

d) Optimum depth of sowing

When seeds are sown on surface or at very shallow depth, germination and seeding growth are affected when surface soil moisture dries up. Sowing at a depth where soil moisture availability is adequate, ensure early and uniform germination and seedling establishment. Optimum depth of' sowing varies with crop, especially seed size and penetration power of plumule.

Sesamum,	1-2 cm
Pearl millet and minor millets	2-3 cm
Pulses, sorghum, sunflower	3-5 cm
Cotton, maize	5 cm
Coriander	7 cm

e) Method of sowing

Sowing method is an important determinant of population. In dry lands, it is important to sow the seeds in moist soil layer to ensure proper germination and seedling emergence. It is therefore necessary to sow immediately after rainfall to avoid sowing in dry soil. It is also important to sow the seeds at correct depth, neither on the surface nor too deep. Establishment of an optimum population also depends on proper spacing between plants. The density, geometry, and depth of sowing are dependent on method of sowing. The sowing methods usually adopted in dry lands include broadcasting, sowing behind plough and sowing by seed drills. Dibbling of seeds and planting of seedlings are also adopted for some crops. (Cotton, tobacco, chillies). Each method has advantages as well as limitations. The choice of sowing method depends on seed size, soil condition time available, cropping system, crop geometry, sowing depth, source of power, cost of sowing, etc.

Merits and limitations of sowing methods

Sowing method	Merits	Limitations
Broadcasting	Quick coverage for small seeds like - ragi, sesamum, minor millets, medium sized seed like sorghum pulses can also be broadcasted	Spacing and depth not ensured high seed rate-intercrop sown separately

Sowing behind plough	For medium and bold seeds cotton, sorghum, maize, groundnut, pulses, castor, sunflower seeding requires wooden plough only. Easy operation-row spacing can be ensured	Low coverage-spacing between plants and depth of sowing not ensured. Intercrop has to be sown separately. Only monsoon sowing is possible
Local seed drill (gorru)	For medium and bold seeds wooden implement easy maintenance, less cost, row spacing is ensured, more coverage than broadcasting and sowing behind plough. Sowing depth and row spacing is uniform	Spacing between plants is not uniform and depends on experience of seed dropper. Intercrop has to be sown separately. Cannot be used for pre-monsoon sowing.
Mechanised seed drill (Bullock drawn/tractor drawn)	Large coverage, row and plant spacing ensured uniform depth of sowing. Base crop and intercrop sown simultaneously, enables early sowing in large area, saves cost and time. Pre monsoon sowing is possible.	Initial cost is high, needs skill for operation and maintenance.

f) Crop geometry

Crop geometry refers to the shape of land occupied by individual plants as decided by spacing between rows and between plants. It depends on the root spread and the canopy size of the crop and the cropping system.

Crop	Crop geometry (cm)	
	Sole crop in solid row	Intercropping
Sorghum	45 x 15	(60+30) x 15 paired row
Pearl millet	30 x 15	
Ragi	30 x 10	
Small millets	30 x 10	
Black gram, green gram, Soybean, horsegram	30 x 10	
Redgram	60 x 30	
Cowpea	30 x 15	
Cotton	45 x 30	(60+30) x 15 in paired row
Cotton (A*rboreum*)	45 x 15	
Groundnut	30 x 10	
Sesamum	30 x 30	
Sunflower	45 x 15	
Sunflower hybrids	45 x 20	
Sunflower varieties	30 x 15	
Coriander	30 x 15	
Senna	45 x 15	
Maize	45 x 30	

LEC 30. SOIL FERTILITY MANAGEMENT – FERTILIZER USE EFFICIENCY – TIME AND METHOD OF FERTILIZER APPLICATION

"Dryland soils are not only thirsty, but also hungry'

Reason for not using fertilizer

1. Uncertainty of return from the investment on fertilizer use
2. The poor resource base of dryland farmers

The fertilizer use in dryland crops might vary between 5 to 40 kg/ha ($N+P_2O_5+K_2O$). Soils are low in N and P and Zn is the most limiting factor among micronutrient others are Ca, Mg, S for which response was recorded.

Reasons for Poor soil fertility

- Slow weathering of minerals
- Low organic matter content
- Reduced microbial activity
- Erosion
- Very low addition of manures and fertilizers
- Soil salinity and alkalinity
- Reduced mobility of nutrients and nutrient fixation

Nutrient removal by dryland crops

Crop	kg /t of yield			
	N	P	K	Total
Sorghum	22.4	13.3	34.0	69.7
Pearl millet	42.3	22.6	90.8	155.7
Groundnut	58.1	19.6	30.1	107.8
Cotton	44.5	28.3	74.7	147.5
Bengalgram	46.3	8.4	49.6	104.3
Soybean	66.8	17.7	44.4	128.9
Redgram	62.0	11.5	65.0	138.5

Nutrient requirement of dryland crops

Crop	kg /q of produce			
	N	P	K	Total
Pearl millet	3.73	0.99	4.89	9.61
Maize	2.00	0.92	3.00	5.92
Soybean	7.40	1.45	7.20	16.05
Red gram	6.20	1.15	6.50	13.85
Groundnut	6.65	2.12	4.39	13.16

Experimental evidence has clearly established as below the high yield potential of dryland crops with sufficient nutrient supply.

	Yield q/ha		
	Sorghum	Cotton	Groundnut
No nutrients	18	3.2	5.5
FYM + NPK	35	6.8	8.7

The beneficial effect of nutrient supply in dry land

- Deficiency in soil supply of nutrients required by crops is corrected
- Nutrient supply promotes root development, which enables higher uptake of soil moisture and high water use efficiency. This positive relationship between nutrients and moisture is mutual
- Increased vigour of a fertilized crop enables it to survive drought better than an unfertilized crop

The above facts obviate the many misconceptions about manures and fertilizers use in drylands. Farmers in drylands however do not apply sufficient quantity of nutrients since nutrient sources like manures and fertilizers are costly and risks to dependable crop production and returns are high. The average consumption of inorganic fertilizers is less than 10 kg per ha in drylands. Even this is confined to a few commercial crops like cotton, groundnut, chillies only. According to an estimate of nutrient application rates in the SAT region of India, 151 district use less than 5 kg ha^{-1}, 22 use 5-10 kg ha^{-1}, 27 use 10-20 kg ha^{-1}, 22 use 20-40 kg ha^{-1} and only 2 districts use more than 40 kg ha^{-1}.

State-wise per cent of rainfed area fertilized

State	Per cent	State	Per cent
Madhya Pradesh	5	Maharashtra	18
Karnataka	22	Gujarat	32
Rajasthan	3	Andhra Pradesh	13
Tamil Nadu	9	Uttar Pradesh	10
Haryana	4	Punjab	37

The reasons attributed by farmers for poor adoption of nutrient supply to rainfed crops include the followings.

- High cost, inadequate availability of fertilizers and inadequate availability plus high cost of transport of organic manures, fear of scorching due to inorganic fertilizer addition.
- Low and uncertain yield and income due to undependable rainfall behaviour
- Apprehension that a well fertilized crop growing vigorously would exhaust soil moisture supply early and subject the crop to moisture stress at later stages
- Adoption of fertilizer non responsive varieties in large

Due to the above reasons, nutrient supply in drylands is at a slow pace. In order to ensure adequate nutrient supply, care must be taken to understand the factors that influence nutrient use efficiency in dry crops and to evolve an integrated nutrient management system that will be efficient, economical and environmentally sustainable.

Scope for fertilizer use in drylands

- Introduction of new high yielding varieties / hybrids in different crops which are fertilizer responsive at a given adequate soil moisture storage level.
- Development of new in situ soil moisture conservation methods enhances the duration time and depth of soil moisture availability. This will increase the fertilizer use efficiency. Hence there is good scope for fertilizer applications.
- Use of integrated nutrient management in different crops, increase the use efficiency of fertilizer and increase the yield.
- Short duration / early duration varieties of crops utilize the fertilizers efficiency than long duration varieties of the same crops.

Factors influencing nutrient use efficiency in drylands

Nutrient use efficiency refers to the yields per kg of nutrient applied. The response of rainfed crops to nutrient application depends on crop and variety, rainfall and soil moisture availability, soil properties, quantity, time and methods of nutrient application, cropping system adopted and management practices such as moisture conservation, timely weed control etc.

Response rainfed crops to nutrients:

	kg grain / kg of nutrient	
	Nitrogen	Phosphorus
Sorghum	3.4 – 43.4	2.4 – 59.0
Pearl millet	2.1 – 24.8	1.7 – 14.3
Ragi	5.0 – 42.4	6.4 – 38.0
Maize	4.1 – 67.4	6.8 – 80.0
Thenai	5.9 – 17.9	-
Sunflower	1.5 – 22.6	1.2 – 2.0
Groundnut	1.3 – 6.0	1.2 – 15.0
Sesamum	1.3 – 5.0	1.1 – 3.1
Greengram	-	1.5 – 11.6
Blackgram	-	1.8 – 6.7
Redgram	-	3.1 – 8.3

a) Rainfall and soil moisture availability

Water and nutrients interact positively and exhibit a mutual complementary effect. Adequate and well distributed rainfall enables higher nutrient uptake and response. This is accomplished through greater mobility of nutrients in a moist soil, improved microbial activity and better root growth. Under moisture stress nutrient uptake suffers due to reduced mobility of nutrients, restricted root growth high salt concentration of soil solution, nutrient fixation and reduced microbial activity.

Soil moisture storage	Yield of sorghum (q ha^{-1})
50 mm	13.0
100 mm	23.3

Rainfall	Response of sorghum (kg/kg)
500 mm	6.5
730 mm	27.7

Nutrient supply improves water use efficiency through, extensive root growth reduced evaporation loss through canopy coverage of soil and higher yield.

Information about rainfall quantity, distribution and probability, are very useful to make decisions on soil fertility management. If a region is defined as one having a dependable onset of monsoon and hence adequate soil moisture for crop establishment, then basal dressing of fertilizer would be safe.

If continuity and assurance of rainfall in early growth stage are present, then top dressing would be beneficial. Since, high intensity rainfall is common in drylands, split application of nitrogen would be advantageous to prevent loss through leaching. Information on rainfall probability could be used with advantage in scheduling fertilizer application to suit moisture storage capacity of soil profile and progress of rainfall during cropping season.

b) Crop and variety

Crops and varieties vary in their ability to use applied nutrients. Hybrids and high yielding varieties (HYV) respond better than local varieties because of their high yield potential at the same level of resource supply.

Cultivar	Sorghum yield q ha^{-1}
Local	12
HYV	20
Hybrid	30

Among the crops also, response to individual nutrients varies with species. Cereals and millets respond more to nitrogen, legumes to phosphorus and oilseeds to N, P and K.

c) Soil properties

Soil physical properties influence crop response mainly by affecting soil moisture availability. Soil nutrient status also has a significant effect on crop response, Drylands are mostly deficient in N and so there is universal response to N. Response to P depends on fixation in soil and to K on leaching loss.

d) Management practices

Nutrient management aspects such as quantity, time and method of application of nutrients, inclusion of legumes in cropping system, soil moisture conservation practices etc. also influence crop response to nutrients.

Crop response to N depending on rainfall (q/ha)

Rainfall	Above normal		Normal		Below normal	
Nutrient	Control	20-40kg	Control	20-40kg	Control	20-40kg
Pearl millet	10.9	20.8	7.5	13.7	2.5	6.3
Sesamum	4.9	14.7	3.2	5.8	-	-
Sorghum	14.8	31.5	-	-	13.8	29.0
Sunflower	-	-	14.9	22.0	12.3	17.0

LEC 31. INTEGRATED NUTRIENT MANAGEMENT FOR DRYLANDS

The components of INM for rainfed crops are the following

1. Organic manures

Organic matter content in dryland soils is low and its improvement is essential to promote soil moisture storage and nutrient supply. This can be accomplished through addition of FYM/ compost, green manure/ green leaf manures and crop residues. Addition of FYM/compost at 12.5 t ha is recommended. Incorporation of green manures / GLM before sowing or incorporation of intercropped legumes is useful. At Bangalore, yield of ragi was increased by 2-6 q ha^{-1}, incorporation of green leaves at 5-10 t/ha . At Bijapur incorporation of sunnhemp or Leucaena leaves increased the yield of sorghum and sunflower. At Sholapur leucaena loppings increased the yield of rabi sorghum. At Bhubaneswar incorporation of glyricidia leaves increased the yield of maize and finger millet.

At Kovilpatti incorporation of sunnhemp not only reduced 50 % N requirement but also sustained yield in cotton, sunflower and improved physico-chemical properties of soil. In Tamil Nadu, Kolinji and Aavarai *(Cassisa auriculata)* are used as GLM in drylands. Leaves of leguminous trees through loppings and prunings can serve as GLM eg. Subabul, Vagai, Neem, Sisoo, Aacha.

Effective management of crop residues can also help to improve organic matter content. Maize residues at 4 t ha^{-1} per year in alfisols of Bangalore increased the organic carbon from 0.5 to 0.9% in 5 years and maize yield increased by 25%. At Hyderabad alfisols, crop residue incorporation caused improvements in soil structure, stable aggregate, hydraulic conductivity and yield of pearl millet and cowpea was increased. At AICRPDA centres crop yield increase due crop residue incorporation was recorded in rainfed rice, sorghum, maize, lentil and sesamum. The materials used were leucaena loppings, leaves and twigs of perennial redgram, stubbles of sorghum and haulms of greengram and groundnut. Farm residue used along with inorganic fertilizer, increased grain yield in bajra at Kovilpatti.

2. Fertilizers

Quantity: Great care is required in deciding on the quantity because of high cost. It depends on soil content, crop and moisture availability

Recommended dose of fertilizer application (kg ha^{-1}) to dry land crops of Tamil Nadu

Crop	N	P	K
Sorghum			
Maize			
Cumbu			
Cotton	40	20	0
Sunflower	40	20	20
Pulses	12.5	2.5	0
Groundnut	17.5	35	53

Method of application must ensure application of nutrients in moist soil and prevention of loss. N can be applied basally at last ploughing and incorporated. Foliar application of N is useful when crops are reviving from stress. For P placement near root zone by basal incorporation or at 5-10 cm from seed rows is effective to prevent fixation and to ensure easy availability. To avoid fixation of applied P, application as enriched FYM is recommended. Deep placement is important for post rainy season crops grown on stored moisture. K is applied basally at last ploughing and incorporated. Micronutrients are applied after sowing but not incorporated. Use of seed cum fertilizer drill is very useful for placement of fertilizers

Time of application should be such to suit crop requirement and moisture availability. Since adequate moisture is always available at sowing basal application is effective. N can be top dressed at 25-30 DAS depending on rainfall. This enables skipping fertilizer if rainfall is not adequate and save the cost. For millets and cotton ½ N and full P and K are applied basally and ½ N is top dressed. For other crops full NPK is applied basally. For pre-monsoon sown crops like cotton, sorghum entire P can be applied basally as enriched FYM. In case of sorghum entire N can be applied at 30-35 DAS and for cotton N can be applied in two equal split at 20-25 and 40-45 DAS depending upon the receipt of rainfall during the corresponding period.

3. Legumes in cropping system

Legume intercropping is very common in drylands. When a short duration legume is intercropped with a long duration non legume the legume haulms after picking pods can be incorporated to benefit the non-legume by current transfer of legume fixed N. Intercropping green gram with sunflower with 30 kg N produced sunflower yield on par with 60 kg N. Intercropping greengram or fodder cowpea in pearl millet provided 20 kg N in Hisar.

In Hyderabad, cowpea ploughed in between castor rows at 40-45 DAS provided N equivalent to 30 kg to castor. Cotton + black gram intercropping system increased the residual N and organic carbon content on soils of Kovilpatti. Sequential cropping short duration legumes grown for grain / fodder as first crop, enrich the soil and the residual effect benefits the succeeding crop. In alluvial soils of North India, short duration fodder legumes like cowpea, cluster beans, moth bean and soybean provided residual effect to barley. Grain yield of barley grown after legumes was better than after pearl millet. Nutrient contribution was equivalent to 40 kg N ha^{-1}. Maize sown after groundnut was benefited by residual effect equivalent to 15 kg N ha^{-1} at ICRISAT. Non legumes grown after groundnut can be fertilized with reduced N by at least 25-50 kg N ha^{-1} due to considerable quantity of minearalisable N left by groundnut. Sole cowpea as first crop provided residual fertility effect equivalent to 25-50 kg N ha^{-1}. Green gram /blackgram grown during kharif incorporated after picking first flush pods improved the yield of succeeding mustard and barley through contribution of residual N equal to 40-60 kg ha^{-1}.

4. Biofertilisers

Seed inoculation of legumes with Rhizobium and seed inoculation and soil application with Azospirillum for cereals, millets, cotton, sunflower and sesamum is recommended. Besides N fixation, Azospirillum reportedly improves root growth through the exudation of growth promoting substances. Use of phosphobacteria as seed inoculation and soil application for solubilising native P also recommended. VA mycorrhizae have been found to play a crucial role in P nutrition of dryland crops especially soybean, sorghum and pearl millet. Biofertilizers constitiute a low cost technology in nutrient management.

Management practices such as moisture conservation techniques, raising responsive varieties, timely weed control and emphasis on low cost and no cost technologies also play a vital role in nutrient management for dryland crops.

Low cost technology and non-monetary inputs in soil fertility management

Nutrient supply is a costly input, compared with other components of dryland technology package. Considering the uncertainty and low level of returns in drylands during years of abnormal rainfall, low cost technologies and non-monetary inputs relevant to soil fertility management must be given due importance. Seed inoculation and soil application of biofertilizers, use of enriched FYM, split application of N fertilizer, suitable method of application, choice of responsive cultivars and inclusion of legumes in intercropping are useful technologies in this regard.

Based on the work carried out at the cooperating centres of the All India Coordinated Research Project for Dryland Agriculture (AICRPDA), fertilizer management practices have been developed for different food crop based production systems operating in different parts of India (Randhawa and Singh, 1983). Important points that emerge from these recommendations are:

- The recommended doses of fertilizers are higher in areas where incident rainfall and moisture storage capacity of the soils are higher.
- By and large, crops respond to application of N and P, the response for K being sporadic in Alfisols and Inceptisols.
- A starter dose of N @ 15-20 kg ha^{-1} is recommended for leguminous pulse crops.
- N is recommended to be applied in splits, whereas P and K are to be applied as basal.
- Fertilizers are recommended to be placed below seeds all at sowing for post-rainy season crops.
- For acid soils, application of lime is recommended as amendment for crops like maize, blackgram, greengram and finger millet. Paper mill sludge can, however, substitute lime as amendment.
- Inoculation with appropriate *Rhizobium cul*ture is recommended for pulses.

LEC 32. CONTINGENCY CROP PLANNING FOR DIFFERENT ABERRANT WEATHER SITUATIONS - INTEGRATED DRY FARMING TECHNOLOGIES

Contingency crop planning for different aberrant weather situations

Rainfall behaviour in dry farming areas is erratic and uncertain. The deviations in rainfall behaviour commonly met with in dry areas include delayed onset, early withdrawal intermediary dry spells during rainy season. The adverse effect of these rainfall aberrations on crop growth vary with the degree of deviation and the crop growth stage at which such deviations occur. Suitable manipulations in crop management practices are needed to minimize such adverse effects of abnormal rainfall behaviour. These management decision, constitute contingency planning. Such management practices done after crop establishment and in the middle of growth are called midterm corrections.

Rainfall aberration	Effect on crops
Delay in onset of rainfall	Length of cropping season or cropping duration is reduced - crop sowing is delayed
Early withdrawal or cessation of rainfall	Moisture stress at maturity grain filling is affected (terminal stress)
Intermediate dry spells	
a. Immediately after sowing	Germination affected, population reduced
b. At vegetative phase	Affects stem elongation, leaf area expansion, branching or tillering
c. At flowering	Affects anthesis and pollination grain / pod number reduced
d. At ripening	Grain filling and size reduced

Contingency plan and midterm corrections vary with the type and time of occurrence of rainfall observation.

Rainfall abnormality	Contingency plan and midterm correction
1. Delayed onset of rainfall	
a) Delay exceeding3-4 weeks	Alternate crops of short duration to be sown
Delay in South west monsoon Normal - June Delay - July Delay - August	 Groundnut Ragi / pearl millet Samai / Cowpea
Delay in South west monsoon Normal - October Delay - Early November Delay - Late November	 Cotton / Sorghum Sunflower / Pearl millet / Ragi Coriander / Senna
b) Delay of 1-2 weeks	Alternate varieties of short duration of same crop Eg. Sorghum Co 19 (150 days) Co 25 (110 days) Red gram local (180 days) Co 5 (130 days)
2. Early withdrawal of rainfall	Antitranspirant spray, harvesting for fodder (millets) harvesting at physiological maturity
3. Intermediary dry spell	
a. Immediately after sowing	Gap filling with subsequent rains if stand

	reduction is less than 20%. Re-sowing if stand reduction is more than 20%, mulching between crop rows. Stirring soil surface to create dust mulch to reduce evaporation
b. At vegetative phase	Mulching, antitranspirant spray, spraying potassium chloride, thinning of 33-50% population
c. At flowering	Antitranspirant spray, harvesting for fodder and ratooning with subsequent rains in millets (e.g) sorghum
d. At ripening	Antitranspirant spray, harvesting for fodder, harvesting at physiological maturity

A contingent crop programme model for dry lands of Aruppukottai and Kovilpatti is furnished below.

Rainfall period	Aruppukottai	Kovilpatti
Rain fall	810mm	730mm
On set of monsoon	37th standard week (2nd week of September)	41st standard week(2nd week of October)
Soil	Shallow vertisol	Deep vertisol
Premonsoon	35th standard week	39th standard week
Sowing	Last week of August	Last week of September
Crops	Cotton, Sorghum	Hirsutum cotton, Sorghum (K8) Fodder sorghum (K3)
Monsoon sowing	37th standard week	41st standard week
Choice of Crops	Cotton, Sorghum, Maize, Redgram, Blackgram	Cotton (Hirsutum and, arboreum spp), maize, blackgram, sorghum
2 Weeks delayed	39th standard week(last week of September) Maize, bajra	43rd standard week(last week of October) Sunflower, coriander
4 Weeks delayed	41st standard week (2nd week of October)	45th standard week(2nd week of November) Coriander, Gingelly, Senna
6 Weeks delayed	43rd standard week (last week of October) Coriander	47th standard week (last week of November) Senna is possible if heavy rainfall is received

Resource management for sustainable agriculture.

Soil and water are two naturally available resources need to be managed efficiently in dryland agriculture.

Under given ecological limitation it is the rainfall variation that causes fluctuation in productivity from year to year.

1. Effective utilization of stored soil moisture is important and hence crops and varieties having high MUE need to be used.
2. Crop planning as per length of cropping season: Select the crop of proper duration to match the length of growing season for stabilizing in crop production.

	Category	Regional canters	Effective cropping season	Cropping programme
a)	<20 weeks	Bellary Hissar	8 weeks 17 weeks	Sole cropping Sole cropping
b)	20-30 weeks	Kovilpatt Akolai	21 weeks 27 weeks	Intercropping Intercropping
c)	>30 weeks	Bhubeneswar Ranchi	31 weeks 45 weeks	Sequence cropping Sequence cropping

3. Instead of compartmentalizing Kharif and Rabi season Kharif-Rabi continuam seemed to be more effective with high yield besides fertility maintenance. Eg. Deccan rabi dryfarming tract Bajra + Pigeon Pea better compared to cereal or keeping land fallow in Kharif.
4. Relative contribution of production parameters critical inputs against full package which affect the productivity considerable experiment results indicated fertilizer application contributed 43 to 81 % increased yield for cereals. Plant density and spacing and change of variety can also bring substantial increase in production.
5. Alley cropping for fertility maintenance subabul green matter incorporation increased sorghum yield by 73%.
6. Contigent crop planning for weather abbreviation to avoid total crop failure and this will help us to get something to sustain.
7. Soil and moisture conservation practices

Dry land horticulture

Fruit trees with drought tolerance potential can substitute annual crops in many dry land tracts. The criteria for selection of fruit trees for dry lands are listed below

- Drought tolerance
- Adaptability to varying soil conditions
- Flowering and fruiting during period of adequate moisture availability
- Quick regeneration after pruning
- Rapid recovery after stress is removed

Rainfall (mm)	Fruit trees suitable
560 – 700	Ber, pomegranate, cashew sapota, pomegranate, jamun, amla
700-900	Mango, cashew, custard apple, guava, fig,

Soil type	Fruit trees suitable
Black soils	Ber, sapota, pomegranate, jamun, amla, wood apple
Red soils	Mango, cashew, custard apple (Annona), pomegranate, sapota, amla.

Successful dry land horticulture depends on many cultural requirements as listed below

- Selection of trees suitable for rainfall and soil
- Planting during monsoon season in one cubic metro pits
- Pot watering during hot months in the early establishment period of 2-3 years
- Pruning to reduce canopy during dry season
- Moisture conservation through vegetative barriers, large basins sloping towards tree trunk, crescent or saucer shape basins, mulching with dry leaves, straw or crop waste.

Inclusion of fruit trees in dry land farming systems can be done through

a) Pure horticulture: Plantations of mango, cashew, guava etc.
b) Agri horticulture: Annual crops intercropped in between fruit trees. Eg: Mango + Groundnut / samai / horsegram, ber + cowpea / green gram
c) Hortipasture: growing pasture grasses and legumes between fruit trees. Eg: Ber / guava + *Cenchrus cilliaris* + *Stylosanthes*

INTEGRATED FARMING SYSTEMS IN DRYLANDS

Integrated farming system (IFS) refers to the adoption of allied agricultural enterprises along with crop production in a mutually beneficial manner in the same farm holding. Eg. Crop + sheep / goat, crop / sericulture, Crop + poultry, crop / tree + forage + livestock.

IFS offers many advantages compared with annual cropping alone.

- Increased farm income
- Stability in farm income
- Increased employment opportunities
- Balanced food to farm family
- Efficient use of resources
- Recycling of farm wastes.

Case studies in dryland IFS

Black soils of Kovilpatti

IFS	Crop + Live stock
a) Crop (0.5 ha)	Cotton, sun flower, sorghum
b) Fodder crops (0.5 ha)	*Cenchrus cilaris*, fodder cumbu, fodder sorghum
c) Livestock	2 Jerssy milch cows

System	Net income Rs/Year
1. Crop	1636
2. Additional income from milch animal	2519
3. Organic matter recycled	1.2 tonnes per year

Black soils of Aruppukottai

IFS	Crop + trees + goat
Crop	Sorghum + cowpea, Cotton + Blackgram
Fodder	Cenchrus grass + Desmanthus
Fruit trees	Ber, custard apple, Amla
Livestock	Tellicherry goats (5 female + one male)

System	Net income (Rs/ha/Year)	Per day income (Rs/day)	Employment Generation (man days /year)
Crop alone	3228	9	35
IFS	10417	29	131

Blacksoils of Coimbatore

System	Crop + trees + goat in one ha
Crop	Sorghum + cowpea for fodder 0.2 Leucaena + Cenchrus 0.2 ha
Trees	*Acacia senegal* 0.2 ha *Prosophis cineraria* 0.2ha
Livestock	Goats in deep litter system (5 females +one male)

	Crop alone	IFS
Net income (Rs/ ha/ Year)	1919	5666
Additional income	-	3749
Employment (man day/year)	40	153
Per day profit (Rs)	2.26	15.52

e) Red soils of Paiyur

System	Crop + dairy
Crop	Ragi /samai /pulses
Livestock	3 cows

System	Per day income (Rs/day)
Crop alone	Rs 2.38
Crop + dairy	Rs 8.10

Integrated dryland technology and its components:

A single technology in isolation will not give desired results. adoption of all related technologies as an integrated dryland technology package alsone will provide a synergistic effect and improve the crop productivity in dry regions. The various components of such an integrated dryland technology (IDLT) are the following.

- In situ soil moisture conservation
- Choice of suitable crops and crop substitution
- Selection of high yielding drought tolerant varieties
- Cropping system to suit rainfall quantity, duration of rainy season and soil moisture storage
- Tillage to conserve moisture
- Establishment of optimum population
- Soil fertility management
- Crop protection against weeds, pests and diseases.

LEC 33. ALTERNATE LAND USE SYSTEM AND THEIR MERITS – AGROFORESTRY SYSTEMS – IFS TO DRYLANDS

Uncertain rainfall, poor soil conditions and low level of management has made annual cropping of field crops a non-remunerative enterprise in many pockets of dry lands. In some instances, cropping has been given up altogether and lands remain fallow and become wastelands overgrown with unwanted vegetation. To arrest this trend and to bring back the land under economically useful vegetation, alternate land use systems such as grasslands / pastures, agroforestry and horticulture are recommended. This has become necessary for the following reasons;

a) Annual field crop production is nonviable and uneconomical in many years
b) Yield of field crops is low and fluctuates widely between years affecting stability and income
c) Continued use of the eroded and degraded lands under the present system of annual cropping may ecologically degrade the lands further affecting sustainability of the fragile eco-system in the drylands, leading to the creation of wastelands.
d) Alternate land use systems such as grasslands and tree culture are less risky, more productive and remunerative in these marginal lands. They will provide stability and sustainability.

The choice of an alternate land use system depends on the land capability. Most of the lands under dry farming tracts come under the land capability classes of III and above.

Land capability class	Alternate land use recommended
Class II	Dry land horticulture
Class III & IV	Agro-forestry / leyfarming
Class V	Pastures / silvipasture / tree farming
Class VI	Range lands / wood lots

Pastures and grass lands

Forage crops play an important role in dry land economy. They help to promote livestock husbandry to improve and stabilize income. Forage grasses and legumes are best suited for marginal lands and sub marginal lands, sloppy lands, eroded and degraded lands for soil and moisture conservation and for reclamation of wastelands.

Forage crops for dry lands include

Annual cereals	Sorghum, maize, pearl millet
Annual legumes	Cowpea, cluster beans (guar)
Perennial grasses	*Cenchrus ciliaris* (Anjan or Kolukkattai grass), *Cenchrus setigerus* (black kolukkattai), *Cenchrus glaucus* (blue buffel) *Dichanthium annulatum* (marvel grass) *Chloris gayana* (Rhodes grass) *Heteropogon contortus* (spear grass)
Annual grass	*Pennisetum pedicellatum* (Deenanath grass).
Perennial legumes	*Stylosanthes hamata*, *Stylosanhes scabra* (Stylo or muyal masal) *Macroptilium atropurpureum* (siratro) *Clitoria ternatea* (sangupuspham) *Desmanthus virgatus* (Hedge lucerne / velimassal) *Leuceana leucocephala* (subapul), berseem.

Forage crops can be introduced into the dry land farming system through any of the following ways:

a) Grasslands or pasture with perennial grasses and legumes for grazing by livestock, cutting and stall feeding, (cut and carry system.) and hay or silage making
b) Strip cropping with alternate strips of grasses / legumes and annual crops
c) Ley farming where in perennial forage crops are grown in rotation with annual crops in 4-5 year cycle Eg. *Stylosanthes hamata* (3 years) – sorghum (1 year) – castor (1 year)

Ley farming offers the following advantages

- Provision of fodder for cattle
- Low risk system
- Soil and moisture conservation
- Enrichment of soil fertility
- Prevention of soil compaction
- Control of perennial weeds

Silviculture

Silviculture refers to the raising of trees. When trees are introduced into farms along with field crops it is known agrisilviculture or agroforestry system. Tress provides many benefits to mankind. They play protective role by making available a variety of products for human consumption, for livestock and for industrial raw material needs. Eg: Fruits, nuts, fuel, fodder, timber, wood, wax, resin, etc. They also play a protective role through soil and moisture conservation, enrichment of soil fertility through nutrient recycling and protection of environment.

Methods of tree cultivation

a) Block culture: Large contiguous area is planted with selected species of tress suitable for fuel, timber, wood or industrial use (multipurpose tree species). It is also known as wood lots or energy plantations when planted for fuel. Eg: Eucalyptus, Acacia, Prosophis.
b) Staggered planting: Trees are grown scattered in the field with annual crops raised in the interspaces. Multipurpose tree species suitable for fuel, fodder, wood and timber can be planted at 20-50 trees per hectare. Eg: Acacia + fodder sorghum vagai / neem + pulses / sorghum
c) Border trees: Trees can be grown along farm boundaries and field borders for economic use as well as boundary markers. Eg: Palmyrah, neem, tamarind, eucalyptus.

Different systems of tree culture

1. A<u>grisilviculture</u> (Agroforestry) Trees and annual crops are raised in an intercropping system in the same field. Trees are planted at 5-8 m spacing and field crops are sown in the interspaces during rainy reason. Eg: Leucaena + Sorghum / Pearl millet / Castor / Pulses, Neem / Vagai + Fodder sorghum / Pulses
2. Silvipasture: Leguminous fodder trees are raised with fodder grasses and legumes as intercrops. Eg: Acacia + Cenchrus + Stylosanthes, Vagai / Sisoo + Cenchrus + Stylosanthes
3. Alley cropping or hedgerow intercropping: Annual field crops are grown in alleys formed by hedge rows of trees and shrubs. The trees or shrubs in hedge rows are cut back to short height (0.5 – 1.0 m) at sowing of annual crops with onset of rains and kept pruned during crop growing season to reduce shade effect and competition with field crops. The width of alley (space between hedges) is about 4-6 m. eg: Leucaena or Desmanthus as hedge row with sorghum, maize, pigeonpea, sunflower as intercrop. Alley cropping offers many benefits.

- Green fodder from hedge rows during dry season and food and dry fodder from annual crops during rainy season.
- Off season rainfall is utilized by hedgerow trees or shrubs
- Hedge rows check runoff and erosion when formed along contour or across slope
- Loppings and prunings from hedgerows can be used as fodder, fuel wood or for mulching.
- Yield of crops raised in the alleys is improved due to better microclimate through reduction in temperature and wind speed, increase in humidity and reduction in evapotranspiration loss

Success in alley cropping depends on alley width and height of hedge rows. Alley width of 5-6 m has been found to be effective. Low height of 45-50 cm is desirable. Usually one cutting of hedge row shrubs at the time of sowing of annual crops and subsequent prunings at monthly interval during cropping season are optimal. During dry season, cutting is done depending on fodder requirement.

4. Timber - Fibre system (TIMFIB system): It involves growing trees and perennial fibre crops together. Eg: Leucaena + agave

Choice of trees for drylands

Trees suitable for dry lands must have the following characters

- Multipurpose tree species (fodder, fuel, timber, wood)
- Adaptable to wide variations in soil and climate
- Rapid growth
- Withstand severe pruning

Soil	Rainfall (mm)	Trees suitable
Black soil	730-830	*Euclayptus viridis, Acacia nilotica, Leucaena leucocephala*
Black soil	510-760	*Acacia nilotica, Acacia auricultiformis, Acacia indica Acacia planifrons, Leucaena leucocephala, Azadirachta indica, Ailanthus excelsa*
Red soil	570 - 830	*Leucaena leucocephala, Eucalyptus cameldulensis, Acacia auriculiformis, Acacia nilotica, Acacia senegal, Acacia holoserecia, Acacia tortilis, Albizzia lebbeck, Prosophis cineraria, Hardwickia binata, Dalbergia sisoo, Azadirachta indica*
Red soil	380 - 500	*Prosophis cineraia, Albizzia lebbeck, Acacia nilotica*
Red soil	Less than 300	*Acacia nilotica, Acacia senegal, Acacia tortilis, Zizljphus jujuba*

LEC 34. WATERSHED DEVELOPMENT TECHNOLOGY – MICRO AND MACRO WATERSHED – NEED AND SCOPE – COMPONENTS OF WATERSHED TECHNOLOGY

Watershed is defined as a natural hydrological unit that covers a specific land surface area from which runoff passes through a common outlet. In simple terms, it implies a catchments or drainage basin from which water drains towards a single channel. It may extend over a few acres only or may cover thou sands of acres.

Watershed development approach aims at developing the entire area in the watershed including the cultivated and uncultivated area. It is therefore different from individual farm as unit for development.

Watershed management is the integration of technology within the natural boundaries of a drainage area for optimum development of land water and plant resources to meet the basic minimum needs of the people in a sustained manner.

It is also defined as the development and management of watershed resources in such a manner as to achieve optimum production without deterioration of resources base or disturbing the ecological balance. It is termed as "Resource centered technology" since it helps in assessment augmentation and optimal utilisation of all the natural resources of land water and vegetation, it prevents deterioration of resources and at the same time ensures sustained productivity of land to meet basic needs of people.

Need and advantages

1. Watershed is an acceptable basic hydrological unit of planning for optimum use and conservation of soil and water resources.
2. Here, development is not confined to agricultural land alone but covers the whole land area starting from the highest point of the watershed (ridge line) to the lower most point of outlet into, the natural drainage stream at the bottom of the slope. It means every part of land including barren, sloppy and marginal lands being treated according to its capability. By adopting watershed as unit for development, different measures are adopted and executed in each of the topo-sequence according to its capability, providing an integrated treatment of arable and non arable lands.

Eg.

Ridge line	Tree culture
Marginal land	Agroforestry, pasture
Arable land	Integrated soil and moisture conservation and cropping

3. It aims at comprehensive development of all resources in the watershed i.e., holistic. It starts from the most important resources viz., soil and water and extends to other resources like crops trees, livestock etc.,
4. Some of the resource conservation measures may have to be carried out cutting across field boundaries E.g. Contour bunding, contour vegetative barriers, shelter belts, drainage channel. For this watershed is more ideal unit.
5. It is a multidisciplinary approach involving scientists from all related disciplines of Agronomy, Engineering, Horticulture, Forestry, Soil Science, Extension, Economics, etc.,
6. It provides for involvement of farmers in planning execution and monitoring of the development.

Principles of watershed management

The main principles of watershed management based on resource conservation, resource generation and resource utilization, are:

(i) Utilizing the land according to its capability;
(ii) Protecting productive top soil;
(iii) Reducing siltation hazards in storage tanks and reservoirs and lower fertile lands;
(iv) Maintaining adequate vegetation cover on soil surface throughout the year,
(v) In-situ conservation of rain water,
(vi) Safe diversion of excess water to storage points through vegetative waterways;
(vii) Stabilization of gullies by providing checks at specified intervals and thereby increasing ground water recharge;
(viii) Increasing cropping intensity and land equivalent ratio through intercropping and sequence cropping
(ix) Safe utilization of marginal lands through alternate land use systems with agriculture - horticulture - forestry - pasture systems with varied options and combinations;
(x) Water harvesting for supplemental and off-season irrigation;
(xi) Maximizing agricultural productivity per unit area per unit time and per unit of .water,
(xii) Ensuring sustainability of the ecosystem befitting the man - animal-plant-water complex;
(xiii) Maximizing the combined income from the inter related and dynamic crop - livestock tree - labour complex over years;
(xiv) Stabilizing total income and to cut down risks during aberrant weather situations;
(xv) Improving infrastructural facilities with regard to storage, transportation and marketing of the agricultural produce;
(xvi) Setting up of small scale agro4ndustries; and
(xvii) Improving the socioeconomic status of the farmers.

Objectives of watershed management

As mentioned earlier, watershed management is enshrined with the concept of sustainability meeting the needs of present population without compromising the interests of future generations. It is multi-pronged approach for steady uplift of masses living in the area. The main objectives of this multipurpose programme can be described in symbolic form by the expression: 'POWER'. Here the letters symbolize the following:

P - Production of food -fodder - fuel - fruit - fibres - fish - milk combine on a sustained basis
    Pollution control
    Prevention of floods

O - Over-exploitation of resources to be minimized by controlling excessive biotic interference like overgrazing
    Operational practicability of all on-farm operations and follow- up programmes including easy approachability to different locations in watershed

W - Water storage at convenient locations for different purposes
    Wild animal and indigenous plant life conservation at selected places

E - Erosion control
    Eco - system safety
    Economic stabili4y
    Employment generation

R - Recharge of ground water
    Reduction of drought hazards
    Reduction of siltation in multi - purpose reservoirs
    Recreation

Components of watershed approach

1. Water -resource improvement
2. Soil and moisture conservation in cultivated lands

Hardware	Software
Permanent / Semi-permanent	Temporary/Recurring
Contour builds	Compartmental bunding
Bench terracing	Ridging after crop establishment
Conservation ditches	Contour cultivation
Land leveling	Mulching
Runoff collection structures	Vegetative barriers

3. Land treatment in non-arable lands
4. Improved cropping
5. Alternate land use system and integration of livestock in farming system.

Aims

1. Increased land productivity through improved technology
2. Sustaining the resource base thorough improved conservation measures
3. Augmentation of resource base viz soil productivity and water availability

Action plan for watershed development (Steps in watershed development)

1. Identification and selection of watershed: The boundary of the watershed has to be marked by field survey starting from the lowest point of the watercourse and proceeding upwards to the ridge line. The area may vary as low as 100 ha to as high as 10000 ha.
2. Description of watershed.
   Basic information has to be collected on
   - Location
   - Area, shape and slope
   - Climate
   - Soil - geology, hydrology, physical, chemical and biological properties, erosion level.
   - Vegetation-native and cultivated species.
   - Land capability
   - Present land use pattern
   - Crop pattern, cropping system and management
   - Farming system adopted
   - Economics of farming
   - Man power resource
   - Socio economic data
   - Infrastructural and institutional facilities
3. Analysis of problems and identification of available solutions
4. Designing the technology components
   a. Soil and moisture conservation measures
   b. Run off collection, storage and recycling
   c. Optimal land use and cropping system
   d. Alternate land use system and farming system
   e. Other land treatment measures
   f. Development of livestock and other allied activities
   g. Ground water recharge and augmentation

5. Preparation of base maps of watershed incorporating all features of geology, hydrology, physiography, soil and proposed development measures for each part of watershed.
6. Cost-benefit analysis to indicate estimated cost of each component activity total cost of project and expected benefit.
7. Fixing the time frame to show time of start, duration of project, time frame for completion of each component activity along with the department / agency to be involved in each component activity
8. Monitoring and evaluation to assess the progress of the project and to suggest modification if any
9. On-farm research to identify solutions for site-specific problems.

Organizational requirement

a. Water shed development agency with multidisciplinary staff
b. Training to personnel
c. Training to farmers
d. Credit institution
e. Farmers forum /village association
f. Non government organization

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- End of guidelines
- Students are requested to refer the class notes for further clarity
- Examples given in classes are to be referred.