A GUIDE TO IRRIGATION MANAGEMENT

Dr. M.R. Narayanswamy

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1.IMPORTANCE OF IRRIGATION WATER AND MANAGEMENT

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

1.1 Importance of water in agriculture:

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 an 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 plants temperature through transpiration.
- It helps to keep the plant erect by maintaining plant’s turgidity.
- It helps to transport metabolites from source to sink.

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 supports human and animal life
- ❖ It helps for land preparation like ploughing, puddling etc., weeding, fertilizer application etc. by providing optimum conditions.

The multivarious uses of good quality water for the purpose of irrigation, industrial purpose, 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 a highly valuable commodity and hence it is stated as **liquid Gold**. Further, historical evidences indicate that all civilization established on river banks 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 diseases 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 a 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 a place for recreation and wild life habitat.

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

1.2 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 output. i.e., allocation of all the resources for maximum benefit and to achieve the objective 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 its inter linked relationship are studied in irrigation management.

- ❖ 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
- ❖ Environments and its changes due to irrigation.

Management of all the above said factors constitute Irrigation Agronomy. Management of irrigation structure, conveyances, reservoirs constitute Irrigation Engineering and social setup, activities, standard of living, irrigation policies, irrigation association and farmer' 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 structures 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 or crop production.

Importance of Irrigation Management

Water is essential not only to meet agricultural needs but also for industrial purpose, 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 is very important for the following reasons:

- To the development of nation through proper management of water resources for the purpose of crop production and activities such as industrialization, power generation etc., which inturn provides employment and good living condition of the people.
- To store and 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 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 (Environmentally safe use).

Impact of excess and insufficient irrigation water in crops

Avoid excess of insufficient use of water to the corps. Express 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, reduction 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 resources 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 inturn is going to feed the growing population.

1.3 Sources of water

Rainfall is the ultimate source of all kinds 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 be able to contribute some quantity of water in heavy snow fall areas like Jammu Kashmir and Himalayan region.

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

Rainfall

Seasons or rainfall can be classified as follows:

1.	Winter (cold dry period)	-	Jan-Feb
2.	Summer (Hot weather period)	-	Mar-May
3.	Kharif (south –West monsoon)	-	Jun-Sep
4.	Rabi (North – East monsoon)	-	Oct-Dec

South- west monsoon

It comprises the month June, July, August and September which contribute about 70% of rainfall to India except for extreme North of Jammu and Kashmir and Tamil Nadu. Hence, the success of agriculture in India depends on timely onset, adequate 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) contributes rainfall to South Eastern part of peninsular India. Tamil Nadu receives its 60% of rainfall from NEM (North East Monsoon). This season in also called as Rabi Season.

Winter

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

- India enjoys monsoonic rainfall with an annual average rainfall of 1190 mm
- There is wide variation in the quantity of rainfall received from place to place. Highly erratic and 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 enjoys about 3000mm 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. In summer and winter, the amount of rainfall is very little.
- Within the season also the distribution is not uniform. A sudden heavy downpour followed by dry spell for a long period is a common occurrence.
- Rainfall distribution over a larger number of days is more effective than heavy down pour in a short period, but it is in negative trend in India. Unwarranted flood, crop damage and loss of crops and livestocks are not uncommon.
- 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.

1.4. 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 corps with dug well water. Irrigation was gradually developed and extended during the Hindus, Muslims and British periods.

The Grand Anaicut (KALLANAI) constructed across the river Cauvery is an outstanding example for the irrigation work by a Chola king, the great Karikal Cholan during second century.

The **Veeranarayanan Tank** and **Gangai Konda Cholapuram tank** was constructed during 10th century in Tamil Nadu. **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 of 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 **Bhakra-Nangal** in Punjab, **Tungabhadra** in Andrapradesh **Damodar Valley** in Madyapradesh were established.

Irrigation development during five plans:

In 1950-51 the gross irrigated area was 22.5 million ha. After completion of I five-year plan the gross irrigated area was enlarged to 26.2 million ha. Further it was gradually increased to 29,33.5,44.2.53.5,75 million ha respectively over the II, III, IV, V, VI, & VII five year plans. The expected increase through VIII and IX five year plans are 95 and 105 mha, 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: I 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 2000-10,00 0 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 farmers.

India has many perennial and seasonal rivers which flow from outside and within the country. Among them, some important rivers of different states are given blow.

Important irrigation projects in India.

States	Project Name
Bihar	Godavari delta system, Krishna delta system, Nagarjuna sagar (Krishna)
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, Malaphrapha and Turga
Orissa	Hirkand and Mahanadhi
U.P	Upper ganga canal, Ramganga
W.B	Damodar Valley
Rajasthan	Rajasthan canal (Sutlej)
Tamil Nadu	Mettur- Lower Bhavani Project Parambikulam Aliyar Project Periyar Vaigai, Cauvery delta, Tamirabarani, etc.

India's water budget

Total geographical area	=	328 mill. ha.
Average annual rainfall	=	1190 mm
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 and hence it is termed as ineffective rainfall.

When rainfall occurs, a portion of it, immediately evaporates from the ground or transpires from vegetation, a portion infiltrates into 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 only is considered as effective rain. The remaining 55 rains are very light and shallow which evaporate immediately without any contribution to surface or ground water recharge. Considering all these factors it is estimated that out of 400 million hectare metre of annual rainfall, 70 million hectare meter is lost to atmosphere through evaporation and transpiration, about 1158 million hectare meter flows as surface run-off and remaining 215 million hectare meter soaks or infilters 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 runoff 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 area lying outside the country through streams and rivers 20 M ha m

d) Contribution from regeneration from ground water in Streams and rivers 45 M ha m

Total 180 M ha m

Disposal on 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 water stored in reservoirs is lost though evaporation and some amount through seepage.

The rest is utilized for various purposes mainly for irrigation and drinking water

Total surface run off	=	180 M ha m
Stored in reservoir and tanks	=	165 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	=	320.00 M ha
Net Area reported	=	307.00 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
No 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	=	36,872 Mm^3
G. Water utilization	=	19,801 Mm^3
Unutilized	=	46.3%

Percentage of area depends upon ground water in various parts of Tamil 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 irrigation area in '000 hectares)

		Canal	Tanks	Wells	Other
India	12,776	4,123		12,034	2,061

Tamil Nadu	931	924	820	35

World Irrigation Statistics

Countries	Area irrigated in million hectares
Australia	1.150
Bostswana	0.002
Brazil	0.141
Burma	0.753
Canada	0.627
Ethiopia	0.030
France	2.600
India	37.640
Indonesia	3.797
Iran	4.000
Iraq	3.107
Israel	0.153
Japan	3.390
Pakistan	11.97
USSR	9.900
USA	16.932
China	74.000

The ultimate irrigation potential of our country is 155 million hectare out of 165m. ha of total cultivable area. So far the achievement has been made through more than 215 major irrigation projects, 900 medium irrigation projects and many number of minor irrigation projects which consume an yearly outlay of Rs.25,000 crores to Rs.35.000 crores in the National budget. After the completion of VI five year plan we could achieve irrigation potential at the rate of 2.2 m ha per annum. Now the rate of increase in irrigation potential is 13 m. ha per year.

Even though the irrigation potential has been increased, the gap between irrigation potential created and utilized is very wide. Hence we are at the critical state to narrow down this gap between created and utilized irrigation potential. More than 80 percent area can be brought under irrigation if the resources (which include surface and ground water) are efficiently utilized mainly through scientifically improved irrigation scheduling. Tremendous national and international scientific efforts have been made on the problem of irrigation scheduling, but achievement has not yet been fulfilled. This is a challenging task to our Scientist, Engineers, Planners, Policy makers and to the Farm managers.

2. SOIL – WATER – PLANT RELATIONSHIP

2.1 Soil

1. Soil is a complex system made of solid, liquid and gaseous materials
2. Soil is a three phase or poly phasic system comprising of
   a) Solid phase
   b) Liquid phase and
   c) Gaseous phase in some proportions

In some occasion, one of the component may be absent. e.g. in water logged soil air is not present, similarly in desert dry sandy soils, water component is not available.

3. Soil is a three dimensional body which supports plant establishment and growth.
4. Soil is a natural and dynamic medium, which supports plant growth.

Simply, soil can be defined as a three phase complex dynamic system composed of solid, liquid and gas with some proportions. Normally the proportion is 50:25:25, but this may vary from soil to soil.

1. **Solid:** the solid phase is made of minerals, Organic matter and various chemical compounds

a. **Mineral**

The mineral particles are the chief components of most soils on volumetric basis. They consist of parent rock particles developed insitu by weathering or deposited in bulk by wind or water force.

The proportion of sizes of these particles determines the soil texture.

b. **Organic matter**

The organic fraction consists of both plant and animal matter in two phases either alive or in different stages of decomposition. It is also known as humus fraction. It varies from 1 to 5% by weight in different soils. Normally in tropics, red soil contains less than 1% and heavy soil up to 2%.

Role of organic matter in soil

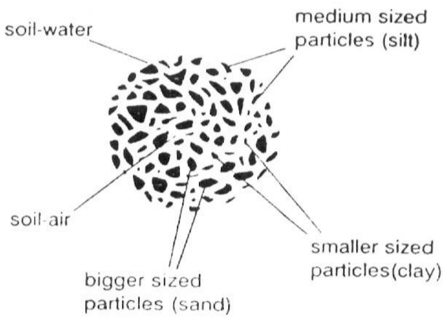
- Organic matter promotes granulation and improves the structure of the soil.
- It has a binding effect of sandy soil and increases its moisture holding capacity. It reduces soil temperature.
- It supplies nutrients to plants.
- It acts as medium for beneficial microbes.

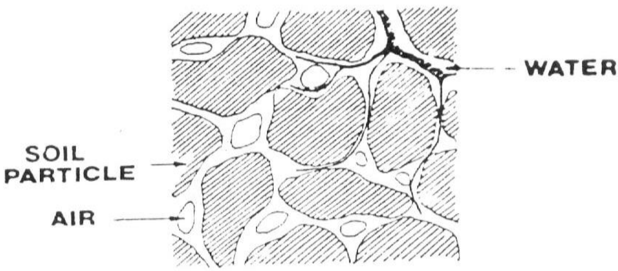
- It improves soil aeration
- It reduces soil erosion and
- It acts as buffering agent in soil.

c. Chemical compounds

The mineral components of soils are made of silica and silicates. It varies from profile to profile, generally the larger particles contain more silica content and finer particles more of potassium, calcium and phosphorus.

The dominant minerals are quartz in sand, quartz and feldspars in fine sand and Silt, mica, Vermiculite, Montmorillonite, Kaolinite and Amorphous colloides in clay. Oxides, carbonates and sulphates are the other common minerals present in the soil.





Soil clods showing sand, silt and clay particles, water and air in soil pores

II. Liquid

The liquid portion of soil consists of water, dissolved minerals and soluble organic matter. This is known as soil water, which is stored in the space between soil particles known as pore space. This pore space is the most important physical structure and play a vital role in irrigation studies.

Plants absorb water from the pore spaces and hence this water must be replenished by rain or irrigation water for the successful growth of crops. Hence, it is concluded that the soil serves as a reservoir for moisture. The knowledge about the capacity of reservoir is the principal factor governing the frequency and amount of irrigation water to be applied to the crop.

III. Gas

The spaces in between soil particles are not only filled with water, but some spaces are occupied with air. The soil air differs from atmospheric air in its composition. Soil air contains lesser oxygen content and more carbondioxide content than atmospheric air, because of the respiration of soil micro organisms and plant roots in which oxygen is consumed and carbondioxide is released.

Composition of soil and atmospheric air in percentage

Air	O_2	Co_2	N_2
Soil air	20.05	0.25	29.20
Atmospheric air	20.97	0.03	78.03

So, the pore spaces enclosed by soil matrix is shared by soil-air and soil-water. As the amount of one increases, that of the other decreases.

Functions of soil

1. It provides place and anchorage for plant growth and development.
2. It serves as a medium for air and water circulation.
3. It acts as a reservoir for water and nutrients.
4. It provides space for beneficial micro organisms.

2.2 Soil water or soil moisture

The pure water properties need not be discussed since irrigation agronomy relates to soil water. The water present in the soil pore spaces (micro and macro pores) is the most important soil ingredient. The pore spaces are not only occupied with water, but also with some amount of air. The quality and amount of soil water play a vital role in plant growth and soil properties. Hence, a detailed study of soil water is necessary. The soil water is also expressed as soil moisture or soil solution.

Rain water or irrigation water is not directly absorbed or utilized by plants. The water received after rain or irrigation is stored in the soil profile as soil water in pure form (without dissolved substance) or solute form (with dissolved substances) in pore spaces of soil column. This stored soil water is otherwise known as soil moisture. Hence, the soil moisture is the most important composition or ingredient of the soil which plays a vital role in crop production or plant growth. Water is retained as thin film around the soil particles and in the capillary pores by the forces of adhesion, cohesion and surface tension.

Adhesion

It is the force of attraction between molecules of different substance. That is the force of attraction between solid surface (soil mass) to liquid surface (soil water). A thin film of water is held in soil particles due to this adhesive force.

Cohesion

Cohesion is the force of attraction between molecules of same substances i.e., between liquid molecules or water molecules. Hence, a thick film of water is formed due to this cohesive force.

Surface tension

It is the total force acting in a solid-liquid-air system. The liquid surface has some properties of stretched elastic nature. This is due to the unequal forces of molecular attraction at the surface layer. This elasticity is known as surface tension. In other words, surface tension is defined as the "Force pulling tangentially along the surface of a liquid" This force tends to make the surface area as small as possible and has the dimension of force per unit length or energy per unit area expressed in newton/meter (N/m) or dynes/cm. As a result of this surface tension, the air-water interspace become curved.

Soil moisture tension

Soil moisture tension is the tenacity with which water is held in the soil. To remove this water, some pressure (force per unit area) must be given or exerted. This pressure or tenacity is measured in terms of potential energy of water and is expressed in atmosphere or bars.

1 atmosphere = 1036 cm water column

or

76.39 cm of mercury

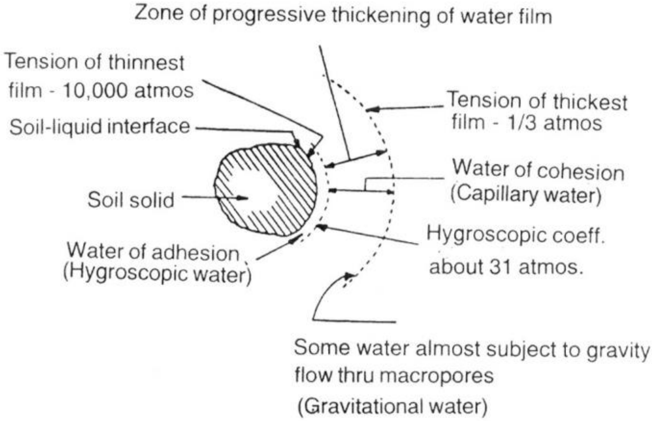
1 Bar = 1023 cm water column

To convert the soil moisture tension to equivalent atmosphere, the above conversion ratio can be used. But here, there is no real vertical pressure of water column. Hence it can be stated as suction or negative pressure. Hence, soil moisture tension of one atmosphere is approximately equal to suction or a negative pressure of 1000 cm of water column. At different soil moisture constants the soil moisture tension will vary. For example, the loam or clay type of soil retains moisture at a tension of 1/3 atmosphere at field capacity level, whereas the sandy soil have a tension of as low as 1/10 atmosphere. The available soil moisture is not only the function of soil physical characteristics like texture and structure but also the soil depth.

2.3 Kinds of soil water

The soil water can be classified based on their nature of attachment to the soil particles.

1. Hygroscopic water
2. Capillary water
3. Gravitational water



Kinds of Soil Water

1. Hygroscopic water

This is the first stage of soil water content where water is held tightly by the surface of the soil particles by the forces of adhesion or adsorption force. Hence it is also known as water of adhesion. At this condition the tension with which water is held in soil surface is from 10,000 atmosphere to 31 atmosphere. So the plant cannot exert this much of energy to extract the water from the soul particles. Hence, it is the unavailable form of water. This condition mostly occurs at permanent wilting point stage or dry condition.

2. Capillary water

This is the next stage after attaining hygroscopic water, with reference to soil-water relationship. In this stage there is relatively better thick film of water around the soil particles and between the soil particles. Hence the cohesive force is responsible for the attraction of water molecules with each other. At this condition some of the pore spaces are not filled with water. Only the micro pores are filled up with water and little chances for macro pores to hold water. This condition will appear at field capacity level where the water is held at a tension of one-third atmosphere to 15 atmosphere. The water is available to the plants because plants can exert the same amount of energy to extract this water. Hence it is known as available water.

When water comes in contact with the surface of soil particles, it will be attracted by the surface of the soil by adhesive force and gravitational force. At the same time there is repulsion for this attraction due to cohesive force along the liquid surface. This elasticity is known as surface tension. Due to the surface tension, the liquid tries to move tangentially along the water surface.

This movement is called capillary water movement and it is also defined as the water held by surface tension in soil capillaries against the pull of gravity.

So the available water to plant is decided by the capillary water, which will be the function of pore space which again depends upon the soil texture, structure and organic matter.

Texture

Finer the texture greater is the capillary capacity.

Structure

Granular structure produces higher capillary capacity

Organic matter

More organic matter increases the capillary capacity

3. Gravitational water

It is the third stage of soil water where water that moves freely as response to gravity percolates downwards and drains out to deeper layer of soil profile. It is also known as free water. At this condition, the macro and micro pores are completely filled up with water. There is no space for air movement in soil pore spaces. This state will appear when the soil is under saturation.

2.4. Physical properties of soil

Soil structure

It refers to the nature of distribution of various size of particles present in the soil. It is the proportion of coarse, medium and fine particles, which are termed as sand, silt and clay respectively. Hence, it can be defined as the proportion of sand, silt and clay particles in soil.

The mineral soil particles are classified according to their sizes as follows.

Textural classification based on size of soil Particles

Particle diameter	**Classified as**
Below 0.002 mm	Clay
0.002 to 0.05 mm	silt
0.05 to 0.10 mm	very fine sand
0.10 to 0.25 mm	fine sand
0.25 to 0.50 mm	medium sand
0.50 to 1.00 mm	coarse sand
1.00 to 2.00 mm	very coarse and
Above 2.00 mm	gravel

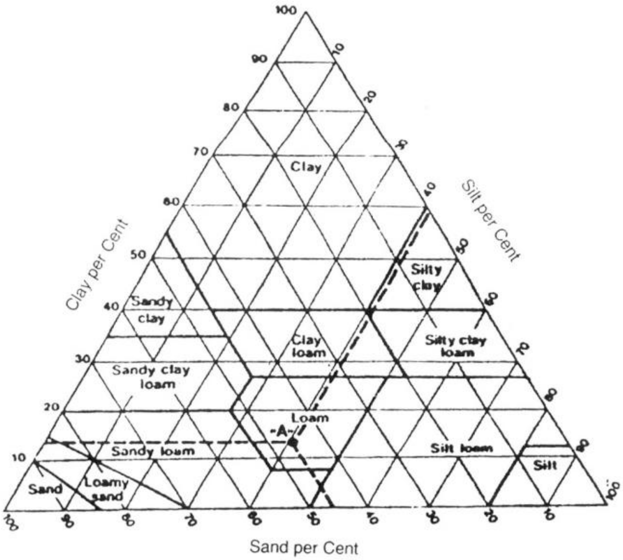
This is simply classified into four groups as follows

Below 0.002 mm	-	Clay
0.002 to 0.05 mm	-	silt
0.05 to 2 mm	-	sand
more than 2 mm	-	gravel

Based on the proportion of sand, silt and clay particles, classification was made and standardized into twelve classes as shown in a triangular diagram.

This triangle is known as USDA (United States Department of Agriculture) soil textural classification triangle. The twelve classes are as follows.

1. Sand 2. Silt 3. Clay 4.Loam Sandy 5. Clay silty 6. Clay 7. Clay-loam 8. Loamy sand 9. Sandy loam 10. Silty loam 11. Sandy clay loam 12. Silty clay loam



USDA Soil Textural Triangle

For example, in a soil sample if the silt percentage is 20, sand percentage is 50 and clay percentage is 30, then these proportions are intersecting at sandy clay loam.

Based on the soil texture, soils can be classified as sand, silt and clay which have the capability with reference to irrigation as follows.

a) Sand

It contains less than 50% clay and silt and at least 70% of sand. Coarse, highly porous, large volume of non-capillary pore space, easy drainage, free air circulation, rapid decomposition of organic matter due to free air circulation, low water holding capacity, low nutrient content, low cation exchange capacity, frequent irrigation requirement and easiness for workability of implements are the characteristic features of sandy soil.

b) Clay

It contains more than 45% of clay and 45% of sand or silt. Minute fine particles, large internal surface area, more active both chemically and biologically sticky when wet and hard when dry, high water holding capacity (WHC), relatively high nutrient holding capacity, slow movement of water and air, hardier for workability of implements and slow release of water to plants with poor drainage are its important features.

c) Silt

It contains 80% silt and less than 12% of clay. Medium in all the above said characteristics

d) Loam

It contains equal amount of sand, clay and silt. These soils are considered better for plant growth.

Importance of soil texture in irrigation management

It plays a vital role in

a) Permeability of water and water movement
b) Gaseous exchange capacity
c) Root growth
d) Water holding capacity of soil
e) Water supplying capacity to the plants

All the above functions are determined by the predominant soil particles viz., sand, silt and clay.

Stones and gravel

If stones and gravels are present less than 10 percent. it

a. Reduces evaporation
a. Facilitates good drainage
b. Easiness for the workability of tillage and intercultural implements.

2. If stones and gravels are present more than 10 percent

a) Soil will be too open and loose
b) It permits rapid drainage
c) Reduces soil water retention capacity

d) Indirectly leaches the soil nutrients

Sand

1. If sand particles are about 40 percent, the soil will be open and friable which favours
    a. Optimum retension capacity of soil water
    b. Optimum gaseous exchange
    c. Drainage is also optimum
2. If sand particles are more than 40% which causes
    a. Rapid evaporation
    b. Excess drainage and percolation
    c. Poor water holding capacity

Silt

1. If silt contents is 30-40 percent provides a good loamy condition which favours
    a) Optimum water holding capacity
    b) Optimum drainage
2. If silt content is more than 40% it cause poor drainage.

Clay

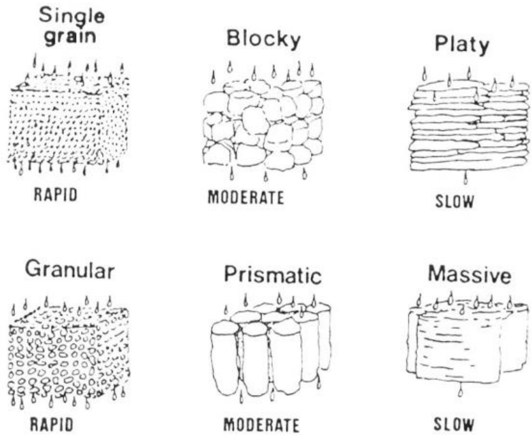
The clay content should be less than 50% for irrigated crops. If clay content is more than this, it will lead to

1. Poor drainage and stagnation of water
2. Poor gaseous exchange
3. High water holding capacity.

Soil structure

It is defined as the shape and arrangement of soil particles with respect to each other in a soil mass or block. The soil aggregates are not solids but possess a porous or spongy character. Most soils are having a mixture of single grain structure or aggregate structure. The number of primary particles (sand, silt and clay) are combined together by the binding effect of organic and inorganic soil colloids. The binding or cementing materials are:

Iron or Aluminium Hydroxide and Decomposing organic matter.
The names of soil structures based on their shapes are,
1. Platy 2. Prismatic 3. Colomnar 4. Blocky 5. Cloddy 6. Granular 7. Crumb 8. Single grain 9. Massive



Different types of Soil Structures

Difference between structure and texture

Structure

1. It is the arrangement of soil particles with each other
2. It can be changed or improved by operations like ploughing, puddling, addition of organic matter, etc.,

Texture

1. It is the proportion of soil particles (sand, silt and clay)
2. It cannot be changed by physical manipulation like ploughing or puddling: but can be improved through addition of organic matter like FYM, tank silt etc.,

Role of soil structure in irrigation management

It play a vital role in soil-air-water system.

a) In surface soil, structure is associated with tilth of soil. The permeability of water and air into the soil and penetration of roots are influenced primarily by soil structure.

b) It is the determining factor for the soil porosity, bulk density, Etc. Hence it directly plays a role on water retention, permeability, etc.

There are two distinct phases in the formation of soil structure.

1) Development of inter particle bonds (aggregates).
2) Separation of structural units from each other (between aggregates).

The structural composition of aggregates will vary in their characteristics like

a) Their resistance against rain drop.
b) Their condition under submergence.

This stability depends upon

i) Clay content
ii) Nature of flocculation
iii) Organic & inorganic linkage
iv) Microbes
v) Chemical constituents such as iron and aluminium oxides.

Soil structures are mainly grouped as single grain structure and massive structure.

Single Grain Structure

Normally occurs in sand and silt having low organic matter content. Single grain structure facilities aeration and capillary movement of soil moisture. In sandy soil the soil structure is mostly of single grain types, so poor water holding capacity and rapid percolation or downward movement of water will occur. To improve such soil structure, organic manures have to be applied to increase the binding of soil structure and also to increase the water holding capacity.

Massive Structure

Massive structure is the dense soil crust. In clay soil, soil particles are fine and massive, so water-holding capacity is high. This leads to difficulty in soil management for e.g. if this type of soil is tilled at wet condition, its pore spaces are reduced and restrict the movement of water and air. Sometimes impervious layers may also be formed. In dry condition, it becomes hard and clods may be formed on ploughing. Addition of organic matter, coir pith, press mud, tank silt, etc will improve the soil structure.

The size of the aggregate is a valuable parameter in soil structure. Medium sized aggregates are more favourable for plant growth, than very small and very large ones. Because of this, size of the soil aggregates are the determining factor to decide the size of the soil pores and porosity. Hence soil structure has a pronounced effect on soil properties such as

a) Erodability
b) Porosity
c) Hydraulic conductivity
d) Infiltration
e) Water holding capacity.

Among this, porosity plays a vital role since all the chemical and biological actions are taking place in the pores only.

- ❖ Large pores enhance aeration and infiltration.
- ❖ Medium pores enhance capillary conductivity.
- ❖ Small pores enhance water holding capacity.

The use of pore space again depends upon

- ❖ Nature of the pore space
- ❖ Climatic condition
- ❖ Depth of water table.

Under Excess Water Condition

Small pores are not important since there is no need for retaining water for longer time.

But pores are needed for better air circulation.

Under Dry Farming Condition

Both the aeration and water storage are needed to facilitate infiltration and retention.

In general, the good soil structural aggregate should be

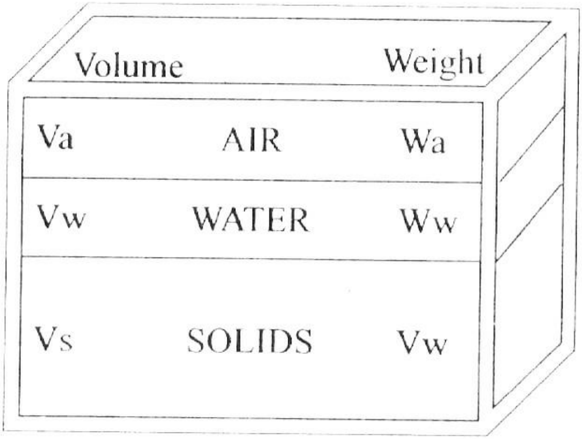
a) Stable to withstand rainfall
b) Stable to withstand submerged condition
c) Sand sized or gravel sized
d) Rounded edged
e) Having Friable condition but not too loose
f) Having High infiltration capacity
g) Having Medium percolation capacity
h) Having Good aeration.

Soil Structure Management

a) Proper land use
b) Suitable tillage practice at optimum moisture level
c) Addition of organic matter
d) Crop rotation
e) Optimum fertilization
f) Mulching
g) Drainage
h) Controlled irrigation
i) Soil conservation
j) Protection against compaction
k) Use of soil conditioner.

Soil physical properties with reference to volume – weight relationship

This relationship can be simply explained through a schematic diagrams as indicated below.



Va	-	Volume of air
Vw	-	Volume of water
Vs	-	volume of solids
Vp	-	volume of pore space alone (Va+Vw)
Vt	-	Total volume = Va+Vw +Vs (or) Vp+Vs
Wa	-	Weight of air (negligible)
Ww	-	weight of water
Ws	-	Weight of solids
Wt	-	Total Weight = Wa + Ww + Ws

As we know the soil mass corresponding to the three phase system of solid, liquid and air is in some proportion, generally 50:25:25. Based on their volume and mass relationship, some physical properties have to be worked out as follows which will be highly meaningful in irrigation studies.

Density of solids (DS) or Particle Density

It is defined as the ratio of weight of solid to its volume alone.

$$DS = \frac{\text{Mass of solid}}{\text{Volume of solid}} = \frac{Ws}{VS \times Pw}$$

Where,

P_w = density of water at 4^o C.

Since density of water = 1, this can be written as

$$DS = \frac{Ws}{Vs}$$ and expressed in g/cc.

Dry Bulk density (Pb)

It is defined as the ratio of mass of dried particles to the total volume of soil including pore spaces. It is also called as real density or true density. It ranges from 2.6 to 3.6 for soil and 1.2 to 1.5 for organic matter.

$$Pb = \frac{Ws}{VA+Vw+Vs} = \frac{Ws}{Vp + Vs} = \frac{Ws}{\cancel{Vt}}$$

expressed in g/cc

Real specific gravity

It can be defined as the ratio of the weight of any volume of soil particles to the weight of an equal volume of water and hence known as real specific gravity or true specific gravity which is more than or equal to particle density.

$$\frac{\text{Wt. Of unit volume of soil solid}}{\text{Wt. Of an equal volume of water}}$$

Apparent specific gravity (Asg)

It is the ratio of weight of unit volume of dry soil including pore spaces to weight of an equal volume of water.

$$Asg = \frac{\text{Wt. Of unit volume of solid + pores}}{\text{Wt of an equal volume of water}}$$

Which has a unit (g/u) and which is equal to dry bulk density.

The bulk density or apparent specific gravity plays a vital role in irrigation. The bulk density is influenced by structure, texture and compaction of soil.

Bulk density influences the water holding capacity, infiltration rate, hydraulic conductivity water movement etc. Normally, it ranges form 1.2 to 1.8 for sandy soils and 1.0 to 1.6 for clay soils. An average of 1.4 g/cc is considered as optimum soil physical condition for irrigation.

Wet Bulk density

It is the ratio of unit mass of moist soil per unit volume of moist soil. This is also called as total bulk density.

$$\frac{Wt}{Vt} \qquad \frac{Ws + Ww + Wa}{VS + Vw + Va}$$

Soil wetness

The soil wetness refers to the relative water content in the soil. It can be described as mass wetness and volume wetness.

a) Mass wetness

It is the ratio of mass wetness to the mass of the soil.

$$\frac{\text{Mass of water in soil}}{\text{Mass of soil}}$$

This is commonly called as soil moisture content or gravimetric moisture content and generally expressed in percentage. It ranges from 25% to 65% depending upon the bulk density.

b) Volume wetness

Relative water content expressed in volume basis of water and soil

$$= \frac{\text{volume of water in soil}}{\text{Total soil volume}} = \frac{Vw}{Vt}$$

$$= \frac{Vw}{Vs + Va + Vw}$$

Degree of saturation

Represents to the volume of water present in the pore spaces.

$$\text{Degree or saturation} = \frac{V_w}{V_a + V_w} = \frac{V_w}{V_p}$$

This is also known as Relative saturation.

$$\text{Relative saturation volume} = \frac{\text{Volume of water filled in pore space}}{\text{Total pore volume}}$$

Pore space

Soil is a porous material consisting of particles of different sizes touching each other but leaving spaces in between. These spaces which are not occupied by the soil particles are known as pore space.

Role of Pore space and its importance

It constitutes about 40 to 60% of soil in volume basis. It provides space for water and air circulation and it plays a vital role in irrigation management.

There are two types of pore spaces

1. Micropore
2. Macropore

There is no sharp line of demarcation between the macro and micro pores. The macro pores allow the ready movement of air and permeability of water freely. In contrast, the micro pore air movement is greatly difficult and water movement is restricted to slow capillary movement. The volume of pore spaces varies according to the texture, structure and organic matter content. Soils having big particles contain less pore space than those having small particles. Thus the volume of pore space in an enclosed container having big particles is less than that of small particles. The size of individual pores is highly important for the movement of water in soil than the percentage of total pore space in soil. For example, percentage of pore space is high in clay soil which contains more micropores where water movement is highly restricted and thereby water holding capacity is more. In sandy soil, the percentage of pore space is relatively less than clay soil, but it contains large number of macropores. Hence the water movement is highly free.

Addition of organic matter increases the volume of pore space by lowering the bulk density there by increasing the unit volume of soil. Similarly mechanical manipulation or stirring of soil, decomposition of vegetation, root penetration, etc., increase the pore spaces.

If macropores are more in top layer, (0 to 30 cm depth) it is desirable for

a) Easy movement of air and water
b) Rapid infiltration of water

Between 30-150cm depth, equal amount of macro and micropores are essential to a) allow sufficient moisture, b) permit moderate percolation to lower layer which acts as storage reservoir.

Below 150cm depth mostly micropores are desirable so as to help to

a) Retain more moisture
b) To replenish the moisture in the upper layer whenever it is depleted
c) To restrict deep percolation loss.

Pore space percentage can be calculated by using particle density and bulk density

Particle density

It is the ratio of weight of soil to the volume of soil alone.

$$\text{Particle density (Pd)} = \frac{\text{Wt. Of dry soil}}{\text{Volume solid}}$$

(excluding pore space volume)

Bulk density

It is the ratio of weight of dry soil to the volume of soil.

Wt. of dry soil mass

$$\text{Bulk density (Bd)} = \frac{}{\text{Volume of soil mass (including porespace)}}$$

Porosity

It is defined as the ratio of volume of pores to the total soil volume and expressed in percentage.

$$\text{Pore space or Porosity} = \frac{\text{Volume of pores}}{\text{Total volume of soil}}$$

$$= \frac{\text{Total pore volume}}{\text{Bulk volume of soil}} = \frac{Vp}{Vt} \times 100$$

This porosity will give the relative volume of pores.

Void ratio or relative porosity

It is the ratio of volume of pores to the volume of solids alone. Here the above ratio between the volume of pores to volume of solids alone excluding of pore space is taken for consideration but Porosity is the comparison between the volume of pores to the total volume of soil i.e including pore space is given consideration. Hence this index has certain advantage and accuracy over porosity.

Capillary and non-capillary pores

The soil pores are also classified as capillary and non capillary pores based on their role in the movement of water or conductance of water.

Capillary pores

They retain the water after gravitational drainage of water is ceased or stopped. This water is held with the forces of cohesion, adhesion and surface tension which is available to the plants. Here the capillary porosity is the percentage that is occupied by capillary water.

Non capillary pore space

This is also termed as aeration pores. Non capillary pores are large pore spaces and do not hold water with tension. Since the water movement is not restricted, its movement is relatively high and thereby the pore space cannot hold water except condition of saturation. Generally this pore space is occupied with soil air. Hence non-capillary porosity is the percentage of pore space filled with air after the soil attains the field capacity level.

The large non-capillary porosity of sandy soil results in better drainage and aeration with low water holding capacity than the clay soil whereas the clay soils have larger proportion of small capillary pores which restricts the movement of water and hence water holding capacity is high but drainage is difficult.

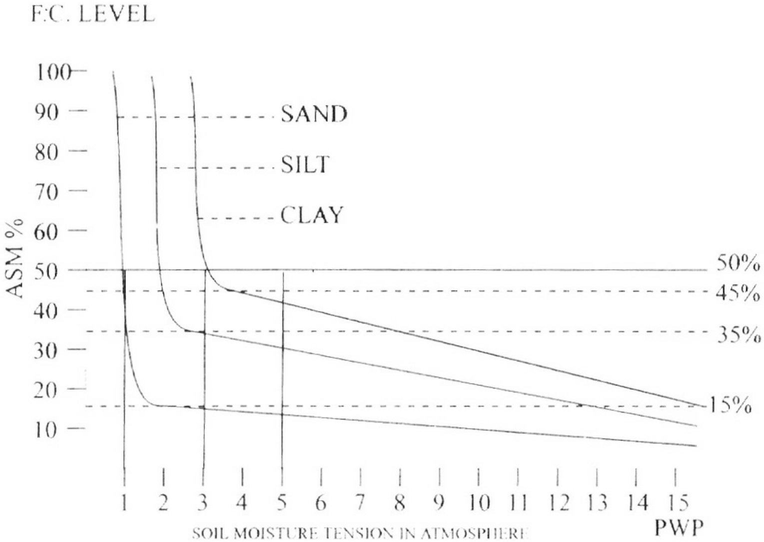
An ideal soil has pore space of equal amount of capillary and non-capillary pores and solids and pore spaces in equal proportion.

2.5. Soil moisture characteristic curves for different Soil types

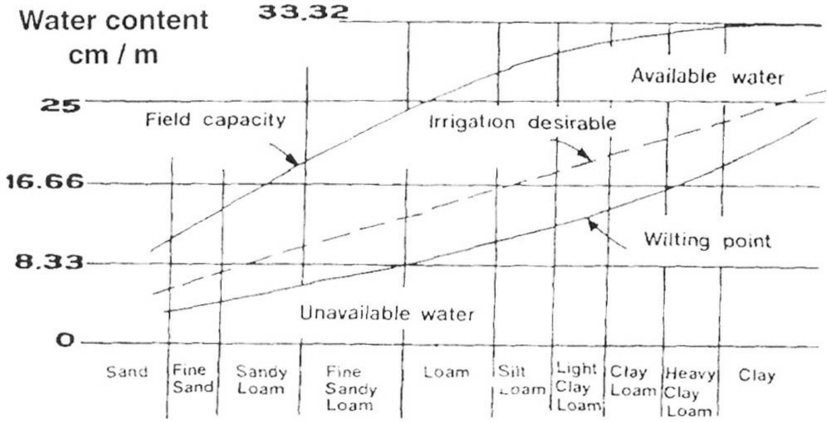
The study of the amount of water present in the soil at various tension is required to understand.

a) The amount of water available to the plants
b) Water that can be given to each irrigation
c) Water that can be held or retained by the soil before deep percolation starts.

This soil moisture tension and the water content relationship is not uniform for all types of soil. Generally tension and water content are indirectly proportional i.e., when the tension increases moisture content decreases. Sandy soil or coarse textured soil may deplete moisture completely at low tensions and fine-textured clay soil holds relatively high amount of soil moisture at low tension. In clay soil, considerable amount of soil moisture is available even at high tensions. Hence soil moisture tension and water content relationship are dependent on the physical properties of soil such as texture, structure etc., The relationship between soil moisture tension and available water content has been shown in the figures given below. Most of the soils require irrigation at 50% depletion of available soil moisture. Hence based on the above curve within 1-3 atmospheric tension, irrigation has to be given for sand, loam and clay soils. At 5-6 atmospheric tension the soil moisture percentage is around 15,35 and 45 percent respectively in sand, loam and clay.



Soil Moisture Characteristic curve



Graphical representation of water holding characteristics of different textured soil

This graph clearly indicates the range of the available soil water content (FC-PWR) in sand, loam and clay soil textures, which is in the order of low, medium and high, respectively, over sand, loam and clay. Normally for annual crops, irrigation at 50% depletion of available soil moisture is considered as optimum time for irrigation. This graph also reveals that the available and unavailable water is high in heavy textured soil than light textured soil.

2.6 Land capability classification

Soil is the reservoir for water in retaining and supplying the soil moisture to plant growth. The periodical recharging of water in soil pore spaces can be made either by irrigation or rainfall. The recharged water has to be supplied to plant system. This retention capacity and supply of capacity varies from soil to soil based on its physical and chemical properties. Based on this, soil classification is made for its suitability for irrigation. This classification is also known as irrigability classification. Generally soil can ho broadly grouped as shallow soil and deep soil.

Shallow soil

It means the actual depth of soil profile to hold moisture is very less and depth of soil medium available for plant to extend its root system for tapping water and nutrients is less.

Deep soil

The soil profile depth is more to hold moisture and the depth of soil medium available for plant roots to extend its branches to tap water and nutrients is also more.

The recent classification of soil for irrigability classes in arid and semi arid regions are as follows.

Class A - No soil limitation
Class B - Moderate soil limitation
Class C - Severe soil limitation
Class D - Very severe soil limitation
Class E - Non suitable for irrigation

This classification can be adopted to our country.

Grouping of soil based on their suitability for irrigation

Based on the suitability, the soils are grouped into 5 classes as 1 to V for the purpose of irrigation, survey and mapping as follows.

Group I

It is mentioned or indicated in green colour in soil mapping.

The soil has the characteristic features of

1) Good available moisture holding capacity
2) Low water table
3) Low salts either soluble or exchangeable
4) No soil crust and pan formation
5) Negligible sodium amount.
6) Negligible sub soil salinity.
7) Good Internal permeability.

Group II

Group 11 is marked in yellow colour

1. Moderately suitable for irrigation.

2. Limitations are relatively higher, salt and exchangeable sodium content is more than
   Group 1
3. Deep soil with loamy sand texture; some permeable clay may be there
4. Subsoil is also permeable in nature.

Group III

It is indicated in red colour.

1. Limited irrigation is practiced with limited cropping intensity.
2. Available soil moisture holding capacity is medium.
3. Medium water table
4. Moderate salt content and exchangeable sodium percentage
5. Moderate internal permeability
6. No soil crust or pan formation within the root zone.
7. Sub soil water may he slightly to moderately saline.

Group IV

Indicated in blue colour

This soil group is usually not suitable for irrigation. It has the characteristic features of

1. Shallow depth due to rocky substrata
2. Hard impervious pan formation
3. High soil pH
4. More soluble salt content (0.5%)
5. Low moisture supplying capacity
6. Low internal permeability

Reclamation work such as addition of organic manures, addition of sand, silt, and application of gypsum may bring the soil under irrigation.

Group V

Indicated in dark green colour

1. The soil is shallow in depth
2. Total soluble salt and exchangeable sodium percentage is high (more than 25%)
3. Stony impervious layers

4. Severe crust and pan formation are common
5. It can not be reclaimed by normal reclamation work.

The soil grouping may be again grouped based on the following limitation.

1) Erosion/drainage which is indicated by the symbol (O)
2) Drainage, wetness or overflow indicated by (W)
3) Root zone limitation indicted by the symbol (S)
4) Climate limitation indicated by the symbol (C)

Based on the dominance, the limitation will be ranked serially.

Irrigability classes and Rating

It is very difficult to classify the lands to determine their suitability for irrigation. The bureau of reclamation, USA has developed a system to classify the suitability of various lands for irrigation agriculture. The system uses six classes.

Class I

1. Land topographic and drainage characteristic are highly favourable for irrigation.
2. Wide range of crops can be cultivated
3. Climate also highly suitable for wide range of crops
4. Higher Yield may be obtained with low cost.

Class II

1. Capacity to produce crops may be high as that for class I land.
2. Production, drainage and land development costs are higher.

Class III

1. The capacity of the soil for crop production is moderately lower than class II.
2. More extreme deficiencies or limitations with soil respect to drainage, topographic undulations even though it is suitable for irrigation.

Class IV

1. Some lands in this may be costly to irrigate but due to intensive cropping the returns are adequate.

2. The reclamation cost will be high in some lands
3. Yields of crops are very low with low cost of production.

Class V

Normally unsuitable for irrigation: temporarily irrigation may be made under specific condition or feasibility are there to irrigate this land.

Class VI

1. Lands will not pay for irrigation. A wide range of physical and economic constraints are there
2. Reclamation work is very difficult.
3. In general the first four groups are suitable for irrigation. Class V is temporarily suitable and Class VI is considered as unsuitable for irrigation.

Rating

In rating some characteristic features will be given important consideration. Based on their dominancy, soil will be rated. The rated characteristics for each land class are:

1. Depth
2. Organic matter content
3. Fertility
4. Ability to absorb moisture
5. Store and release of moisture for crops
6. Drainage characteristics
7. Salt content
8. Response to fertilizers
9. Erodability
10. Workability for implements

Range of available water holding capacity of different soils

Soil type	Moisture (%)		Depth of available water per unit of soil (cm/m depth of soil)
	F.C	PWD	

Fine Sand	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	7-10	10-18
Clay	54-40	12-20	16-30

3. SOIL MOISTURE MOVEMENT

Immediately after irrigation or rainfall, the first action or process of water intake is called infiltration, then percolation and then seepage take place.

Infiltration

It is defined as the process of entry of water into the soil profile through the surface of soil.

Infiltration rate

It is defined as the rate of entry of water into the soil profile and expressed as cm/hr.

Percolation

It is the downward movement of water in the soil profile due to the force of gravity and moisture potential gradient. Percolation occurs from saturation point (where tension with which water held is very small about ½ atmosphere or Zero tension) to unsaturated soil where water is held at high tension.

Seepage or inflow

The sideward or lateral water movement is termed as seepage or inflow. This will occur both vertically and horizontally. The capillary rise is the reason for seepage in surface layer.

Practically it is impossible to separate the water movement as percolation and seepage but for our study purpose, the seepage and percolation can be separated and calculated through some methods.

Permeability

It is the characteristic feature of soil medium referring to its ability or capacity with which it conducts water or fluids, under normal conditions. It depends upon soil porosity and fluid density.

3.1 Water movement in soil profile

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

1. Water moves through the water filled pore spaces due to gravity and Hydraulic conductivity or it can also be termed as water movement under saturated condition, i.e., when soil pore spaces are completely filled with water.
2. Film of water surrounding the soil particles moves due to the force of surface tension under unsaturated condition or it can be stated as capillary water movement along the potential gradient.
3. Water also diffuses as water vapour through the air filled pore spaces along the gradient of decreasing vapour pressure.

3.2. Water movement in saturated conditions

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

Sand > loam > clay.

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

Darcy's law

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

Hydraulic gradient

It is the rate of change in hydraulic head with distance.

$$Hg = \frac{\text{Difference in hydraulic head}}{\text{Distance}} \text{ i.e., } I = \frac{h}{d}$$

Where,

Hg = Hydraulic gradient= I

Generally, Darcy's law is used to compute the velocity of flow of water through soil by using the formula.

$$V = k \frac{h}{d} \cancel{= ki}$$

Where,

V = velocity in cubic centimeter/ second/ centimeter

h = hydraulic head in centimeters

d = flow length or distance in centimeters.

k =hydraulic conductivity or proportionality constant

This formula can also be written as

V = ki, (since h/d = I)

V = effective flow velocity

k = hydraulic conductivity.

i = hydraulic gradient.

Here, the value of 'k' depends upon the properties of fluid as well and those of soil.

In mathematical expression Darcy's law can be written as

$q = kia$

in which

q = volume of flow per unit time (cm3/sec)

i = hydraulic gradient (dimensionless)

a = cross section of flow area (cm2)

k= hydraulic conductivity (cm/sec)

3.3 Water movement in unsaturated condition

The unsaturated soil water movement is also called as capillary movement. In this condition the macro pores are filled with air and only micro pores are filled with water which is held relatively more tightly and water is able to move very slowly. When soil moisture decreases, a part of pore spaces is occupied by soil air and the cross sectional area for water movement is reduced and three by hydraulic conductivity becomes low.

In unsaturated conditions, the conductivity is more in fine soil than coarse textured soil. Hence the unsaturated hydraulic conductivity is the function of soil moisture content, number, size and continuity of soil pores etc. The rate of unsaturated flow in various soil texture is in the following order.

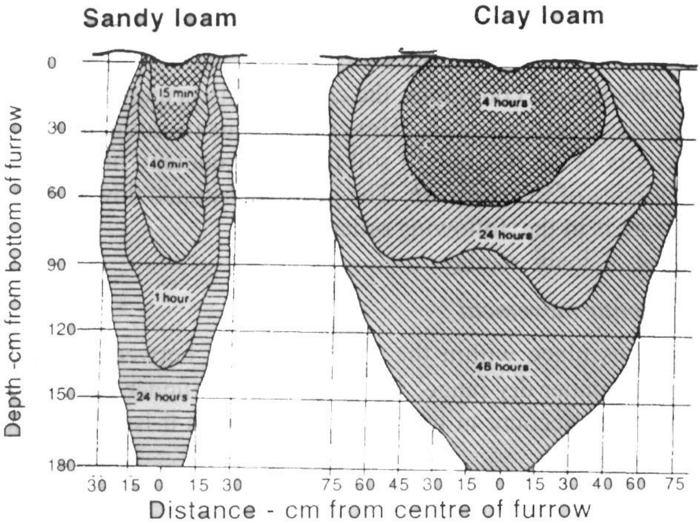
Sand < loam < clay

3.4 Water vapour movement

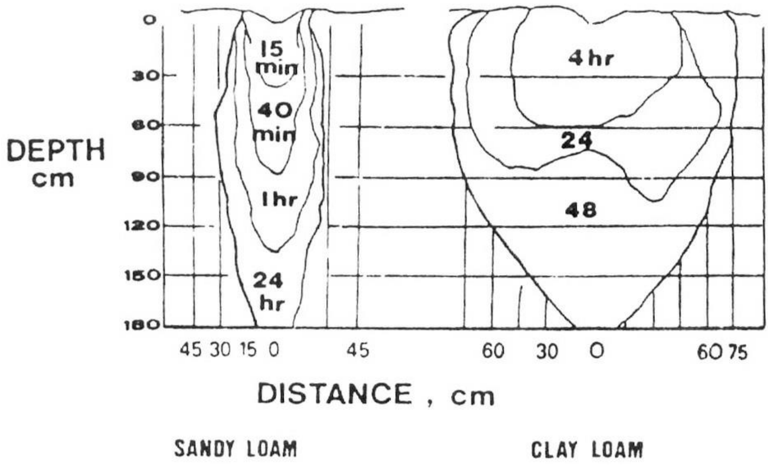
It takes place within the soil as well as between soil and atmosphere under dry range. The vaporization under wet range is not taken into account in irrigation practices as it is in negligible range. The finer the soil pores higher is the moisture tension under which maximum water vapour occurs. In the coarse textured soil, at low tension the soil pores become free of liquid water when soil dries out. There is little moisture left for vapour transfer. But fine textured soil retains substantial amount of moisture even at high tensions thus permitting vapour movement in soil occurs before it reaches PWP (Permanent Wilting Point). In this situation water vapour movement contribution is considered for the survival of plants.

Distribution of water in sandy loam and clay loam type of soil is given in figure. In coarse textured sandy loam soil the water distribution is very narrow and it percolates down to 180 cm within 24 hours of time period. At the same time horizontally the water spread to the maximum of 30 cm width.

But in clay soil, the water percolates down to a depth of 90-120 cm after 24 hours of irrigation. The water distribution is to a width of more than 60. cm horizontally during the same period. The figure clearly indicates that in finer texture soil, water movement is slow vertically and spread horizontally more than coarse textured soil.



Distance – cm from centre of furrow



Soil Moisture Distribution in Clay Loam and Sandy Loam Soil

4. Soil moisture constants

Soil moisture constant is nothing but the status of the soil mass or changes occurring in the soil mass after the irrigation or rainfall. In real sense we cannot expect constants of soil moisture, since it is very dynamic and always tends to change due to potential gradient or pressure gradient. These phenomenon helps to find out the soil moisture status, the availability condition of soil moisture, time and quantity of irrigation water to be applied etc.

4.1. The soil moisture constants

1. Saturation or maximum water holding capacity (MWHC)
2. Field capacity (FC)
3. Permanent wilting point (PWP)
4. Available soil moisture (ASM)
5. Moisture equivalent
6. Hygroscopic coefficient.

1. Saturation

Immediately after surface irrigation or heavy downpour (or) good amount of rainfall, soil below the surface are completely filled up with water. At this stage, all the micro and macro pores are filled with water. This condition is said to be the saturation point or maximum water holding capacity of soil. In saturation point, water is held without any force or tension or the tension is almost zero. This is equal to free water surface. At this point, the gravitational force tends to pull some water or part of water, which moves downwards due to gravitational force. This water is known as Gravitational water or Free water.

2. Field capacity

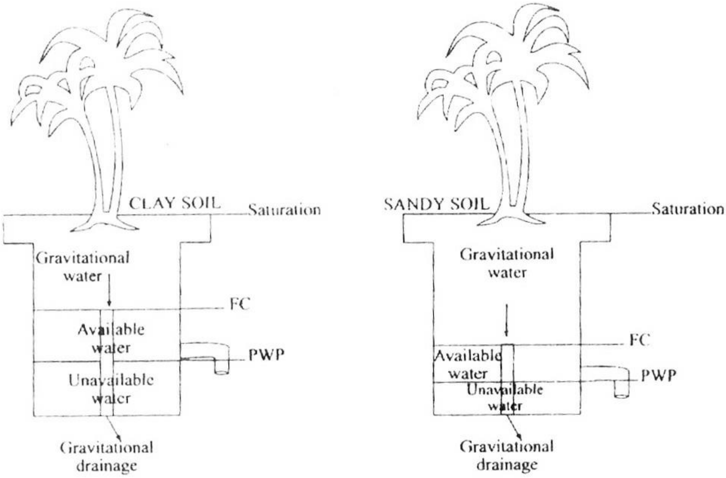
This can be defined as the moisture content present in the soil after the drainage of water due to gravitational force is stopped or ceased or become very slow. Hence, it can also be stated as the moisture content retained against the gravitational force. It can also be defined as the moisture present in the micro pore or capillary pore which cannot be drained off due to gravity.

At this point, the moisture content in the soil is comparatively stable and each soil particle is completely surrounded with thick film of water. Hence, it is also known as capillary water. This soil moisture is held with some force or tension against the gravitational force. The force with which water is held is measured in terms of moisture tension. Normally it ranges from 1/10 atmosphere to 1/3 atmosphere for coarse and fine textured soils, respectively.

The field capacity is the upper limit of available water to plants or maximum water available point to the plants. Hence, it is also known as Full point. The field capacity of soil is influenced by the soil texture or size of the particles, structure and amount of water applied. Immediately after irrigation or rainfall soil will reach saturation and its field capacity after two or three days depending upon the soil texture. The time required to reach field capacity condition is increased if soils are fine textured and rich in organic matter which restricts the downward movement of water.

3. Permanent wilting point

It is the condition of soil moisture at which plant cannot extract water from soil due to its high tension. It is the soil moisture condition at which water is held so tightly by the soil particles and this water cannot be removed by the plant roots. The plants wilting cannot be changed by further addition of water (or) the plant cannot regain its turgidity even though water is made available to the plants. This condition is called permanent wilting point. At this point, soil moisture tension will reach very high i.e., the moisture held in soil particles with a tension of about 14 to 15 atmospheres. Wilting and drooping of leaves are the most common symptoms at PWP. Some highly drought resistant crops will not wilt but show the symptoms like stunted plant growth, drooping of leaves, change in appearance and leaf colour, drooping of flowers, fruits etc.,



Soil Moisture Constants

4. Available soil moisture

This is the moisture content between the FC and the PWP level. After reaching PWP, the plant roots cannot extract water. It can be defined as the water available in the capillary pores after the cessation of gravitational movement of water and up to the limit of permanent wilting point.

This available soil moisture is not only the function of soil physical properties like texture and structure but also the soil depth. Hence it is expressed in terms of depth dimension for the particular root zone depth and described as:

$$ASM = \frac{FC - PWP}{100} \times bd \times d$$

ASM = Available soil moisture in root zone

FC = field capacity %

PWP = permanent wilting point %

bd = bulk density of soil (g/cc)

d = depth of root zone in cm.

In layered soil or at different depths the water storage capacity or available water capacity (AWC) is computed as the summation of capacity of different layers comprising the root zone as below.

$$AWC = \sum_{i=1}^{n} \frac{(FC - PWP)}{100} \times bdi \times di$$

i = i^{th} layer

di = denotes depth of i^{th} layer

bdi = bulk density of the i^{th} layer

n = denotes the number of soil layers

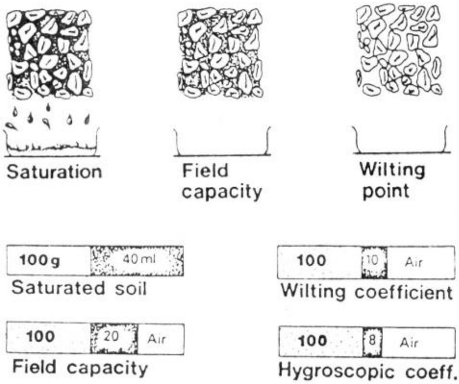
Field capacity and PWP are not fixed points but represents a range because water is always dynamic in soil. Hence this available soil water is influenced by Agro-climatic functions and soil factors.

5. Moisture Equivalent

It is defined as the amount of water retained by the saturated soil sample after being centrifuged for 1000 times that of the gravitational force for definite period of time usually for half an hour. A small mass of soil sample is saturated with water and the same is subjected to centrifugal force of 1000 times that of gravitational force for half an hour and the soil moisture percentage is worked out by gravimetric method. This moisture percentage is equal to field capacity. In light textured sandy soil it is less than FC, whereas in heavy textured clay soil it is more than FC.

6. Hygroscopic coefficient

It is the lower limit of soil moisture or very thin film of soil moisture around the soil particles. Simply it is expressed as the percentage of moisture in air – dry soil i.e., the moisture which remain in the soil after drying in air. At this point the moisture is held very tightly with soil particles with a tension of 10,000 atmosphere to 33 atmosphere. Hence this water cannot be absorbed by the plants since, plant cannot exert this much of tension or force to remove the water. Hence it is said to be the unavailable water. This water can be removed from soil particles by drying them in an oven at 105°C.



Soil Moisture Constants

4.2 Hydraulic conductivity

Hydraulic conductivity is the permeability of soil pores to the water movement under submerged condition. Hydraulic conductivity can be expressed as the proportionality factor of fluid properties (like its velocity, viscosity) and soil properties (such as infiltration, percolation and seepage) and soil influenced by soil structure and texture for water movement in soil profile. Simply it can be defined as the effective flow velocity at unit hydraulic gradient at saturated conditions and has the dimension of velocity. It is the ratio of flow velocity to the driving force of the soil solution or viscous flow under saturated condition.

$$H.C. = K \quad \frac{\text{Flow velocity (V)}}{\text{Driving force of viscous flow (i)}}$$

(Here Driving force of viscous flow is nothing but the Hydraulic gradient (i))

(K = Proportionality constant in Darcy's law)

Therefore, $V = Ki$

Hydraulic gradient

It is the rate of change in Hydraulic head per unit distance in the soil in the direction of flow.

Hydraulic Head

It is defined as the elevation of water column at different points. It has the dimension of length.

This hydraulic conductivity is expressed as proportionality factor in Darcy's law as V=ki

Where,

V = Effective flow velocity

I = Hydraulic gradient

The value of 'k' depends upon the properties of fluid as well as those of soil.

Hence, highly porous soil or coarse open textured soil has high hydraulic conductivity value whereas a fine textured soil restricts movement of water, and so has low value of hydraulic conductivity.

Viscosity

It is defined as the property of liquid, which oppose the relative motion among its parts. It is nothing but internal friction that makes resistance to flow of liquid.

4.3. Estimation of soil moisture constants

1. Water holding capacity

Water holding capacity is estimated with Keen and Razowaski cup. The soil is paced in this cup after fitting a filter paper at the bottom. Soil is soaked by capillary action. Weight is taken immediately after wiping the water on the sides of the cup and moisture is computed on oven dry basis.

2. Field Capacity

Field capacity is estimated directly in the field by ponding water in the plot covered all round by a bund. The test area may be $2m^2$. After a copious rain or heavy irrigation, estimation may be taken up. Soil is allowed to drain the excess water. Surface is covered to prevent evaporation. This may be accomplished by spreading a polythene sheet or thick straw mulch on the ground surface. Soil sampling is to be done at 24,36,48 and 72 hours. Soil moisture content is estimated by gravimetric method after drying in an oven at 105C for 6-9 hours till concordant weights are obtained. Moisture curves are to be drawn to locate the relatively stable values against time. For all soils except heavy clay soil, the sampling time may be 48 hours from irrigation. For experimental fields, field capacity may be estimated for few layers (0-15,16-30,30-45 and 45-60 cm) depending upon the rooting depth and information to be generated. Field capacity is also estimated with pressure plate apparatus by maintaining 1/3 atmosphere in disturbed soil sample.

3. Moisture equivalent

Moisture equivalent is estimated in the disturbed and air-dried soil sample. The soil is passed through 2.0 mm sieve. A porcelain buchner funnel of 5 x 2 cm is taken. A filter paper is slightly wet to enable to stick on the bottom. Air-dry soil is added to the funnel with gentle tapping against a smooth surface to ensure uniform packing. Soil is added to the full capacity of the buckner funnel and cut of the surface with the spatula. Soil sample in the funnel is left into water to enable the water to move by capillary action through the stem of the funnel. Soil in the funnel is left for 24 hours to be in equilibrium with water through capillary movement. After 24 hours, the funnel is removed from water column and fitted to a filter flask. The filter flask is connected to a vaccum pump (550 rpm) and subjected to suction for 15 minutes. During the process of suction, the soil is put into an aluminum cup without filter paper and moisture content is estimated by oven dry method.

Field capacity and moisture equivalent in few coimbatore soils (values in per cent) on oven dry basis.

S.No	Soil/ location	Field capacity 48 hours	Moisture equivalent	Difference
1	Soils in field no. 37	29.80	27.65	+2.15
2	Soil in cotton breeding station F.10B	32.05	33.35	-1.30

3	Soil in field No. 40 western Block	30.60	31.32	-0.72
4	Soil in field No. 70 Eastern Block	18.87	18.19	+0.68
5	Soil in college orchard	19.98	19.24	+0.74

(Thangamuthu and Aruna Rajagopal, 1974)

4. Wilting point

Estimation of wilting point moisture involves growing of sunflower as indicator plant in tin can. The tin can is closed with lid and the plant is allowed to grow through an opening in the lid. The plant is watered to grow for three to four weeks till three to four leaves develop. The plant is watered last and the space in the lid around the stem of the plant is plugged with cotton to control evaporation. The plant in the tin is allowed to wilt gradually. When the plant shows signs of loss of turgor, the can with plant is transferred to a dark humid cabinet to create high humidity. To reduce transpiration the humid cabinet is covered with a black polythene sheet. Inner sides of the cabinet are lined with gunny to retain moisture. The plant is allowed to extract moisture form the soil. If the plant is gaining turgidity, it is exposed to atmosphere for two hours and then transferred to humid cabinet. This process is repeated till the plant does not recover in the humid cabinet. At the stage the moisture content of the soil in the can is estimated to find out the wilting point of the soil.

4.4. Use of pressure plate apparatus for estimating soil moisture constants.

Soil moisture content values may be obtained by the use of pressure plate apparatus or pressure membrane apparatus. The soil in test is placed in this layer in the cups of the pressure membrane apparatus. Desired pressure is applied to obtain the required soil moisture constant (FC 1/3 atm) and the moisture content of the soil sample is estimated. Results of the study on soil moisture constants with pressure membrane apparatus and sunflower method (PWP) are given below.

Soil moisture content (values) of different soil moisture constants with pressure plate apparatus (Values in percent)

Soil	Black soil	Alluvial soil	Red soil	Laterity soil
Moisture Equivalent (1/3 atm)	31.1	30.8	19.9	27.1
Permanent wilting point (15 atm)	16.9	13.9	12.4	17.8
P. Wilting point (Sun flower method)	17.0	12.3	9.1	16.9

(Selvakumari et.al.,1974)

5. Moisture extraction pattern of crops

Plant absorbs moisture from soil through their root system. The method and quantity of water absorption varies with crops and their rooting pattern. The moisture extraction pattern revels about how the moisture is extracted and how much quantity is extracted at different depth level in the root zone. The moisture extraction pattern 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 from the first quarter of the root zone, 30% from second quarter, 20% from the third quarter and 10% from last fourth 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 have to be taken.

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

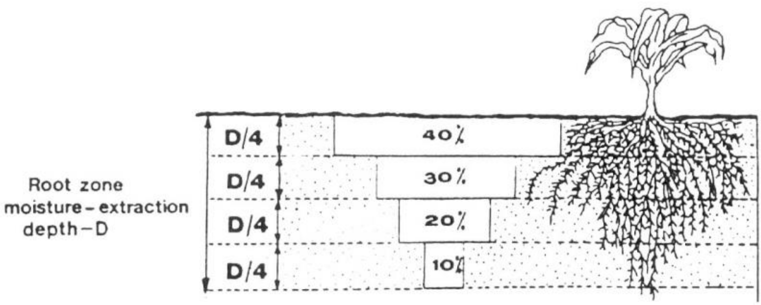
5.1. Rooting characteristics and moisture extraction pattern

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 than other crops. For example, it has been proved that cereals' roots extend to 200-400 cm 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 layer of soil as well as from the larger surface area. Plants vary genetically in their rooting characteristics. (Figures) 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 other 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, ground nut, grams tolerate medium level of soil water reduction.



Moisture Extraction Pattern

Root Zone Moisture Extraction Pattern

The root growth of the crop plants is affected by

1. Genetic nature

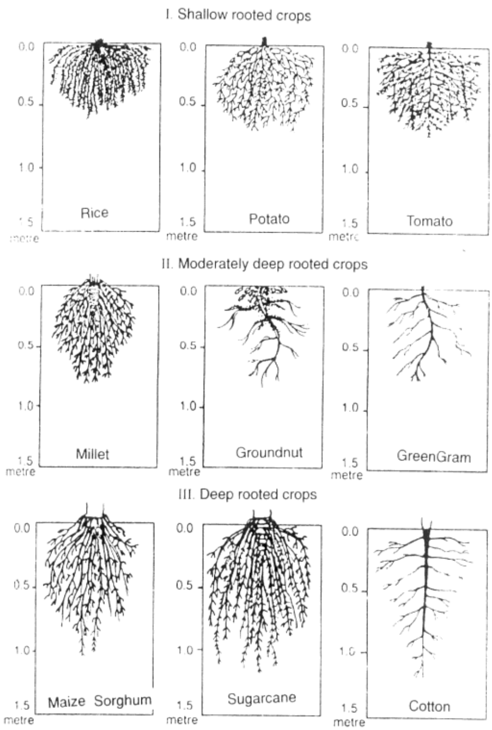
2. High water table
3. Shallow nature of soil and permeability of soil layer.
4. Soil Fertility
5. Salt status of soil

5.2. Effective root zone depth

It is the 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.

Effective root zone depth of some common crop depth:

Shallow (60 cm	Very deep (180 cm)
Rice	Sugarcane
Potato	Citrus
Cauliflower	Coffee
Cabbage	Sunflower
Lettuce	
Onion	



Rooting Depth of Different Crops

5.3. Water movement in soil-plant –atmospheric system

The total quantity of water required for the essential physiological functions of the plant is usually less than 5 per cent of all the water absorbed. Most of the water entering the plant is lost in transpiration. But failure to replace the water loss by transpiration results in the loss of turgidity, cessation of growth and death of plants due to dehydration.

The following are the main areas of water movement in plant system:

1. Water absorption
2. Water adsorption
3. Water conduction and translocation
4. Water loss on transpiration

The path of water movement may be divided into four sequential processes as follows:

i) The supply of liquid to root surface - Adsorption

ii) The entry of water into the root-Absorption

iii) The passage of water in the conducting tissues – (Xylem) Translocation or conduction.

iv) Movement of water through and out of leaves – Transpiration or loss of water.

The rate of water movement is directly proportional to potential gradient i.e. higher potential to lower potential and inversely proportional to the resistance to flow.

5.4. Mechanism of water absorption

In plants, water is absorbed through root hairs which are in contact with soil water. The wall of the root hairs are permeable and consists of pectic and cellulose substances which are strongly hydrophilic (water loving) in nature. There are two types of absorption.

a) Active absorption b) Passive absorption

a) Active Absorption

Here the process of osmosis plays an important role. The soil plant water movement can be effected due to forces of imbibition, diffusion and osmosis.

Imbibition

The first process in the absorption of water by the plant is the imbibition of water by the cell walls of root hairs.

Diffusion

Movement of diffusing particles from higher concentration to lower concentration is called diffusion. It is an essential step in exchange of gasses in respiration and photosynthesis and stomatal transpiration.

Osmosis

The movement of water from lower concentration to a higher concentration or higher potential to lower potential through a permeable membrane.

Significance of Osmosis

1. Large quantities of water are absorbed by roots from soil by osmosis.
2. Cell to cell movement of water and other substances takes place through this process.
3. Opening and closing of stomata depends upon the turgor pressure of guard cells.
4. Due to osmosis the turgidity is maintained and give a shape to the plants.

b) Passive absorption of water

It is mainly due to transpiration and the root cells do not play active role. Passive absorption takes place when rate of transpiration is very high. Rapid evaporation from the leaves during transpiration creates a tension in water in the xylem of the leaves. These tension is transmitted to the water in xylem of roots through the xylem of stem. Due to this, water rises upward to reach the transpiring surface. As a result, soil water enters into the cortical cells through the root hairs to reach xylem of the roots to maintain the supply of water. The force for this entry of water is created in leaves due to rapid transpiration and hence the root cells remain passive during this process. It is otherwise known as transpiration pull.

5.5 Factors affecting absorption of water

1. **Available soil water**

   Capillary water is available to plants. Hygroscopic water and gravitational water are not available to plants. The capillary water is absorbed by the plants which inturn reduces the soil water potential. Hence the water from higher potential area tends to move to lower potential area and root will absorb this water. This is the chain of process involved in water uptake.

2. **Concentration of soil solutions.**

   High concentration affects the process of osmosis.

3. **Soil air**

   Sufficient amount of O^2 should be there and excess amount of CO_2 affects the availability of water by root suffocation.

4. **Soil Temperature**

   Upto 30°C favours absorption. Very low and very high temperature affects absorption.

5. **Soil texture**

   Clay - neither good nor bad

   Sand – Not good for absorption

   Loamy - good for absorption

5.6. Crop response to irrigation and fertilizers

The requirement regarding the number and their timings vary widely for different crops. It has been observed that water requirement of crops vary with the stages of its growth. When the water supply is limited, it is necessary to take into account the critical stages of crop growth with respect to moisture. The critical stages of crop growth is commonly used to define the stage of growth. Certain critical stages at which if there is shortage of moisture, yield is reduced drastically. When there is shortage of water, it is better to take care of the critical stages first to obtain increased water use efficiency.

Water and Fertilizer

Water is the key factor in all the three mechanisms (mass flow, diffusion, transpiration pull) of nutrient uptake. Root intercepts more nutrient ions when growing in a moist soil than dry soil. In moist soil, the effective root zone area will be more and extensive which in turn absorbs more water and nutrients. This is especially important for calcium and magnesium.

If the applied fertilizer uptake is more, it enhances the growth and increases the yield under irrigated condition than dry condition which in turn increases the water use efficiency. Hence it is concluded that there is a close relationship between soil moisture and nutrient uptake by plants. The application of fertilizer or nutrients without adequate moisture in root zone is not useful to plants. Similarly, mutual benefits are also obtained from fertilizer. For e.g., in drought situation balanced fertilized crops is able to withstand drought, than relatively low fertilized crop.

Even well balanced fertilized crop may not show its normal growth and development unless adequate moisture is available. This is not only due to poor uptake, but also due to poor ET and which in turn reducing the use of absorbed nutrients for photosynthesis.

Fertilizer use efficiency can be increased by,

1. Soil test to evaluate nutrient deficiency and use of proper quantity of the needed fertilizer. Applying fertilizer based on soil test values.
2. Placement of fertilizers rather than broadcasting.
3. Split does of application at suitable time interval rather than bulk application.
4. Controlled application of water to avoid leaching of fertilizers to deeper layers.

In most cases there is significant correlation between soil moisture regime, fertilizer requirement and the availability of fertilizer for plant use.

Nitrogen

Mineralization of nitrogen increases as the water content of soil increases from PWP to FC and to saturation. When the fertilizer is applied to the surface soil, its uptake is inhibited when the soil dries.

Phosphorus

Increase in soil moisture to an optimum level is generally possible because of reduced aeration and root penetration or the increased activity of sesqioxide fraction on 'P' fixation under reduced condition. In dry areas 'P' applied close to the seed is more effective than the broadcast application. The availability and uptake of P is less in dry or rainfed condition.

Potassium

Soil moisture content affects the level of exchangeable 'K' in the soil. In high soil moisture zone, availability of k is increased.

The results of studies on fertilizer-irrigation relationship lead to the following conclusions.

1. Water use efficiency is raised by fertilizers by increased DMP (DRY matter production) and yield
2. The response of fertilizer is generally of a higher order under irrigated condition than under unirrigated condition.

Response to frequent irrigation is generally enhanced by increased levels of fertilizer application, particularly crops grown for its vegetative plant parts.

6. SOIL MOISTURE ESTIMATION

Moisture content of the soil is determined by using various methods, viz gravimetric method and by using sophisticated instruments like Tensiometers, Resistance blocks and Neutron probe. In this chapter all the following four methods are discussed.

1. Tensiometer method
2. Gravimetric method
3. Resistance block method and
4. Neutron probe method

6.1. Tensiometer method

Tensiometers are widely used for measuring soil water tension in the field and laboratory. A tensiometer consists of a 7.5 cm long porcelain cup filled with water which is connected to a water filled glass tube, a vacuum gauge and a hollow metallic tube holding all parts together. (At the time of installation, system is filled with water through the opening at the top and closed with a rubber cork.)

Principle

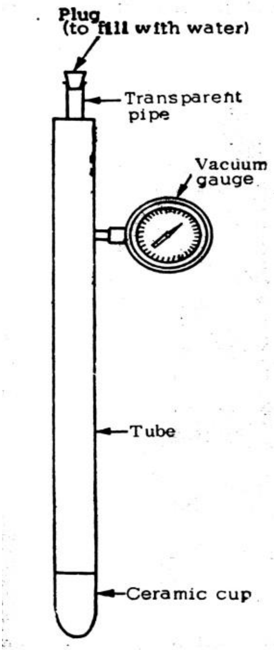
When installed in the soil at the required depth, water moves out through the porous cup till the surrounding soil is saturated. It creates a vacuum in the tube, which is measured in the vacuum gauge. When desired tension is reached, the field is irrigated.

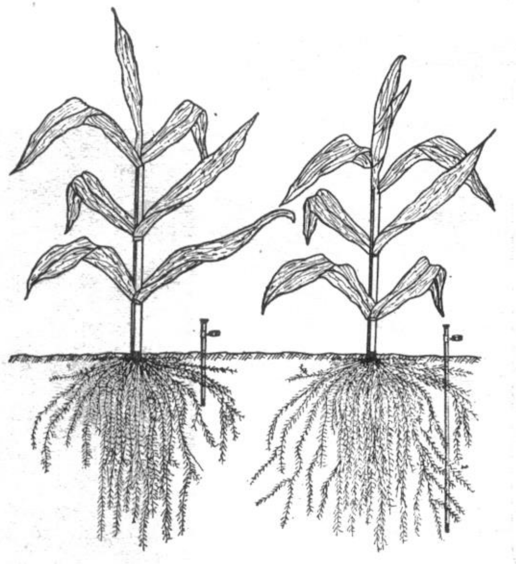
Merits

1. It is simple and easy to read soil moisture.
2. Useful to crops requiring frequent irrigation at low tensions.

Limitations

1. Costly (costs about Rs.150/- depending upon its length).
2. Sensitivity is only upto 0.85 atmospheric pressure.





Tensiometer **Installation of Tensiometer in the field**

Materials required

Tube auger, hammer, tensiometer and coloured stakes.

Procedure

Select the spot for installation and bore the soil by driving a tube auger or a hallow pipe with
sharp cutting edge which is driven into the soil by hammering it to the desired depth. Insert the tensiometer into the access hole. Compact the soil around the stem of the tensiometer to the original density of soil and make a small soil heap near the tube so that water will not stagnate near the tensiometer. Take the reading in the morning at 8. a.m. Record the reading frequently so that the difference between two consecutive readings is not more than 10 centibars. Plot the readings on a paper against the days.

6.2 Estimation of Soil Moisture by Gravimetric Method

Moisture content in the soil is determined by

a) Weight basis and

b) Volume basis

Weight Basis

This is otherwise called as gravimetric method. The method is extensively used for determination of moisture of the soil. In this method the soil moisture is expressed in oven dry weight basis. For example, when a soil is stated to contain 10% moisture on oven dry weight basis i.e that 100g dry soil holds 10g water. This is expressed as gravimetric wetness and it is expressed on dry soil basis.

Principle

The moisture contained in a known quantity of fresh soil sample is removed by using hot air oven and this moisture is expressed in percentage on dry weight basis.

Materials required

Screw soil auger, screw aluminum sample bottles, polythene bag, weighing balance, hot air oven.

Procedure

The soil sample in which the moisture content to be determined is taken from the field using the screw auger. The sample is transferred to an aluminium or stainless steel soil sample container. The weight of the sample container along with the soil sample is noted. Then it is placed in a hot air oven for 24-28 hours at 105 degrees centigrade. The dry weight of the soil sample with container is again weighed. From the dry and wet weights of the soil, moisture content cab be calculated.

Fresh weight of soil sample with container = w1 grams

Oven dry weight of soil sample with container = w2 grams

Empty weight of the container = w3 gram

Moisture content of the
Soil on dry weight basis =

(Moisture lost from fresh sample)

x 100

Dry weight of sample

$$= \frac{((W1-W3) - (W2-W3))}{(W2-W3)} \times 100$$

$$= \frac{(W1-W2)}{(W2-W3)} \times 100$$

Volume Basis

Expression of moisture content in percentage on dry weight basis may not include the amount of water available to plant. The conversion from weight to volume units can be made by.

oisture content % by volume = Moisture content% (by wt.) x Bulk density (gm/cm^2)

The percent by volume of moisture content obtained by the above relationship is numerically equal to the centimeter of water per meter depth of soil.

Moisture content in a profile depth of soil can be obtained from moisture content on dry weight basis by multiplying it with bulk density and profile depth as

= Moisture content (by wt)% x Bulk density (g/cm^3) X profile depth (cm)

Cautions

1. Sampling must he done maximum to the root zone of the crop.
2. Sampling should be in between two plants or rows.
3. If continuous soil moisture are to be studied, the sampling must be done within a radius of 50 cm from center.
4. Don not unscrew the auger while taking out the sample. Instead, pull out the auger with the soil.
5. Use a tube auger when the soil is dry to avoid spill out of sample.

6. Fresh weight of samples should be weighed without much lapse of time to avoid moisture loss during transport and lapse of time.

Advantages

1. Direct and simple
2. More reliable
3. More accurate

Limitations

1. Sampling, transporting and repeated weighing give room for errors.
2. Laborious and time consuming.
3. Needs costly equipments and technical know-how.

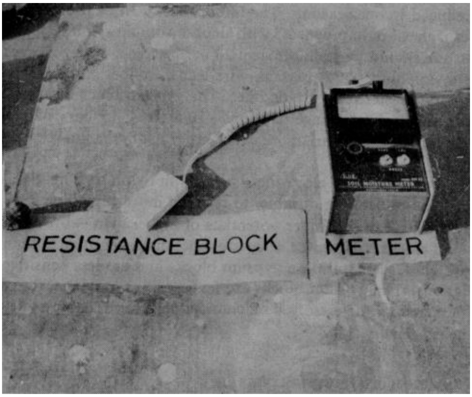
6.3. Resistance Block

Gypsum bocks or plaster of paris resistance units are used for measurement of soil moisture in situ.

Principle

It works on the principle of conductivity of electricity. When two electrodes are placed parallel to each other in a medium and when electric current is passed, the resistance offered in between two electrodes for the flow of electricity is inversely proportional to the moisture content in the medium. Thus, when the block is wet, resistance is low (conductivity is high.). The resistance at field capacity various from 400 to 600 ohms and at wilting point it varies from 50,000 to 75,000 ohms. The reading on resistance are taken with a portable resistance meter (Bouyoucos meter) operated by dry cells.

Installation of resistance block



Material Required

Gypsum or nylon blocks, a post-hole auger, bouyoucos moisture meter.

Procedure

Make a bore (access hole) with a post hole auger to the desired depth. Place the block inside and fill back the bore in small depth by packing the soil with a metal red to the original density. Ensure and intimate contact of the blocks with the soil. There should not be any root pieces pebbles etc., near the blocks. Normally 3-5 blocks can be placed in one hole at a vertical interval of 30 cm for experimental purpose. Heap the soil to a height of about 3cm near the surface at the bore space to prevent any water stagnation. Irrigate the field and record the readings, check the resistance readings at the field capacity. In a wide spaced crop, install the block in between two rows of plants. Two or four units are enough for an acre of land for irrigation scheduling.

Merits

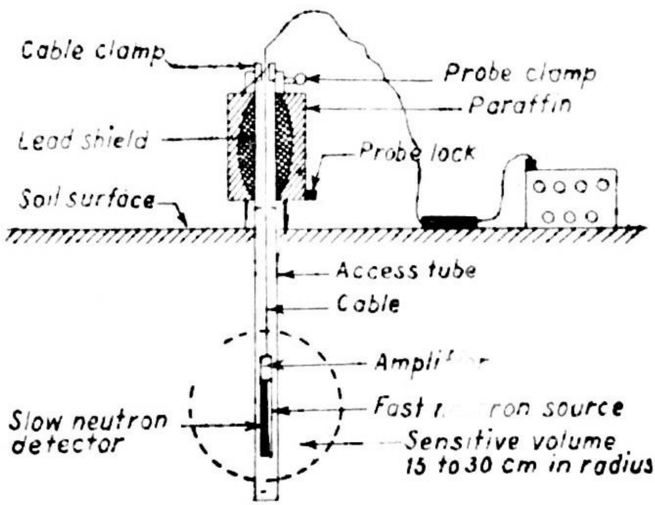
1. Works at low moisture level upto wilting point.
2. Suitable for repeated measurement at a point.
3. Simple and easy method.

6.4. Neutron probe Method

The neutron probe is designed as a field instrument for measuring insitu moisture content of the soil. The measurements are made by means of a probe, which is lowered into access tube installed vertically in the soil profile. Soil moisture is determined at specific depths to provide a soil moisture profile.

Principle

The probe contains a sealed Americium- Beryllium radioactive source having fast neutrons. When this source come in contact with soil, it emits fast neutrons into the soil and they collide with the hydrogen atoms in soil water causing the neutrons to scatter. Thus slow neutrons generated within the soil around is a function of soil moisture content. It is measured by boron trifluoride detector in the probe. This is amplified, displayed digitally as counts per second. The count rate is converted into soil moisture content by calibrations.



Installation of Neutron probe

1. **Probe Carrier:** Cylindrical, made from tough pvc, contains spherical poly propylene moderation shield for the fast neutron in its lower part.
2. **Cable:** This connects the rate scaler to the probe, normally 5m length but permitted to record at the correct count rate to the rate scaler.

3. **Rate Scaler:** Cylindrical unit, attached to upper end of the carrier body ; shows digitally the density of neutron cloud as counts per second.
4. **The Probe:** Consists of a stainless steel cylinder 38 mm diameter and 75mm long overall. Probe contains Americium-Beryllium source of fast neutrons. Probe can be operated below soil surface to a depth not exceeding 10m
5. **The Transport case:** Serves as a store for the probe and the carrier. It contains compartments to cells, spare cable, field record books, and the charged neutrons.
6. **The Access Tube:** The access tube is made out from material having low cross section of absorption for both fast and slow neutrons. Galvanized iron pipe of 50mm diameter with be good.

Procedure

The access tube is first inserted into the soil by drilling a hole with the help of an auger. It is few centimeters above the soil and covered with an inverted case.

The neutron probe is inserted into the access tube by carefully lowering down cable to the desired depth. Then the counting rates are determined. Initially the probe is to be adjusted and calibrated against volumetric determination of soil moisture content.

Merits

1. More reliable
2. Very rapid method.
3. Soil conditions are not disturbed.
4. Repeated measurements are possible in the same location
5. Moisture contents at different depth at a smaller depth interval are possible in one stoke.

Demerits

1. Costly (Rs.1 to 1.5 lakhs) and not within the reach of farmers.
2. Needs technical skill to operate the instrument.
3. Radiation hazard may affect the device and soil. Periodic check up is needed.

4. Small change in soil moisture content cannot be detected.

7. Soil Moisture stress

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 evaporative demand during the night and early morning (Prior to sunrise) the values of water potential are often 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 of 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 the 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 crop is the integrated result of a number of physiological processes. Water stress can affect 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 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.

Drought tolerance of plants

Plants survive the periods of water stress by various means. Short duration varieties that avoid extensive drought period may be better drought resistant than other varieties. Researches on producing idiotype plants with leaf and stomatal characteristics suitable for drought resistance may result in developing suitable drought resistant varieties. Plants exhibit drought tolerance either because the plants are able to survive tissue desiccation. Drought-hardy plants usually have smaller cells than those living in moist habits. When desiccated, small cells undergo a much smaller proportionate reduction in volume than do large cells and therefore do not suffer large disturbances as the latter. In general, increased osmotic values are the characteristics of plants having superior drought hardiness. The higher osmotic values not only increases the ability of cells to retain water, but may also have an additional effect by increasing the resistance of the protoplasm to dehydration. One of the most effective safeguards against drought injury is a deep and wide-spreading root system as that of sorghum. Plants with shallow, sparsely branched root systems like potatoes, onions etc. suffer sooner than deep rooted species like Lucerne and maize.

Terminology

Chemical potential of water: The chemical potential of a substance in a system is a measures of the capacity of that substance to work. In a simple solution of a non-electrolyte in water, the chemical potential of water depends on the mean free energy per molecule and the concentration of water molecules.

Osmotic pressure: When a solution is separated from pure solvent by membrane permeable only to the solvent there tends to be a net flux of solvent into the solution since the chemical potential of the solvent is higher in the pure phase than in the solution. This process is called osmosis and the pressure difference which must be applied to the solution to prevent a net flux of solvent is called osmotic pressure. In general dehydration is accompanied by an increase in osmotic pressure. Osmotic pressure, however, is not sufficiently sensitive to be used as an indicator of small changes in water balance.

Diffusion pressure deficit: Diffusion pressure deficit (usually abbreviated as DPD) of water in a cell or solution is defined as the amount by which its diffusion pressure is lower than that of pure water at the same temperature and under atmospheric pressure. The DPD of a cell may be regarded as a measure of the pressure with which water would diffuse into the cell when immersed in pure water. The equation for the DPD in a cell is: DPD = OP- TP in which OP is the osmotic pressure of the cell contents and TP is the turgor pressure within the cell. The DPD is a more sensitive indicator of the degree of turgidity. It is comparable to the total soil moisture stress (moisture tension + osmotic pressure) of a soil. A fully turged tissue has a zero DPD. The DPD increases as the water deficit increases until it equals the osmotic pressure, except when a negative wall pressure of tension develops when it may even exceed the osmotic pressure. This value is especially useful because it is expressed in atmospheres and can therefore be compared with soil moisture tension and osmotic pressure of the soil solution. The main difficulty in the extensive use of DPD is the difficulty in measuring it. Another objection to its usage is that it is no longer used in physical chemistry and or thermodynamics and that diffusion is no longer considered as the only mechanism by which water will move under the influence of free energy or chemical potential gradients. The term water potential is often used instead of DPD.

Cell water potential: Water potential is a measure of the free energy status of water. As applied to plant cells, under isothermal equilibrium conditions, the various factors involved in cell water relations can be summarized by the following equation.

$$\Psi_{cell} = \Psi_S + \Psi_D + \Psi_M$$

in which Ψ_{cell} is the potential of water in the cell and the other terms express the contribution to Ψ_{cell} by solutes Ψ_S pressure Ψ_D and matric forces (Ψ_M). Ψ_S and Ψ_M are both negative while Ψ_P is positive. Ψ_S

expresses the effect of solutes in the cell solution, and Ψ_M expresses the effect of water-binding colloids and surfaces in the cell. The sum of $\Psi_S+\Psi_P+\Psi_M$ is a negative number, except in fully turgid cells when it becomes zero. In this case, the positive pressure potential Ψ_P balances the sum of the negative osmotic and matric potentials. It may be shown that DPD is numerically equal to Ψ_{cell} but opposite in sign (Kramer, 1969), that is,

$$\Psi_{Cell} = DPD$$

The potential of water in a cell is less than that of pure water, i.e., it is negative whereas, DPD is positive because it is defined as a deficit.

8. CROP WATER REQUIREMENT

Water requirement is defined as the quantity of water required by a crop or a diversified pattern of crops in a given period of time for its normal growth at a place under field conditions. The source of water may be anything like wells, tanks, artisan wells of canals of rivers.

8.1. Water requirement to crops

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 water 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).

f) The water required for special purpose (WSP) like puddling operation, ploughing operation, land preparation, leaching requirement , for the purpose of weeding for dissolving fertilizers and chemicals. 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 garden land crop, the ET loss alone is accounted for crop water requirement.

The estimation of the water requirement of crop is one of the basic needs for crop planning in the farm and for the planning of any irrigation project.

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 for demand point of view as;

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

It can also be stated based on 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 to water needed and its efficient use of 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 to meet 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

8.2. Evaporation

Evaporation is defined as the process by which water moves out of the water surface or soil surface in the form of water vapour to atmosphere due to pressure gradiance.

Evaporation from natural surface such as open water, bare soil or vegetative cover is a diffusive process by which water in the form of vapour is transferred from the underlying surface to the atmosphere.

The essential requirement for evaporation process are.

1. Source of heat energy to vapourise the irrigated water
2. The presence of a concentration gradient of water vapour between the evaporating surface and surrounding air of atmosphere.

Evaporation can occur only when vapour concentration of evaporating surface exceeds that of the surrounding air. The sources of heat energy are solar energy and wind energy. The energy required for evaporation is 590 calories per gram of water to evaporate at 20^{o}C.

The fundamental principle of evaporation from a free surface has indicated evaporation as the function of difference in the vapour pressure of water surface and the vapuour pressure of air.

Measurement of Evaporation

This can be made by the following methods.

1. Pan evaporimeter
2. Tin can evaporimeter
3. Pitche evaporimeter

Pan Evaporimeter

Evaporimeter is an instrument which integrates the effect of all the different climatic elements and furnishes their combined effect. It is relatively simple, cheap and more useful in irrigation practices.

U.S.W.B. Class A pan Evaporimeter

It is the standard type used globally. It is made of GI pan having a diameter of 120cm with a depth of 25 cm. It is painted with white colour to reduce heat absorption and mounted on a wooden platform at a height of 15cm from ground level to reduce the effect of soil temperature. The water level is measured by the Hook gauge or a fixed scale attached to a stilling well. The pan is covered with a mesh to prevent animals' and bird's disturbances to the water.

Evaporation is recorded at a fixed time in the still well by adding water in the evaporimeter to compensate the daily loss of water by evaporation. Evaporimeter is to be cleaned periodically and tested for it's leakage. Development of algae etc., should be avoided.

Tin can evaporimeter

A small tin is fitted with a scale and water is filled in the tin and kept in the cropped field at different locations. The daily loss will be taken as evaporation.

Pitche evaporimeter

It consists of a graduated tube of 30 cm with one open end and covered by a drier paper and is attached in a metallic stand. The tube is filled with water and turned upside down. The water slowly wets the paper and evaporates and the water loss in the tube is considered as a measurement of evaporation.

Evaporation, transpiration and consumptive use are the important factors in estimating irrigation requirement and planning irrigation system.

8.3 Transpiration

This is the process by which water in plant body transfers to the atmosphere in the form of water vapour. Transpiration is the process by which water evaporates in the form of water vapour from living plant body especially from leaves to atmosphere. It involves a continuous movement of water from soil to atmosphere through root, stem and leaves.

The rate of transpiration depends on:

a) Supply of energy to vapourise the water and

b) The water vapour concentration gradient at atmosphere.

It is further influenced by the climatic, soil and plant factors.

Climatic factors

Light intensity, temperature and wind.

Soil factors

Texture, infiltration rate, water holding capacity, Field capacity, moisture releasing pattern etc.

Plant factors

Root system, leaf area, leaf arrangements, leaf structure, stomatal behaviour, etc.

8.4 Evapotranspiration or Consumptive use

It is very difficult to separate the losses due to evaporation and transpiration in a cropped field. Hence, these two processes are combined to a term called Evapo-Transpiration (ET). These two losses are considered as water used for plant growth and hence it can be considered as Consumptive Use (CU). The consumptive use includes all water consumed by the plants and the water evaporated from bare land and water surface in the area occupied by the crop plants.

Factors affecting ET

1. Solar radiation which supplies energy for ET
2. Wind which removes the water vapour from cropped area and makes changes in water vapour concentration gradient.
3. Temperature which increases ET rate.
4. Relative Humidity which changes the ET rate due to changes in water vapour gradient. All the above are interrelated with each other
5. Stage of the crop

It has a considerable influence on ET rate. This is very particular in annual crops which has a distinctive stage of growth. These are:

a. Emergence and development
   ET or Consumptive use rate increase rapidly from low value and approaches its maximum.
b. Maximum Vegetative phase.
   ET or CU rate is maximum if abundant soil moisture is available.
c. Maturity phase
   ET or CU rate begins to decrease.

6. Rooting characters of crop plants.
7. Environment

If the surrounding lands are barren, ET or CU will be more than the cropped area which is covered with vegetation.

Evapotranspiration or Consumptive use is the important phenomena in irrigation management since, it denotes the quantity of water transpired by plants during their growth or retained in the plant and the moisture vaporized from the surface of the soil under vegetation.

8.5. Potential Evapotranspiration (PET)

It is the evaportranspiration from a large area fully covered with short vegetation with sufficient available water. Or it can also be stated that ET from the fully covered vegetative area under unlimited water available at all the times. This concept was suggested by Thornthwait in 1948.

Further, Jensen in 1968 assumed that PET is the upper limit of ET that would occur with a well irrigated, well grown agricultural crop, it is also known as reference evapotranspiration and denoted as ET0. It can be calculated by four empirical methods using different climatic components suggested by irrigation scientists. They are i. Blaney and Criddle 2. Radiation method. 3. Pan evaporation method 4. Modified pennman method.

The reference crop evaporation (ET_o) can be obtained from

ET_o = Kp x E_{pan}

KP =Pan coefficient

E_{pan} = Mean evaporation in mm/day

The Kp values for different agro climatic conditions have been already standardized (Refer-Table 18. From FAO Irrigation and Drainage paper 24). For our condition, 0.8 can be taken as kp value.

Selection of crop coefficient for estimating ET

The value of ET need to be adjusted for actual crop ET, since under natural field condition PET rarely occurs in most of the irrigated field crops. Normally the PET will occur in low land rice and two to three days after irrigation or rain in gardenland condition.

For convering ET_o value into ET crop, suitable crop coefficients (denoted as Kc) should be evolved for different crops, soil, climate and different stages of crops.

Crop coefficient is the ratio between ET crop and Eto.

ET crop = Kc x Eto

$$Kc = \frac{\text{ET crop}}{Et_0}$$

This ratio is usually 0.2 during early growth stage and about 1.0 when the crop develops maximum canopy and root system. The ratio again gets reduced as the crop approaches maturity. Value of crop factors have to be worked out for local situation.

Some approximate values of crop coefficient for some common crops at different places

Stages *	Maize (Ludhiyana)	Sorghum (USA)	Cotton (Puen)	Sugarcane (Hawai)	Rice (Philippines)
5	0.42	0.44	0.22	0.37	1.02
25	0.75	0.72	0.35	0.60	1.09
50	1.09	1.79	1.08	1.02	1.20
75	1.04	1.09	1.93	1.16	1.19
100	0.70	0.40	0.70	1.19	0.80

* growth in %

Seasonal consumptive use

It is the total water requirement for the crop growing periods to meet the ET loss. Hence, it can be stated as the total water used in evapotranspiration by cropped area during the entire growing season which is called as seasonal consumptive use. It is expressed as depth of water in cm. This value is used to evaluate and determine the seasonal irrigation water requirement. Seasonal consumptive use values are required to evaluate and determine the seasonal irrigation water supplies.

Peak period consumptive use

The highest consumptive use for certain period in the growth season is called the peak period consumptive use. This value is used in the planning and designing of irrigation system. The peak period consumptive use will vary from soil to soil and from crop to crop.

In the irrigation project designs, this peak period CU will be accounted for proper planning and use of the available water effectively for different cropping pattern. This peak use rate also varies in different climatic conditions.

The table given below indicates the peak rate of soil moisture removed by crops under different climatic conditions.

Maximum rates of soil moisture used by crops under different climatic condition

Climate	Peak rate of soil moisture removed (mm/day)
Cool humid	3
Cool dry	4
Moderate humid	4
Moderate dry	5
Hot humid	5
Hot dry	8

8.6. Measurement of Evapotranspiraton

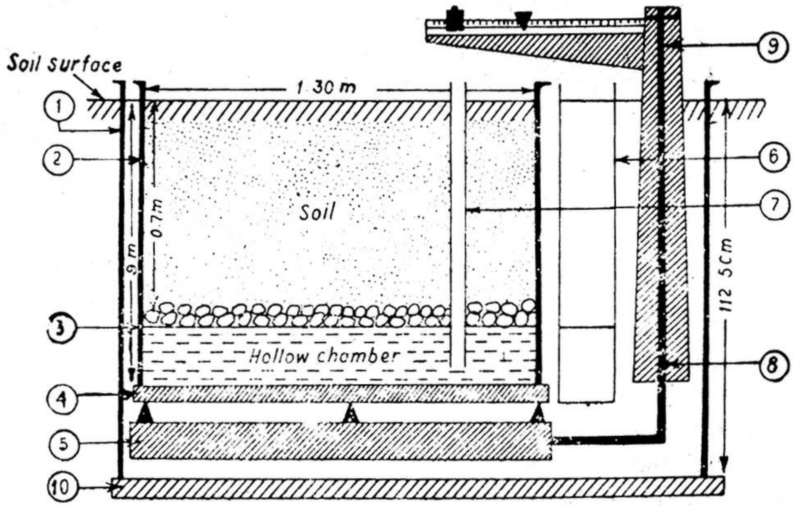
The methods which are adopted to measure the evapotranpiration or actual consumptive use are

1. Lysimeter experiment
2. Filed Experimental plot method
3. Soil moisture depletion studies
4. Water balance method.

All the above methods are time consuming, laborious and involving high cost.

1. Lysimeter experiment

It is otherwise known as evapotraspiration meter. It is nothing but growing the crop in big containers (filled with soil) under natural conditions of the field to determine the water gain and loss to work out the evaporation and transpiration. In this method, ET is measured directly to study the climatic factors.



Schematic diagram of Mechanical weighing Lysimeter
(1.Retaining tank, 2.Lysimeter tank, 3.Perforated plate, 4.Platform, 5,8,9 - Balance, 6.Dummy tank, 7.Pipe to remove percolated water, 10. Foundation)

Important precautions in establishing Lysimeter

The soil condition inside the lysimeter must be similar to that of the outside field. The lysimeter must be surrounded by the same crop that is growing inside the lysimeter. The lysimeter should not be surrounded by side walls, path or gravel which will affect the reliability of data. The rim or border of the lysimeter should be as small as possible to reduce the difference in soil temperature in the lysimeter wall as in the fields.

There are two types of lysimeters.

a. Weighing type

Here the added water and water losses are weighed through the weighing balance fitted in the lysimeter. The weight difference is taken into account to measure the ET.

b. Non- weighing type

Here the changes in the soil moisture at time intervals is measured by using neutron probe to work out the ET.

(In both the cases different sizes of lysimeters are available)

Disadvantages

Reproduction of same physical condition as that of the field such as temperature, water table, soil texture, densities etc., within the lysimeter are very difficult.

2. Field Experimental plot method

In this method, seasonal water requirements are computed by adding measured quantities of irrigation water, the effective rainfall received during the season and the contribution of moisture from the soil.

$$WR = IR + ER + \sum_{i=1}^{n} \left[\frac{Mbi - Mei}{100} \, AiDi \right]$$

Where,

WR	-	Water requirement in mm
IR	-	Total irrigation water applied in mm
ER	-	Seasonal effective rainfall contribution in mm
Mbi	-	Moisture content at the beginning of the season in the i^{th} layer of soil
Mei	-	Moisture content at the end of the season at i^{th} layer of soil.
Ai	-	Apparent specific gravity of the soil at i^{th} layer.
Di	-	Depth of soil at i^{th} layer unit.
n	-	Number of layers in the soil.

3. Soil moisture Depletion studies

This method is applicable to the irrigated field crops in fairly uniform soil when the depth to the ground water is such that it will not influence the soil moisture fluctuation within the root zone. These studies involve measurements of soil moisture form various depths at a number of times throughout the growth period. Consumptive use (Cu) is calculated from the change in soil water content in successive samples from the following relationship.

$$Cu = \sum_{i=1}^{n} \left[\frac{Mbi - Mei}{100} AiDi \right]$$

Where,

CU	-	Consumptive use in mm
Mbi	-	Moisture content at the beginning of the season in the ith layer of soil
Mei	-	Moisture content at the end of the season at ith layer of soil.
Ai	-	Apparent specific gravity of the soil at ith layer.
Di	-	Depth of soil at ith layer unit.
n	-	Number of layers in the soil

Disadvantages

It does not provide information on

- Intermediate soil moisture condition
- Short term use
- Deep percolation losses and
- Peak use rate of the crop

4. Water Balance Method

This is done at macro level. This is also called as the inflow-outflow method, which is suitable for larger areas (watersheds) over longer periods. A knowledge of the water balance is necessary to evaluate the possible methods to minimize loss and to maximize the gains and utilization of water which is the limiting factor for crop production. The water balance of a filed is comprehensive statement of all gains and losses of a given field within specified period of time. The task of monitoring and controlling of field water balance is important to the efficient management of water and soil. Gains of water in the field is generally due to precipitation and irrigation and occasionally due to run off collection from higher tracts and from shallow ground water table.

Losses of water includes a) surface run off b) transpiration from foliage c) evaporation from soil surface d) deep percolation out of the root zone etc., The change in storage of water in the field can occur in the soil as well as in the plants. The total change in storage must be equal the difference between the sum of all gains and sum of all losses and is represented by the hydrological equation .

Change in storage = Gain –loss

$$(P + 1 + GW) - (ET + R + D)$$

Where,

P	=	Precipitation
I	=	Irrigation
GW	=	ground water contribution
ET	=	Evapotranspiration
R	=	ruff off loss
D	=	deep percolation loss
P	=	$ET+O+D+\Delta W$

Where,

P	=	Precipitation ; ET Evapotranspiration
O	=	Surface run off ; D- Sub surface drainage;
ΔW	=	Changes in soil water content

8.7 Factors affecting water requirement

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

b) variety
c) growth stages
d) duration
e) plant population
f) 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.

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

In general, this crop water requirement can be classified as:

1. **Low** ranging from 300 to 450 mm Greengram, Blockgram, Sunflower , safflower Finger millet and minor millets.
2. **Medium** ranging form 450 to 650 mm Maize, Sorghum, Wheat, Groundnut, Sunflower.
3. **High** ranging from 600 to 1000 mm Cotton and Perennial Redgrarn.

4. **Very High** ranging from 1000 to 2250mm Rice, Sugarcane, Banana and plantation corps.

WR range for different crops

Crop	**WR (mm)**
Rice	1200 - 1400
Maize	400 - 550
Sorghum	400 - 550
Wheat	450 - 550
Ragi	350 - 550
Pulses	350 - 450
Groundnut	350 - 650
Sunflower	300 - 500
Cotton	600 - 850
Sugarcane	1400 - 2000
Banana	1650 - 2250
Plantation crop	1250 - 1850

8.8 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 = 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
b) Area of crop
c) losses in the farm water distribution system etc.

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

Net irrigation requirement

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

It is the water applied by irrigation in terms of depths 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 demand of the crop. It is the difference between the F.C and the soil moisture content in the root zone before starting irrigation.

$$d = \sum_{i=1}^{n} \left| \frac{MFCi - Mei}{100} AiDi \right|$$

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

Gross irrigation requirement

The total quantity of water used for irrigation is termed as 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.

$$\text{Gross irrigation Requirement} = \frac{\text{Net Irrigation requirement}}{} \times 100$$

Field efficiency of system

8.9 Irrigation frequency

Irrigation frequency is the interval between two consecutive irrigations during crop periods. Irrigation frequency is the number of days between irrigations 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 tow irrigations in the period of highest consumptive use of crop growth, i.e. peak consumptive use of corp.

Design frequency (days)

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

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.

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

Growth Duration

Growth duration of different crops varies considerably. The growth duration of the irrigated dry crops (ID crops) like sorghum, maize, groundnut, pulses etc., is restricted to a single crops season and known as seasonal crops. The growth span of crops like cotton, red gram, chillies, etc., is spread over to two seasons and are known as biseasonal or two seasonal crops.

Crops like sugarcane, and banana take more than a year and are referred as annual or biennial crops and plantation crops like coconut, tea, coffee etc., which take one to several years for their growth are referred to as perennial crops.

The growth period of ID crops are broadly divided into three phases namely:

1) Vegetative

a) Crop establishment (first two or three weeks)

b) Crop development (two to six weeks)

2) Reproductive

a) Flowering stage

b) Fruiting stage

3) Maturity

a) Enlargement

b) Ripening

c) Harvest

The entire reproductive and flowering phase in most ID crops are highly sensitive growth periods. In this period, water stress or excess water condition should be avoided.

Growth stages of cereals in relation to irrigation

Stage	**Details**
1. Germination	the appearance of radicle
2. Tillering	the formation of tillers
3. Jointing	the stage when two nodes be seen i.e beginning of shooting
4. Shooting	the stage of elongation of internodes.
5. Booting	the end of shooting stage and just prior to the emergence of ears
6. Heading	the emergence of ear head from the tube formed by the leaf sheath

7. Flowering the opening of flowers
8. Grain formation the period of grain development from fertilization to maturity.

Further divided into
Milk stage - Milky consistency
Dough stage - Doughy consistency
Dead ripe - Ripe for harvesting

8.10. Effective rainfall

ER means useful or utilizable rainfall. All the rainfall received are not used by the crops because of its erratic nature such as untimeliness, lesser or higher quantity etc. The useful portions of rainfall which is stored in soil and supplied to the crop for its consumptive use is called effective rainfall.

The term effective rainfall has been interpreted differently by different specialists.

To a canal engineer, the rain which reaches the storage reservoir is the effective portion.

To a hydro electrical engineer, the rainfall which is useful for running the turbines that generate electricity is effective.

To an agriculturist, the portion of total rainfall that directly satisfies crop water needs and also the surface run off which can be stored and used for crop production is considered as effective rainfall. The rain water which moves out of the field by surface runoff and deep percolation beyond the root zone of the crop are ineffective rainfall.

Factors influencing Effective Rainfall

Several factors influence the proportion of effective rainfall and these may act singly or collectively and interact with each other.

1. Rainfall characteristics

Large quantity as well as high intensity will reduce effectiveness because of excess run off and less infiltration rate. A well distributed rainfall with some frequent light showers is more conducive to crop growth than downpour.

2. Land slope

Here, because of the slope very less infiltration opportunity time is available which results in rapid run off loss and less effective.

3. Soil Properties

Properties like infiltration rate, retention capacity, releasing capability and movement of water influence the degree of effectiveness.

High infiltration, high W.H.C. etc., increase effectiveness by avoiding run of losses. High moisture content, low infiltration rate, low WHC reduces effectiveness.

4. Ground water characteristics

Shallow water table cause more run off and effectiveness is low. Deep water table causes more
infiltration and percolation and effectiveness of
rainfall is more.

5. Management practices

Bunding, terracing, contour tillage, ridging, mulching, etc., reduce the run off and increases the effective of rainfall.

6. Crop characteristics

Crop with high water consumption creates greater deficits of moisture in the soil. The effective rainfall is directly proportional to the rate of water uptake by the plant.

7. Carry over soil moisture

It is the moisture stored in the crop root zone depth between cropping seasons or before the crop is planted. This moisture is available to meet the consumptive water needs of the succeeding crop. The contribution of rain occurring just prior to sowing may be equivalent to one full irrigation.

8. Seepage and percolation

Surface and sub surface seepage and deep percolation below root zone will also influence effectiveness of rainfall.

In drawing the seasonal or monthly irrigation requirement for a given crop or cropping pattern, the main variables composing the field water balance include.

1. Crop water requirement as determined by dominant crop characteristics.
2. Contribution from precipitation, ground water and carry over soil moisture.

9. METHODS OF IRRIGATION

Application of irrigation water to cropped field by different types of layouts are called as irrigation methods. The methods of irrigation initially might have been started to check the over flow of water from one field to another. But today, it has become necessary to save the water by proper methods to arrest run-off loss, percolation loss, evaporation loss etc. and to optimize the crop water need.

Hence, irrigation method can be defined as the way in which the water is applied to the cropped field without much application and other losses, with an objective of applying water effectively to facilitate better environment for crop growth.

9.1. Factors influencing Irrigation Methods.

1. Soil Type

The soil physical properties such as texture, Structure, porosity, infiltration rate, etc. influence the selection of irrigation methods.

- ❖ Heavy texture soil restricts water movement than light texture soil wherein water move freely to deeper sections due to high porosity.
- ❖ Single grain structure soil allows water freely to move downward compared to other structures

2. Soil depth

If soil is shallow which holds less water, leveling and forming bunds etc. to hold maximum water to increase the irrigation interval. Similarly if the soil is deep, it holds more water and needs longer irrigation interval. Accordingly, the irrigation methods can be selected.

3. Topography of Land

In undulating topography, it is very difficult to adopt normal methods of irrigation. The slope of he land also decides the methods to be adopted. If the land is more sloppy, basin method can not be used. In this condition strip method can be used. For undulating topography instead of strip or basin method, sprinkler or drip methods can be used.

4. Climate

Rainfall, temperature, humidity, wind velocity, radiation, etc. influence the irrigation methods. For example, heavy wind affects sprinkler irrigation and temperature affects surface method of irrigation by high evaporation loss.

5. Water Sources

The flow velocity, quantity and quality of available water are the other main factors which decide the methods of irrigation to be adopted.

6. Crops to be grown

The value of the plant and the geometry of the crop to be cultivated are the main criteria to decide the method of irrigation. For example, if the crop is a high value or cash crop or wide spaced crop, sprinkler or drip method of irrigation cab be adopted. Irrigation water cab be applied to the land in the following general ways.

- By flooding (wetting all the land surface)
- By furrows (wetting only a part of the ground surface in which crops are grown)
- By Sub irrigation (sub surface soil irrigation)
- By sprinkler (soil is wetted through sprinkling water)
- By drip irrigation (water is applied at the individual root zone of the plant).

9.2. Classification of irrigation methods

The irrigation methods are broadly classified as

1. Surface method or gravity method of irrigation
2. Sub surface or sub irrigation
3. Pressurized or micro irrigation
    a) Drip irrigation
    b) Sprinkler irrigation

1. Surface or Gravity Irrigation

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

Advantages

i. Easy to maintain
ii. Low cost
iii. Technical skill is not required.

Prerequisites to adopt this method

1. Uniform soil.

2. Smoothness of field surface or levelled surface.
3. Adequate quantity of water.

9.3. Classification of surface methods

1. Border Strip method

The field is divided into number of long parallel strips by providing small parallel earthen bunds or levees or dykes along both sides of the strips. The end along of the strip may or may not be closed, which is based on the length of the strips. If the length of the strip is very long, the end will be closed to have a uniform distribution and to avoid run off loss. Each strip is irrigated independently from upper end (turned on) and water flow as thin sheet and uniformly spread along the strips. The water is turned off when the required volume is delivered to the strip. The application efficiency of this system is 75-85%.

Suitability

a) **Soil**

Suitable to the soils having

a. Moderately low to moderately high infiltration rate.
b. To the field which is having 0-0.5 %Slope.
c. For dense, closer spaced crop it can be advocated upto 4% slope provided there should not be any erosion hazard.
d. Not suited for very sandy soil and very clayey soil as they have too high and low infiltration rate, respectively.

b) Crop

All closely spaced crops like pulses, wheat, Barley, Alfalfa, Berseem, Grasses, Ragi,Cumbu and small grains.

Dimensions

a. The width of the strips depend upon the size of the stream and normally this varies from 3-15m.
b. The length varies according to the slope, stream size, soil type, etc.

c. Length of the border strips and recommended safe limits of slopes for various types of soil are given below.

	Length	Slope(%)
Sandy and sandy loam soil	6.0-12.0 m	0.25 to 0.60
Medium loam soil	10.0–18.0 m	0.20 to 0.40
Clay loam to clam soil	15.0–30.0 m	0.05 to 0.20

Classifications

It can be further classified as

1. Graded Borders 2. Level Borders

Graded Borders have slope ranging form 0.1 to 0.5% in the longitudinal directions and there is no or very little slope across the strip. For level border, there is no slope in either direction.

2. Check Basin Method (Beds and channel)

It is the common and simple method of irrigation mainly adopted in levelled land surface. It is also known as Beds and channel method of irrigation. The land is divided into small basins/beds. The area of basin is surrounded by earthen bunds or levees or dykes. The applied water is kept within the basin and not allowed for run off. This is the most common method adopted for most of the crops. The size of the levees or ridges or bunds depends upon the depth of water to be impounded in the basin. The water is turned on the upper side and after applying the required quantity of water it is turned off.

Check Basin Method of Irrigation

Suitability

a) Soils

a. More efficient (More than 90%) in fine textured soil. This is due to the uniform rapid spread of water and more infiltration opportunity time for all areas and thereby depth of infiltration is uniform all along the basins.
b. The correct quantity of water can be applied as there is no run off.
c. Leaching of salt is possible by impounding water and giving more opportunity/time for infiltration, stagnation and drainage.
d. Suitable to lands with smooth, gentle and uniform slope with low to medium infiltration rate.

b) Crops

All Cereals, Millets, pulses, oilseeds etc.

Disadvantage

a. It needs high degree of levelling for uniform distribution of water
b. Within the basin, soil should be uniform
c. It is not suitable for coarse textured soil with high infiltration rate.
d. The bunds should be strong enough to withstand ponding of water.
e. In fine textured soil with very low infiltration rate, precaution may be taken to avoid long time water stagnation.

Dimensions

The basin area for different soil types, inflow rate and slope percentage are given below for reference. The size of the basin is also influenced by the depth (in mm) of irrigation water. It the required irrigation depth is large, the basin can be large. Similarly, if the required irrigation depth is small, then the basin should be small to obtain good water distribution.

Maximum Basin Areas (M2) for various soil types and available stream sizes (L/Sec) (Lps)

Stream size (L/Sec)	Sand	Sandy loam	Clay loam	Clay
5	35	100	200	350
10	65	200	400	650
15	100	300	600	1000
30	200	600	1200	2000
60	400	1200	2400	4000
90	600	1800	3600	6000

Average width and range of width based on slope percentage

Slope percentage	Average	Range
0.2	45	35-55
0.3	37	30-45
0.4	32	25-40
0.5	28	20-35
0.6	25	20-30
0.8	22	15-30
1.0	20	15-25
1.2	17	10-20
1.5	13	10-20
2.0	10	5-15
3.0	7	5-10
4.0	5	3-8

Check Basins should be small if the

a. slope of the land is steep
b. soils is sandy
c. stream size to the basins is small
d. required depth of the irrigation application is small
e. Field preparation is done by hand or animal drawn implements

Check Basins can be large if the

1. Slope of the land is gentle flat
2. Soil is clayey
3. stream size is large
4. required depth of the irrigation application is large
5. field preparation is mechanized.

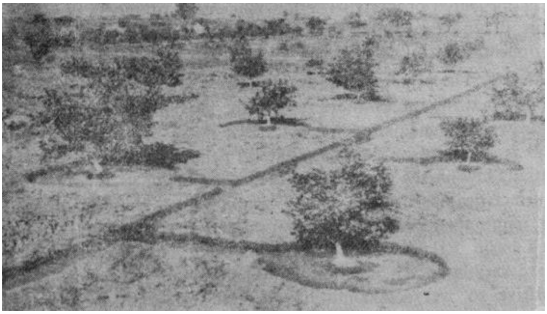
Based on the shape of the basin, it can be classified as rectangular or square or irregular basin. Mostly, the rectangular shape is preferable for easiness in other farming operations,

3. Basin Method

Basin method of irrigation is used in soil submergence method of irrigation in low land rice, bunded rainfed rice and forage grasses, where water is stagnated to the required depth by providing bunds on all the sides to sufficient width and height. The optimum size for efficient water management to rice crop is 0.25 to 0.40 ha. The field is to be leveled thoroughly for uniform depth of water. Provision of separate irrigation and drainage channels is more efficient than field to field irrigation.

4. Ring Basin

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



Ring Basin

5. Furrow method of Irrigation

it is the common method adopted for row planted crops like Cotton, Maize, Sugarcane, potato, Beetroot, Onion, Sorghum, vegetable crops etc. In this method, small evenly spaced shallow furrows or channels are formed in the beds. Another method of furrow irrigation is forming alternate ridges and furrows to regulate water. The water is turned at the high end and conveyed thorugh smaller channels. Water applied in furrows infiltrate slowly into the soil and spread laterally to wet the area between furrows.

Dimensions

Based on the soil slope and stream size, the length can be fixed. The furrow width or spacing varies from 60-120 cm which depends upon the crop to be grown. The depth of furrow varies from 12.5cm, which depends upon a) soil type b) flow size and c) effective root zone depth of crop.

Suitability

- This method is mostly suitable for medium to moderately fine textured soil which allows free water movement both horizontally and vertically.
- In sandy or coarse textured soil, this method is not suitable because here the water movement is primarily downward and very little in horizontal direction. Besides, the length of ridges or furrows to resist the velocity of flow is very low which inturn may lead to breaching of the structures.

- This method is adopted for soils having the problem of surface crust or hard pan.
- The labour requirement to form the furrows is relatively higher than other surface methods of irrigation.

Precautions

While using the furrow method of irrigation, care must be taken in strengthening the furrow since erosion hazard on sloppy areas may damage the furrow. To work out the maximum non erosive flow in the area, the below mentioned empirical formula can be used.

$$Q = \frac{0.60}{S}$$

Where,

Q = Maximum non erosive stream in lps.

0.60 = Constant

S = Slope of the furrow in percentage

The following table also can be used as reference for selecting maximum non erosive flow rate to critical slopes in furrows.

Practical values of maximum furrow length (m) depending on slope, soil type, stream size and net irrigation depth.

Furrow slope (%)	Maximum stream size per furrow (lps)	**Net irrigation depth (mm) and furrow length (m)**						
		Clay		**Loam**		**Sand**		
		7.5cm	**15.0cm**	**5.0**	**10.0**	**5.0**	**7.5**	**10.0**

0.05	3.0	300	400	120	270	60	90	150
0.1	3.0	350	440	180	270	90	120	190
0.2	2.5	370	470	220	370	120	190	250
0.3	2.0	390	500	280	400	150	225	280
0.5	1.2	380	500	280	370	120	190	250
1.0	0.8	270	400	250	300	90	150	220

Irrigation furrows may be classified into two general types

1. Straight furrow and
2. Contour furrow

Straight Furrow:

Best suited to soils where land slope does not exceed 0.75%

Contour furrow:

This method is similar to graded and level furrow method. Furrow carries water across slopping field rather than downwards. They are designed to fit the topography of field. Furrows are given a gentle slope along its length as in graded furrow. Field supply channels run down the land slope to feed the contour furrow and are provided with erosion control structure. Successfully used in all irrigable soils. All row crops including grains, vegetables and cash crops are adapted to this method. Light soil can be irrigated successfully across slopes upto 5% slope. Up to 8 to 10% can be irrigated by contour furrow. Contour furrow may be used on all types of soil except in light sandy soil and soil that crack.

Corrugation Irrigation:

It consists of running water in small furrows, which direct the flow down the slope commonly used for irrigation in non-cultivated close growing crops such as small grains, pasture on steep slopes. Corrugation can be made with a simple bamboo corrugation or cultivators equipped with small furrows. Corrugations are ‘V’ or ‘U’ shaped channels about 6-10 cm deep spaced 40 – 75cm apart. This method is not recommended for saline soil or for saline water irrigation. The permissible length of corrugation varies from 15cm within light textured soil with slopes of 2-4% to about 150cm in heavy texture soil upto 2% slope.

Furrow Irrigation Design Consideration:

Efficient irrigation by furrow method is obtained by selection of proper combination of spacing, length and slope furrows.

Furrow spacing:

Furrows can be spaced to fit the crops grown and types of machines used for planting and cultivation. Crops like Potato, Maize, Cotton, etc. are planted 60 – 90 cm apart and have furrow between all rows. Carrot, Lettuce and Onion are spaced 30-40cms and often have two rows between furrows. Furrows should be close enough to ensure that water spreads to the sides of the ridge and the root zone of crop to replenish soil moisture immediately.

Furrow length:

Optimum length furrow is usually the longest furrow that can be efficiently and safely irrigated. Long furrows are an advantage in inter cultivation. Proper furrow length depends largely on hydraulic conductivity of soil. It should be shorter in porous sandy soil than clayey soil. If only a small area is to be irrigated, the length of field may determine the length of furrow. In large area it may be desirable to have furrow length equal to an even fraction of the total length of the field.

Furrow Slope

The slope or grade of furrow is important because it controls the speed at which water flows down the furrow. A minimum furrow gradient of 0.05% is needed to ensure Surface drainage.

Furrow stream:

The size of the furrow stream is one factor which can be varied after furrow irrigation system can be installed. The size of furrow stream usually varies from 0.5 – 2.5 lit/sec. The max nonerosive low rate in furrow is estimated by following equation, qm = 0.6/S

qm = maximum no-erosion stream(lit/sec)

S = Slope of furrow(%)

Average depth of irrigation water applied during irrigation can be calculated by the following relationship.

D = (q x 360 x t) / (w x l)

Where

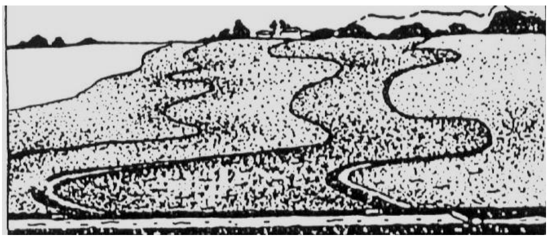
D = Average depth of water applied (cm)

q = Stream size (lit/sec)

t = duration of irrigation(hrs)

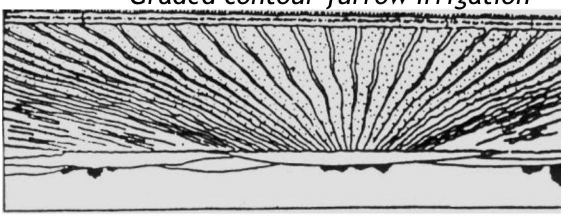
l = Furrow length(m)

w = Furrow width(m)

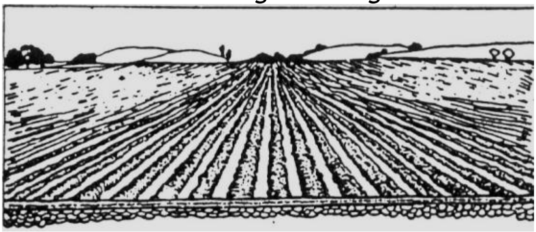


Contour Irrigation

Graded contour-furrow Irrigation



Corrugated Irrigation



Graded or level-furrow Irrigation
Different types of Furrow Irrigation

6. Surge Irrigation

Surge irrigation is a method of surface irrigation through furrows or border strips wherein water is applied intermittently in a serious of relatively short on and off time periods during the irrigation (Humphrey, 1989). Water is let into a long furrows or border strips in an intermittent flow instead of conventional continuous flow. Each flow is termed as a surge.

Surge irrigation practiced under favourable conditions can improve the performance of surface irrigation system compared to the other methods of surface irrigation. Irrigation is given in an on-off cycle or by cut back method. The cycle time means the time from the beginning of one surge to the beginning of next surge. Cycle ratio is the ratio of flow time (continue) to the cycle time. Assuming the cycle time as 20 minutes and cycle ratio as 1:2 (0.5), the on-time is 10 minutes and off time is 10 minutes. This cycle ratio can also be the ratio of on-time and off-time as 1:1. if the on time is 10 minutes. Water is allowed for 10 minutes and stopped for 10 minutes. This 20 minutes is the surge time or cycle time. This surge is repeated until the water reaches the whole furrow or strip.

The first surge of water over a portion of dry furrow wets the soil surface at a slow advance rate and high infiltration rate. When the next surge is allowed to flow along the first surge length, water makes faster to the second surge length. Thus in surge flow, the advancing water along the furrow is faster resulting in uniform wetting from the head to the tail end of furrow. Under the conventional continuous flow, wetting is more in head end than at tail end. When more water is allowed to increase the wetting depth in the tail end, it leads to loss of water through tail end run off. This loss and the rate of infiltration along the whole length of flow distance are reduced in surge irrigation, in addition to saving time of irrigation.

Advantage:

- Reduction in infiltration rate
- Rapid advance of wetting front
- Less difference in intake opportunity between upper and lower ends of furrow
- More uniform distribution of water along the length
- Improvement in application uniformity and irrigation efficiency.
- Reduces water requirement
- Water reaches the furrow end much earlier than under continuous stream.
- It is a non erosive method, suitable for erodable soils
- Useful for light textured soils with high infiltration rate
- Saves irrigation time and the energy cost for lifting water
- About 20% of land area is saved in cross channels with shorter furrow lengths
- It offers scope for automation of surface irrigation

Limitations:

- Little or no advantage in clay or silty soils

- Tail end water loss may increase if not managed properly.
- Lengthy furrows of more than 100m are required
- Ensuring proper gradiance to such lengthy furrows is difficult.
- With progress in surge cycles and number of irrigations, the bulk density is increased due to soil consolidation
- More suited to shallow rooted crops only.

9.4. Subsurface Irrigation

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

Suitability

It is mainly suitable for the high temperature area where ET losses are very high wherein controlling and maintenance of surface water and application is very difficult.

Pitcher Pot irrigation method

It is one way of applying water below the ground or soil surface. In this method, in a mud pot, some small holes are made and the holes are closed by either threads or material which is able to conduct water very quickly. The pots are kept around the root zone in pits made for it. The pits are completely covered tightly with sand mulch mix. The pots are filled with water and closed. The water slowly penetrates to root zone through the holes and wet the root zone area. This method is mostly suitable for widely spaced tree crops under water scarce conditions.

10. PRESSURIZED IRRIGATION METHODS

It includes both sprinkler and drip irrigation methods where water is applied through network of pipelines by means of pressure devices.

10.1 Sprinkler Irrigation System /Point source method

In this method the irrigation water is sprayed to the air and allowed to fall on-the ground surface more or less resembling rainfall.

The sprinkling of water or spray of water is made by pumping water under pressure through network of pipelines and allowing to eject out by means of small orifices or nozzles or holes.

The water required by the crop is applied in the form of spray by using some devices, wherein the water application rate should be somewhat lesser than the soil infiltration rate to avoid run off or stagnation of water in the filed.

Suitability and Advantages

a. It is highly suitable for sandy soil where infiltration rate is more
b. For shallow soil where levelling operation is technically not possible.
c. For lands having undulating topography or steep slopes where levelling is economically not advisable
d. Irrigation steam size is very small where surface flow is low
e. It is almost suitable for all crops except crops like rice, which needs stagnation of water, but under water scarcity it can be tried for rice also. For cotton during reproductive phase sprinkler irrigation is not advisable.
f. Application of fertilizer (fertigation), pesticides (pestigation) and herbicides (herbigation) are possible through irrigation systems which reduce labour cost and increase the use efficiency of any chemical.
g. It controls crop canopy temperature
h. In crust soil, it facilitates early germination and establishment by
i. means of light and frequent irrigation.
j. Wastage of land for basin, ridges and furrows and irrigator channels are reduced.

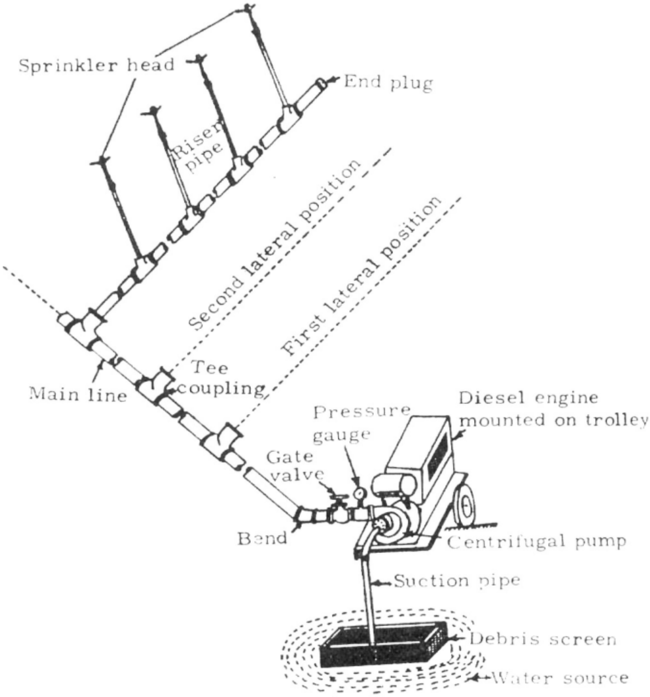


Fig. 8.32. Components of a sprinkler irrigation system.

Components of sprinkler irrigation system

Disadvantages

a. In heavy windy areas the distribution efficiency is reduced due to drifting of water droplets.

b. In saline water conditions, it causes leaf burns besides clogging and corrosion of the pipe line.

c. Continuous power supply is required to operate the system to maintain pressure

d. It is very costly to install and to maintain

e. Uniformity of application is difficult due to over application or neglected corners in the field.

10.2. Major Components of Sprinkler Irrigation System.

1. Pump set
2. Network of pipes lines (Main, lateral, sub lateral, etc,)

3. Riser pipes with tripod stand

4. Sprinkler head

10.3. Classification

There are two types

1. Rotation Head system
2. Perforated pipe system

Further it cab be classified as

a. Portable – All components are portable

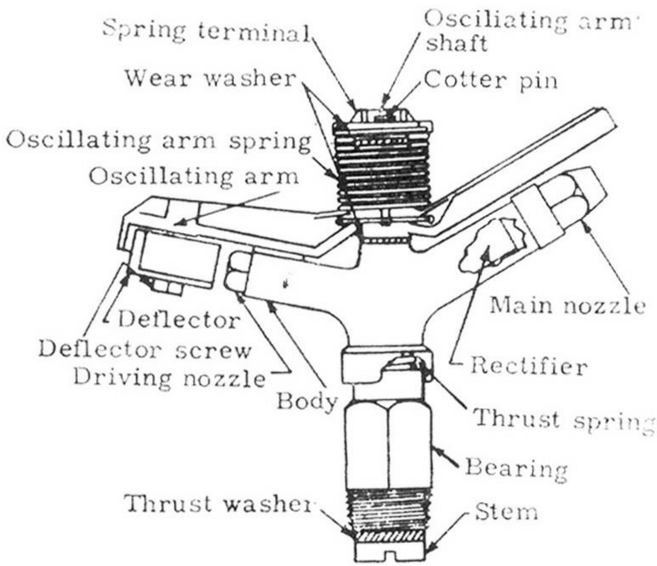
b. Semi portable (or) Semi Permanent

- Water source, Pumpset, main and sub mains are fixed. Only laterals are portable.

d. Permanent – All components are fixed

1. Rotating Head System

A special device to sprinkle the water called “Sprinkler Head” is used in this system. The sprinkler head consists of small nozzles and metal ring or vane with a spring. The water ejected through the nozzle strike the metal ring which changes its direction by the help of the spring attached to this which in turn causes the spray of water in all directions. The whole sprinkler head system is fitted on the riser pipe, which is erected from lateral pipes at uniform intervals. Rotating sprinkler heads are of two types viz., single nozzle type and twin nozzle type (main nozzle and driving nozzle).



Twin nozzle rotating type sprinkler head

2. Perforated Pipes System

In this method, small holes are made in lateral pipes based on the nature of the crops to distribute water uniformly.

Uniform Distribution of Water:

Irrigation efficiency of sprinklers depend upon the degree of uniformity of water applied. Uniformity coefficient is computed with field application. Open cans are placed at regular interval within sprinkled area. Depth of water collected in open cans is measured and the coefficient of uniformity is computed by Christiansen (1942) equation.

$$Cu = 100 (1-\sum X/m.n)$$

Where,

Cu = uniformity coefficient

m = Average value of all observations

n = Total number of observation points

X = Numerical deviation of individual observation from average application rate.

A uniformity coefficient of 85% or more is considered to be satisfactory. The uniformity coefficient is affected by pressure – nozzle size relation, sprinkler spacing and wind condition.

Sprinkler selection and Spacing:

The choice depends on diameter of coverage required, pressure available and discharge of sprinkler. The data given in tables 1 and 2 may serve as guidance in selecting the pressure and spacing desired.

Maximum Spacing of Sprinklers Under windy Condition

Average speed of wind	Spacing
No wind	65% of the diameter of the water spread area of sprinkler
0 – 6.5 km/hr	60% of the diameter of the water spread area of sprinkler
6.5 – 13 km/hr	50% of the diameter of the water spread area of sprinkler
Above 13 km/hr	30% of the diameter of the water spread area of sprinkler

Choice of Nozzle size, Spacing of Sprinkler and Sprinkler

Rotation to Types of Sprinklers

Types of sprinkler	Gravity fed under free sprinkler system	Normal under free sprinkler system	Permanent over head system	Small over head system	Low pressure system	Inter mediate pressure system	High pressure system
Pressure range (kg/cm2)	0.7-1.0	1.0-2.5	3.5-4.5	2.5-4	1.5-2.5	2.5-5	5-10
Sprinkler discharge (lit./sec)	0.06-0.25	0.06-0.25	0.2-0.6	0.6-2.0	0.3-10.0	2-10	10-50
Diameter of nozzles	1-6 mm	1.5-6 mm	3-6 mm	6-10mm	3-6mm	10-20mm	20-40mm
Diameter of coverage	10-14m	6-23 m	30-45 m	25-35 m	20-25 m	40-80m	80-140m
Range of sprinkler spacing	-	-	18-30m	9-24m	9-18m	24-54m	54-100m
Recommended speed of sprinkler rotation	-	0.5-1 rpm	1 rpm	0.67-1 rpm	0.5-1 rpm	0.7 rpm	0.5rpm

The discharge of an individual sprinkler is calculated using the following formula

$$q = (sl \times sm \times r) / 360$$

where

q = required discharge of individual sprinkler (lit./sec)

sl = Spacing of sprinkler along the laterals (meter)

sm = Spacing of sprinkler along the main (meter)

r = Optimum application rate (cm/hr)

Height of sprinkler rise pipe:

$$Q = (2780 \times A \times D) / (F \times H \times E)$$

Where,

Q = Discharge capacity of pump (lit/sec)

A = Area to be irrigated (ha)

D = Net depth of water supplied (cm)

F = Number of days allowed for completion of Irrigation

H = Number of operating hours/day

E = Water application efficiency (%)

Rate of Application

Average rate of application is often called as precipitation intensity. It can be estimated by

$$Ra = Q / (360 \times a)$$

Where,

Ra = Rate of water application

Q = Discharge rate of sprinkler (lit/sec)

A = Wetted area of sprinkler (m2)

Discharge of Nozzle:

The discharge of water through the nozzle can be given by the following equation.

$$Q = ca \sqrt{2gh}$$

Where

Q = Nozzle discharge

a = Cross-sectional area of nozzle

h = pressure head at nozzle (mts.)

Head of water = 10 x pressure (bar)

Head of water foot = 2.31 x pressure (Poundsfoot / inch2)

G = Acceleration due to gravity

C = Discharge coefficient

Water Spread area of Sprinkler:

The water-spread area of a sprinkler is given by the following equation

$$R = 1.35 \sqrt{dh}$$

R = Radius of wetted area (m)

d = Diameter of nozzle

h = pressure head at nozzle (m)

Design of Sprinkler systems:

A sprinkler system is designed in order to achieve high efficiency in its performance and economy. The information needed for designing sprinkler system are

1. Map of area
2. water source availability and dependability
3. climatic condition
4. depth of irrigation to be applied
5. irrigation interval
6. water application rate
7. sprinkler spray and
8. power source

Lay out of Sprinkler System

Sprinkler operates at a low time duration and pressure and can irrigate an area of 9-24 m wide and upto 300 m long at one setting. Application rate vary from 5-35 mm/hr

Layout of portable system

It consists of a pump, mainline, lateral and rotary sprinkler spacer 9-24m apart. The laterals remain in position until irrigation is completed. After irrigation is over, lateral is disconnected from main and is dismandled and moved to the next point of main line and reassembled. The lateral is gradually moved around the field until the whole field is irrigated. In this system, only laterals are moved. Sometimes the whole system including pump and mainline are moved from point to point (semi permanent)

Permanent system

When sufficient laterals and sprinkles are provided to cover the whole irrigated area so that no equipment needed to be removed. Then the system is called permanent system. This system requires less labour than portable system and large area can be irrigated by using few skilled operators. They are more expensive initially because of extra pipes, sprinklers and fittings required but, savings can be made because of reduced labour. It is suitable for automation irrigation system and areas where labour is difficult to obtain.

Fertilizer application with Sprinkler system:

Suitable chemical fertilizers can be mixed into the sprinkler system and applied to crop. Quantity of fertilizer added to the system for each setting can be calculated by using the formula.

$$wf = (Ds \times Dl \times Ns \times Wf) / 10,000$$

where,

wf = Amount of fertilizer per setting

Ds = Distance between sprinklers

Ns = Number of sprinklers

Wf = Recommended fertilizer dose

Dl = Distance between laterals.

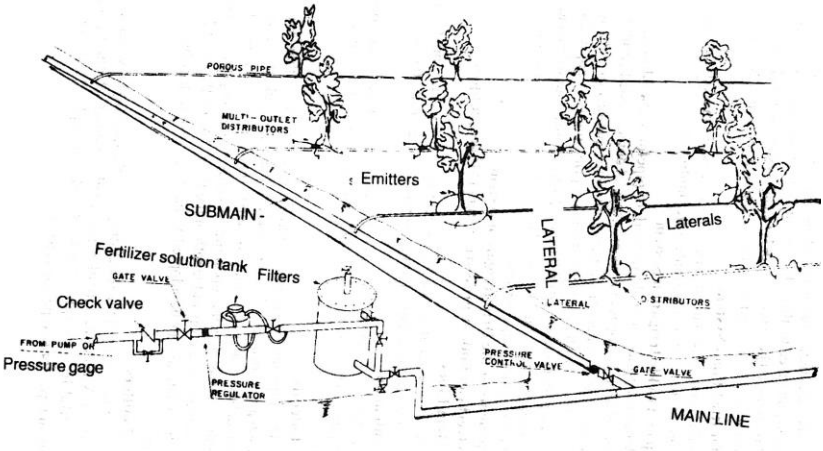
10.4. Drip or Trickle Irrigation System /Line source irrigation

Water is applied through net work of pipelines and allowed to fall drop by drop at crop root zone by a special device called emitters or drippers. These drippers or emitters control the quantity of water to be dropped out. In this system, the main principle is to apply the water at crop root zone based on the daily Evapotranspiration demand of the crop without any stress. Hence, the root zone is always maintained at field capacity level.

Components of the Drip Irrigation system

1. Overhead tank or pressure system (Motor pumps.)
2. Main Lines

To take water from source to field which is usually made of black poly alkathene pipes having an inner diameter of 50 mm



Drip Irrigation System

3. Sub main

If the area is larger, the sub mains are used to take water from main pipes to field which is normally having an inner diameter of 37mm.

4. Laterals

These pipelines are normally having lesser diameter than mains and sub mains usually of 12 mm made of black poly alkathene pipes which deliver water from main or sub mains to crop root zone. The length of lateral depends upon the pressure created in pump as well as spacing of the crop and length of the field. Normally about 25 m length of lateral can be adopted to have a uniform distribution of water.

5. Emitters

Emitters control the water drops and the quantity of water to be delivered. Various designs of drippers with various discharge capacity are available. (5 l_{ph}, 7 l_{ph}, 8 l_{ph}, 10 l_{ph} and 20 l_{ph}, etc., Button types, spray type, tap type etc.,). Instead of drippers microtubes are inserted into the laterals and water is allowed to drip in the root zone of crops or trees.

Advantages

1. Application of water in slow rates facilitates the easy infiltration into the soil
2. The required quantity of water is applied near the root zone alone which inturn save water.
3. The root zone is always maintained with field capacity level and hence plants do not suffer for want of water.
4. There is no seepage or percolation or evaporation losses.
5. Weed growth is restricted due to limited area of wetting zone.
6. Fertilizers (fertigation), chemical like pesticides (chemigation) and herbicide (herbigation) can be applied through irrigation. Hence, saving of input quantity and labour cost besides increase in their use efficiencies is possible.
7. Reduce the slat content near the root zone and dilute it in saline soil.
8. The saline water also can be put under use if irrigation is applied through drip irrigation
9. It can be adopted for any type of topography
10. Yield increases due to optimum maintenance of soil moisture at root zone.
11. More area can be maintained with little quantity of water.
12. It cab be used for widely spaced crops like Cotton, Sugarcane, tomato, brinjal, coconut and orchard crops.

Disadvantages

1. Clogging in emitters due to salt content of water and other impurities like moss, dust etc
2. Damage of pipe lines by rodents
3. It is not economical for closely spaced crops which require more number of pipes and drippers per unit area.

Proper maintenance and periodical cleaning of drippers and pipelines (with 1% hydrochloric acid) are very important to maintain the system efficiency.

10.5. Irrigation Systems

In India, various types of irrigation systems are in practice. The following are some important system.

1. Gravity irrigation 2. Tank irrigation
3. Lift irrigation

1. Gravity irrigation

Here water is supplied to the land by gravitational flow. There are tow types in this (i) Perennial (ii) Inundation

i. Perennial

In this system, water is assured throughout the crop period from the reservoir. This may be either direct or indirect irrigation. In direct irrigation, river water is directly directed to canal by constructing diversion weirs across the river without storing water at any point, where adequate perennial supply of water is assured to feed the canal during the cropping period. In indirect irrigation, during monsoon period water is stored in dam or any reservoirs and directed to flow during cropping season and hence also called as storage irrigations. This is adopted where the river flow is inadequate in cropping period. This has got significant importance than direct one.

ii. Inundation

In this system, the water is directed to canal without any diversion work. It depends on the periodical rise in water levels of the river and supply is drawn through natural coarse or open which acts as Head.

2. Tank irrigation

It is the oldest irrigation system of India wherein water is stored by forming a big bund across the natural drainage to avoid the surface runoff loss through natural streams. The tank size vary according to the drainage capacity. It has irrigation capacity from 10ha to 1000ha. It is further classified as

a. System tank

The system tank receives allotted quantity of water from river system during the cropping period for its command.

b. Non-system tanks

The Non system tanks depend upon rainfall in their catchment area and do not have any link to river system to get water.

3. Lift irrigation

In this system, water is lifted from a reservoir or river or canal or well by using mechanical or electrical power to irrigate the field. Lift irrigation includes.

a. Lift canal irrigation
b. Well irrigation
c. Tube well irrigation.

11. MEASUREMENT OF IRRIGATION WATER

Irrigation water is measured because

- It is a valuable resource and scarce commodity
- Measurement helps to reduce excessive use, wastage and allows optimum water use, uniform distribution, increases conveyance, distribution, application and usage efficiencies. Water measurement is essential in the operation and maintenance of any irrigation system, lay out of irrigation structures, layout and planning of irrigation projects and for drawing cropping programmes.

11.1 Definition of some units:

1. **Litre:**

   It is a volume equal to one cubic decameter or 1/1000 cubic metre

2. **Cubic meter (M3)**

   A volume equal to that of a cube having 1m long, 1m wide and 1m deep.

   1 cubic metre = 1000 litres

3. **Hectare – Centimeter:**

   A volume of water necessary to fill an area of 1 hectare of land to a depth of 1cm

   1ha. Cm = 100m3 = 1,00,000 litres.

4. **Hectare-meter**

   A volume water required to irrigate one hectare of land to a depth of 1m

   1ha m = 10,000 m^3

5. **Acre - Inch**

   A volume of water necessary to cover an area of one acre of land to a depth of one inch. The volume of this water is 3630 cubic feet (102.8m3)

   1 cubic feet = 0.0283m3 = 28.32 litres.

6. **Acre - Foot**

A volume of water required to irrigate an area of one acre to a depth of one foot. This is equal to 43,560 c. ft or 1233.5 m^3.

7. **Cubic metre per second (cu mec)**

   A continuous flow of water equal to a stream of 1 metre wide and 1 metre deep flowing at a velocity of 1 metre per second

8. **Cubic foot per second (cu sec)**

   A continuous flow of water equal to a stream of one foot wide, one foot deep, and flowing at a velocity of one foot/second. It is equal to 0.0283m3/sec. or 28.3 litres/second.

   1 cusec = 1 acre inch/hr = 1 ha. Cm/hr = 24 ha.c m/day = 2 acre feet/day.

9. One TMC = one thousand million cubic feet (10^9 cubic feet) = 100 crore c.ft

10. **Duty of water**

    The area of a crop in acres that can be irrigated throughout the crop period by a continuous flow of 1 cusec of water or the area of a crop in hectares that can be irrigated throughout the crop period by a continuous flow of 1 cumec of water.

11.2. Methods of water measurement

Measurement of irrigation water may be done by

1. Volumetric method
2. Velocity area method
3. Direct discharge method and
4. Tracer method

1. **Volumetric method**

   Materials required:

   Plastic bucket, alkathene pipe and stop watch.

   Procedure:

   A known volume of bucket or barrel (210 litre) is taken and placed under the delivery end of a pump or pipe. The time taken to fill the bucket / barrel is recorded using stop watch. The rate of low of water in a water pipe or a pumpset is worked out by using the formula.

$$\text{Discharge Rate(lit/sec)} = \frac{\text{Volume of bucket (lit)}}{\text{Time taken to fill the bucket (sec)}}$$

2. **Velocity area method**

   This method is used to determine the discharge rate in a pipe or open channel by multiplying the cross-sectional area of flow at right angles to the direction of flow by the average velocity of water.

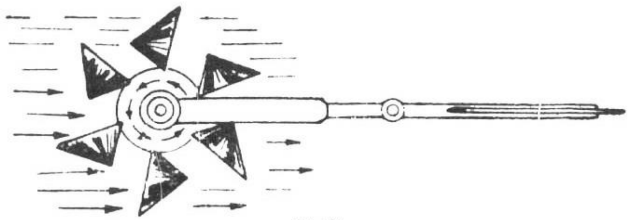
   Rate of flow/Discharge rate = Area (a) x velocity (v) (in m3/sec)

   a = Area of cross section of a channel or pipe (m2)

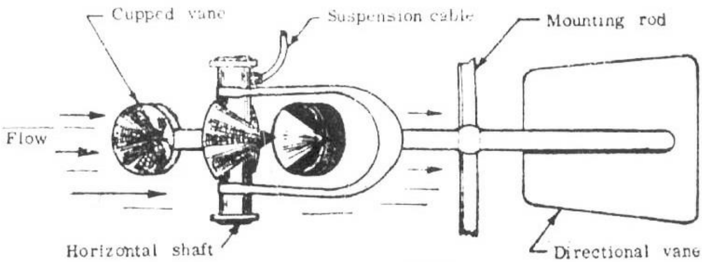
   v = Velocity of flow (m/sec)

There are important methods under the velocity area method to find out the velocity of flowing water.

1. Float method
2. Using Current meter and
3. Using water meters



PLAN



ELEVATION

Current Meter

i. Float method

Here, the rate of movement of floating body over a flowing water is equated to the velocity of running water with a co-efficient of 0.85

Materials required

A rubber ball or a closed empty plastic bottle or a block of wood or any floating material, measuring tape, stop watch etc.

Procedure:

Measure 40m length in a strainght channel and mark the upstream (A) and downstream (B) points. Allow the float to float on the running water at A, the upstream point. Note the time when it touches the upstream point and let this be the initial time. Also note the time when it reaches the down stream point (B) which will be the final time. Repeat the procedure several times and find out the mean time to travel this 40m distance. The velocity is determined by the following relationship.

$$\text{Velocity} = \frac{\text{Length of channel (m)}}{\text{Average time taken by float (sec)}} \times 0.85 = \text{m/sec}$$

The average velocity is calculated by multiplying a co-efficient factor (0.85) as above.

The flow rate of the water is worked out using the formula Q = a x v

Rate of flow(Q) = average velocity x cross sectional area of the channel.

ii. Using current meters:

It is a small instrument containing a revolving wheel or vane that is rotated by the movement of water. The number of revolutions of the wheel in a given time is noted and corresponding velocity is reckoned from a calibration table/graph.

iii. Water meters:

Water meters utilize a multiplied propeller made of metal, plastic or rubber, rotating in a vertical plane and geared to a totalizer which totalizes the flow in any desired volumetric units. To use the water meter at all times accurately, the flow of water should be full and the rate of flow must exceed the minimum for the rated range. Meters are calibrated and no field adjustments are necessary. Care should be taken to avoid obstruction due to foreign materials in the propeller.

3. Direct discharge methods:

In this method, the volume of flow of water is determined directly by installing certain devices of known dimensions at a desired point across the channel.

The most commonly used devices for measuring the irrigation water are 1. weirs / notches, 2. Flumes, 3. Orifices, 4. Pipes and siphon tubes

These devices are used to measure the rate of flow commonly read on a scale and computing the discharge of flow from standard formula or table.

Water measuring devices

i) Weirs	ii) Flumes	iii) Orifices
1. Triangular	1. Parshalflume	1. Free flow
2. Rectangular	2. Cut throat	2. Submerged flow
3. Trapesoidal	3. Trapezoidal	

iv) Pipes and Siphon tubes

1. Weirs:

A weir is an opening provided in a structured bulkhead of timber or concrete through which water is made to flow. It is used to measure the flow in an irrigation channel or the device may be built as stationary structures or portable.

Precautions in using weirs:

1. The weir should be set at the lower end of the long pool sufficiently wide and deep to give smooth flow of the stream
2. The weir wall must be vertical and not leaning to the upstream or downstream
3. The center line of the weir should be parallel to the direction of flow
4. The crest of the weir should be level so that water passing over it will be of same depth at all points along the crest

5. The notch should be a regular shape and its edges must be rigid and straight.
6. The crest of the weir is placed high enough so that water will fall freely leaving an air space under falling sheet of water.
7. The depth of water flowing over the rectangular weir should not be less than 5mm and not more than two thirds of the crest width
8. Measurement should be made using a scale located at a distance of about four times the head.

Limitations:

1. Not accurate unless measurements are properly maintained
2. Require considerable loss of head
3. Not easily combined with turn out (diversion) structures
4. Not suitable for water carrying silt. The general formula for determining the discharge through a weir Q = CLmH

Where,

Q = Discharge (lps)

C = Co-efficient depending upon the nature of weir crest and channel approach conditions

L = Length of crest known as crest head causing flow

m = The power value depending upon the shape of the notch

H = Head on the crest

Types of Weirs:

a) Triangular Weir (90 Degree 'V' Notch)

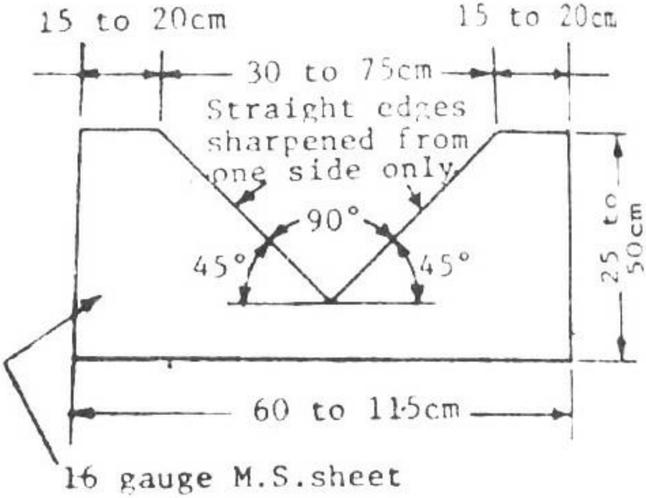
'V' Notch is commonly used to measure small and medium size streams. The advantage of the V notch is its ability to measure small flows accurately. Typical dimensions are given in figure. It is found to measure discharge upto 113 lps.

The discharge through a 'V' notch may be computed by the formula.

$Q = 0.0138\ H^{5/2}$

Where Q = Discharge in litre/sec

H = Head in cm



Triangular weir

b) Rectangular Weir:

The rectangular weirs are used to measure comparatively large discharge. It has horizontal crest and vertical sides. They may be

i) Contracted rectangular weirs or

ii) Suppressed rectangular weirs

The discharge through rectangular weirs may be computed from the Francis formula

Contracted rectangular weir $Q = 0.0184\ (L-0.1H)^{3/2}$ (one end contraction)

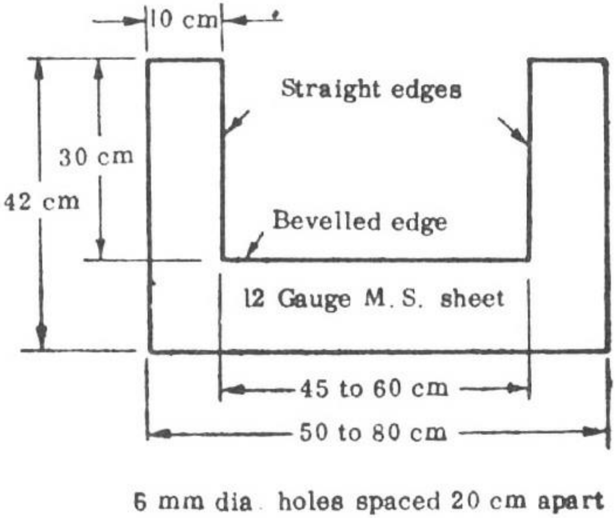
Contracted rectangular weir $Q = 0.0184\ (L-0.2H)^{3/2}$ (two end contraction)

Contracted rectangular weir $Q = 0.0184\ LH^{3/2}$ (no end contraction)

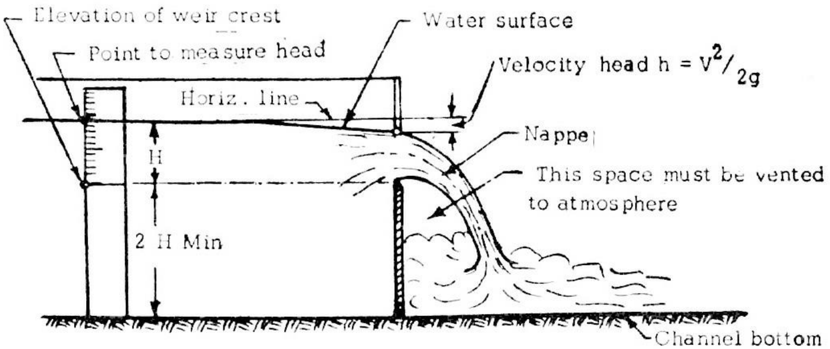
where, Q = Discharge (lit/sec)

L = length of crest (cm)

H = Head over weir (cm)



Rectangular weir



Sectional view of weir installation

c) Trapezoidal Weir (Cipoletti weir)

The cipoletti weir named after the inventor, is a special type of trapezoidal weir. Each side of the weir has a slope of 1 horizontal to 4 vertical. It is used to measure medium discharge. Since the discharge through the triangular portion balances the loss due to end contractions no correction is necessary for end contractions. The discharge through cipoletti weir is computed by the following formula.

$Q = 0.0186\ LH^{3/2}$

Where

Q = Discharge (Litre/sec)

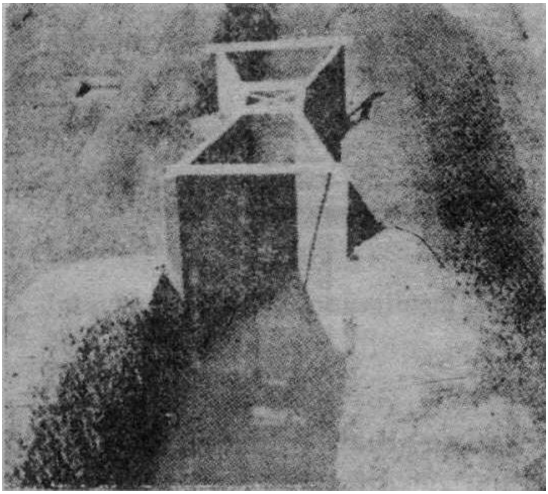
L = length of crest (cm)

H = Head over the crest (cm)

ii) Flumes:

a) Parshall flumes: (Venturi Flume)

This has been developed by Parshall (1950) and hence named after him. This parshall flume is an open channel type measuring device that operates with a small drop in head. It is a self-cleaning device and hence sand or silt in the flowing water does not affect operation or accuracy. It gives reasonably accurate measurement even when partially submerged. The flumes of 7.5, 15, 23 and 30 cms sizes are generally used in field measurements.



Parshall Flume

b) Cut – Throat Flume:

There is an improvement in construction details over parshall flume. It is developed by Skogerboe etal. (1967). The flume has a flat bottom, vertical walls and no throat section. The flume width ranges between 2.5 cm to 1.8m.

The cutthroat flume may be used either in free flow or in submerged flow condition. It should be installed in a straight section of the channel and not near gate because of unstable and surging effects, which might result from the gate operation. However, it is better to have a flow-measuring device to operate under free flow condition.

c) Trapezoidal Flume:

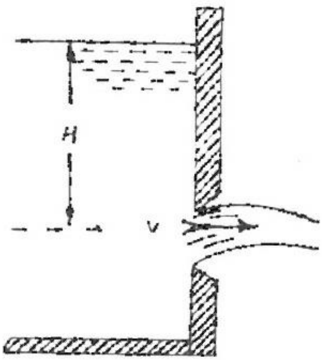
It is somewhat similar to rectangular flume and devised based on the study of Robinson Chamberlin (1958). The characteristics are listed as follows,

i) A large range of flows can be measured through the structure with a comparatively smaller change in head.
ii) The flumes will operate under submergence than rectangular shaped ones without correction being necessary to determine the exact relationship.
iii) Extreme approach conditions and sediments deposited in the approach does not affect the head discharge relationships.
iv) The trapezoidal shape fits the common canal section more closely than the rectangular one.
v) Construction details such as transmission and frame work are simplified

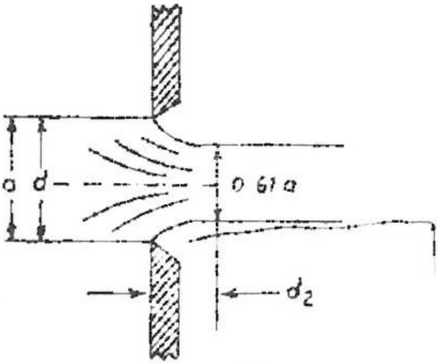
iii). Orifices:

Orifices are the circular or rectangular openings in vertical bulkhead placed across the stream. They may operate under free flow or submerged flow conditions. Under free flow conditions the flow from the orifice discharges entirely into air forming a napple. If the orifice is fully submerged, the downstream water level is above the top of the opening and the flow is disturbed into the down stream water.

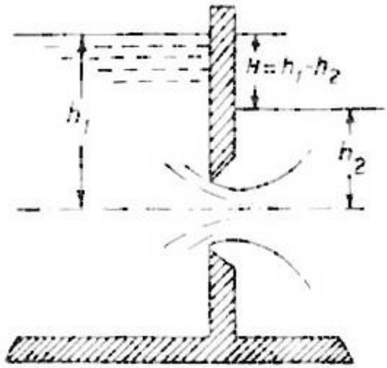
A plastic scale is fixed on the upstream face of the orifice plate in such a way that zero of the scale coincides with the center of the orifice.



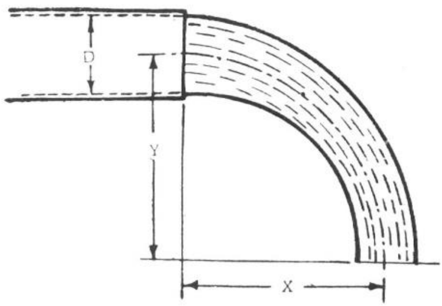
Free flow orifice jet



Contraction of jet after passing through orifice



Head in submerged orifice



Coordinates of full flowing pipe

The discharge through orifices is calculated by the formula

$$Q = 0.61 \times 10^{-3}\ a \sqrt{2gh}$$

Where

Q = discharge in litres/sec

a = area of cross section of the orifice in cm^2

g = acceleration due to gravity in cm/sec^2

h = depth of water over center of orifice in cm.

In case of submerged flow orifice the difference in elevation between upstream and downstream is measured as 'h'

iv. Pipes and Siphon Tubes:

The trajectory of stream of water from a horizontal pipe can be used to estimate the discharge. Such a procedure is rapid, inexpensive and convenient. Measurement is made for the x and y coordinates, where x is measured parallel to the pipe and y is measured vertically.

Horizontal measurement of the jet (x) is measured from the end of the pipe to the centre of the jet in cm distance from the centre of the pipe to the ground i.e., vertical coordinate is measured in cm (y).

The discharge formula is obtained by combining the three equations.

$Y = ½ gt^2$ $X = Vt$ $q = av$

$V = (x \sqrt{g}) / \sqrt{2Y}$

$Q = (Ca X \sqrt{g}) / \sqrt{2Y}$

Where,

Q = Discharge in lit/sec

C = Coefficient of discharge

g = Acceleration due to gravity

a = Cross sectional area of water at end of pipe in Cm2 coordinate of the point on the surface to the pipe measurement in cm.

y = Vertical coordinate measured in cm

x = Horizontal coordinate

b. Flow from a Vertical Pipe:

When water flows vertically out of an open pipe, the height to which it will rise above the pipe is proportional to the flow. Lawrence and Brawnworth made careful measurements and found that the height of the jet was less than 0.37 dp., where Dp is the inside diameter of the pipe, then flow is subcritical. When the jet height exceeds 1.4Dp, water discharges from the pipe with supercritical flow in jet flow.

The discharge from a vertical pipe can be estimated using the equation given by Lawrence and Brawnworth in metric system as

Q for hs<0.37 dp = 5.47dp 1.25hs 1.35

Q for hs>1.4dp = 3.15dp 1.99hs 0.53

$$Q = 0.0195D^2X/Y$$

Where,

Q = Discharge in lit/sec

D = Diameter of the pipe

X = Vertical coordinate (from pipe end to the top of the jet)

y = Horizontal coordinate (from centre of pipe to the centre of nappe.

C. Siphons:

Siphons are provided to deliver water from a ditch furrow of check dam. The rate of flow of water delivered by siphons may be measured by knowing the area of cross section and head as given in the formula

$$Q = 0.65 \times 10^{-3} A^2 \sqrt{gh}$$

Where,

Q = discharge from siphon tube in lit/sec

A = cross section in cm^2

g = Acceleration due to gravity (cm^2/sec)

h = Head causing flow in cm

For free flow, the head causing flow 'h' is the height of water in the ditch above the center of the inlet end of siphon tube and when submerged, the differences in level between layers in the ditch and furrow is the 'h'.

4. Tracer Method:

Tracer methods of water measurement are independent of stream cross section and are suitable for field measurements without installing fixed structures. In these methods, a tracer substance in concentrated form is introduced into the flowing water and allowed to mix thoroughly. The concentration of the tracer is measured at a downstream section. Since only the quantity of water necessasity to accomplish the dilution is involved, there is no necessary to measure velocity, depth, head, c.s. area etc.

After assessing the amount of water to be applied to the soil and the type of water measuring device, the irrigator is to work out the time duration to supply water.

This method is yet to become popular in India.

12. IRRIGATION SCHEDULING

Definition

Irrigation scheduling is defined as the 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 technique 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 an 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.

- it wastes water below root zone
- it results in loss of fertilizers nutrients
- it causes water stagnation and salinity
- it causes poor aeration
- 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 of supplying water in optimum ratio and minimizing all field losses.

12.1. 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)i.e, IR=WR-ER. It can be expressed either in mm/day or in 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 cautious that the interval should not allow the crop to suffer for want of water.

12.2. 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.

4. **Crop factors**
   a) Sensitiveness to water shortage
   b) Critical stages of the crop
   c) Rooting depth
   d) Economic value of the crop
5. **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 (Farmer's decision is final)
6. **Type 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
7. **Salinity hazard**

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

8. Irrigation methods

a) Basin method allows more infiltration through more wetting surface which inturn 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.

9. Irrigation interval

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

10. 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.

12.3. Theoritical 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
e) Indicator plant technique
f) Micro plot technique

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

c) Simulation approach—computing and modelling

d) Empirical approach

IV. System as a whole approach

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 many 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 useful.

b. Soil moisture deficit and optimum moisture regime approach.

This approach considered 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 that 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 cab be indexed as below.

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

d) Plant observation method

Normally in field condition farmers use to adopt this practice for scheduling irrigation. The day-to-day change 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.

e) 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 at 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.

f) Micro Plot technique or indictor plot technique

In this method, one cubic feet micro plot is made with coarse textured soil to have more infiltration, less water holding capacity and more evaporation than the actual main filed. Normally the field soil is mixed with sand in 1:2 ratio and refilled 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 practice 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 cab be made.

II. Predictive approach or Indirect approach

a) Critical stage or phenological stage approach

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

a) **Initial stage:** from sowing to 10% ground cover

b) **Crop development stage:** 10 to 70% ground cover.

c) **Mid season stage:** Flowering to grain setting stage.

d) **Late season stage:** Ripening and harvesting stage.

The stage at which the water stress causes severe yield reduction is 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 stages will not even help in recovering the yield loss due to stress at critical periods.

In general, the mid season stage is the most sensitive stage 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 stages of different crops

Crops		**Critical stages/ Sensitive stages**
Cereals and millets		
Rice	-	Active tillering, panicle initiation, heading and flowering
Sorghum	-	Flowering and grain formation
Maize	-	Tasselling, silking and milky stages
Cumbu	-	Heading and flowering
Ragi	-	Primordial initiation and flowering
Wheat	-	Crown root initiation, tillering and booting
Oil seeds		
Groundnut	-	Flowering, peg initiation and pod formation 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

Chilles - Flowering and fruit setting

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

b) Meteorological approach/Climatological approach

The basic principles employed with this approach is estimation of daily potential evapotranspiration rates. Hence, it requires knowledge on

1. short term evapotranspiration rates at various stages of plant development
2. soil water retention characteristics
3. permissible soil water deficit in respect to evaporative demand
4. 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)

$$R = \frac{IW}{CPE} = \frac{\text{depth of water to be applied per irrigation (mm)}}{\text{Cumulative pan evaporation for particular period (mm)}}$$

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 50mm. Therefore IW/CPW ratio is

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

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

The irrigation depth (IW) for different crops are fixed based on the soil and climatic conditions. The ratio of IW/CPE that gives relatively best yield is fixed for each crop by doing experiment with different ratios, for different soil types and growth stages.

The irrigation depths (IW) divided by the ratio (R) will give the cumulative pan evaporation value at which irrigation is to be made i.e., IW/R = CPE.

For example, the irrigation depth (IW) needed is 50 mm and th ratio (R) to be tried is 0.5,
therefore, the Cumulative Pan evaporation value needed to irrigate the field is,

IW/R = 50/0.5 = 100mm

If the 100mm 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 (depths) are considered

Disadvantages

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

For example,

a) U S W B 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 stretch of grass, 176 cm when pan is sited on dry land without stretch of grass

b) Pan readings generally over estimate ET during early stage and maturity stage.

III. Mathematical approach

a. Estimation method approach

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

a). Soil type

Sol types are classified as follows

1. Sandy/shallow Little water and more frequency
2. Loamy soil More water and Less frequency
3. Clay soil More water and Less frequency

b). Climate

Climate is classified based on reference ET as follows:

Reference ET

1) 4-5 mm /day – Low
2) 6-7 mm / day – Medium
3) 8-9 mm/day - High

Reference ET (mm/day) for different climatic zones

Climatic zone	**Mean daily temp**		
	15 ºC Low	**15-25ºC Medium**	**> 25 ºC High**

Desert/arid	4-6	7-8	9-10
Semi arid	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	17 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°C

2* - Medium temperature of 15 – 25°C

3* - High temperature of > 25°C

Adjustment in this method for Non peak periods

1. In early growth stages

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

2. In late growth stage

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

3. 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.

4. 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 interval is 10 days and the depth is 70mm 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 50mm per 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 56mm for every 8dyas or 49mm for every 7 days or 42mm for every 6 days, The 49mm for every 7 dyas is the appropriate interval for local situation. Hence, this method of intervals for irrigation cab 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,

1. Estimate the net and gross irrigation depth (d) in mm.
2. Calculate the irrigation water need (mm) over total growing season.
3. Calculate the number of irrigation over total growing season.
4. Calculate the irrigation interval.

Estimating 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 appropriate for most of the field crops. The root depth can be measured locally and adjusted. Approximate net irrigation depth (mm).

Soil type	Rooting depth		
	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, ragi, onion, potato, pineapple, cabbage,

Medium (50-100 cm):Banana, bean, coconut, groundnut, peas, soybean, sunflower,tobacco, tomato, cumbu, pulses.

Deep(90-150 cm) :Citrus, graphs, wheat, Cotton, maize, wheat, sorghum, soybean

We known 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 (Ea) can be used. The gross irrigation depth includes the water loss through deep percolation and run off.

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

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

If reliable data on field application efficiency are not available, the efficiency rate given below can be used which are more appropriate

For surface method = 60%

Sprinkler method = 75%

Drip method = 90%

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

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

b) Calculation of irrigation water need for total growing season

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

Water need mm/month

Feb	Mar	Apr	May	June	Total
67	110	166	195	180	718

Calculate the number of irrigation over total growing period

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

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

$$\text{irrigation interval} = \frac{\text{Duration (days)}}{\text{Number of irrigation}}$$

150

$$= \frac{\quad}{18} = 8.3$$

Conclusion

Irrigation schedule for tomato

Net d= 40 mm

Gross d = 65 mm

Interval = 8 days

Adjustment in simple calculation method

a) Growth stage

The calculated irrigation interval is once in 8 days with 40mm depth. But this may very depending upon the crop stage. In critical stage crop needs more water and in early stages it needs less water, (eg)

For every 30 days $= \frac{30 \times 40}{8} = 150\text{mm}$

has to be applied. This application should be compared with amount of water needed during different month and workout the

	Feb	March	April	May	June	Total
Irrigation need	67	110	166	195	180	718
Net application based on simple Calculation	150	150	150	150	150	750
Difference	+83	+40	-16	-45	-30	+32

difference as shown in the table below.

To overcome this, application of too little or too much of water by adjusting ht interval and depth based on the crop stage as below.

Peak season is April May and June.

Early growth stage is in Feb –March

Water requirement for peak season

	April	May	June
=	166	195	180

depth(d) = 40 mm

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

= 13.5 approximately 14 irrigations.

$$\text{Irrigation interval} = \frac{\text{Duration}}{\text{No.of irrigation}} = \frac{90 \text{ days}}{14} = 6 \text{ days}$$

Water requirement for Early growth period

Feb	March	Total
67	110	177

$$\text{No. of irrigations} = \frac{177}{40} = 4.4$$

Approximately = 4 irrigations

$$\text{Irrigation interval} = \frac{60}{4} = 15 \text{ days interval}$$

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 depths as follows.

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

$$\frac{177}{30} = 5.9 = 6 = \frac{60 \text{ days}}{6} = 10$$

10 days irrigation interval cab be adopted

c) Simulation method approach

This is noting but construction of mathematical models with essential features and behaviour of real system. Adoption of such models to get solution by computers and studying the property of such models in relation to those of prototype system is followed. In this, all the complex components like supply system, soil, climatic condition, crop, cultural practices, crop responses and plant nutrient level are considered to work out the model.

d) Empirical methods

Many empirical methods have been developed to estimate Evapotranspiration values of the crop. Among this, modified Penman, Blaney and Griddle methods have much acceptability among Researchers.

The estimated values of ET crop by the different methods were compared with the actual values. The error of different methods are as follows.

Method	**Error Value (%)**
Penman	14.2
Pan evaporation	10.3
Blaney & Griddle	11.9

Modified Penman method

The form of the equation used in this method is:

ETo = c [W.Rn + (1-W). f(u).(ea-ed)]

(Radiation term) (Aerodynamic term)

Where,

ET_o = reference crop Evapotranspiration in mm/day

W = temperature – related weighting factor

Rn = net radiation in equivalent evaporation in mm/day

F(u) = wind related function

(ea-ed) - difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air, both in mbar.

C =adjustment factor to compensate for the effect of day and night weather conditions

To work out ET through this equation, many standard tables given by the authors has to be referred.

(Refer: :Crop water Requirement . FAO Irrigation and Drainage Paper No 24.")

Blaney and Criddle equation

The relationship recommended, representing mean value over the given month, is expressed as:

ETo=c[p(0.46T + 8] mm/day

Where, ETo =reference crop Evapotranspiration in mm/day for the month considered

T = mean daily temperature in ^{o}C over the month considered

P = mean daily percentage of total annual daytime hours obtained from Table 1 for a given month and latitude (Refer: "Crop Water Requirement, FAO Irrigation and Drainage Paper No 24.")

c = adjustment factor which depends on minimum relative humidity, sunshine hours and day time wind estimates.

After determining ETo, ET crop can be predicted using the appropriate crop coefficient (kc), or ET crop = kc x ETo.

Hargreaves temperature method to estimate ETo

ETo = 0.0023 x RA(Tc M7.8) x TDO.5

ETo = PET

RA = Extraterrestrial radiation (mm/day)

$$Tc = \frac{Tmax + Tmin \text{ in oc}}{2}$$

TD = Tmax – Tmin in c.

Pan Evaporation Method

In this method, to work out the reference crop evaporation (ETo) the pan factor and the pan evaporation readings are taken into account. The empirically derived pan coefficient (Kp)for different agro climatic zones is multiplied' with pan evaporation (E pan) to get Reference Crop Evaporation (ETo).

$$ET_o = E\ pan \times K_p$$

$$ET_c = ET_o \times K_c = E\ pan \times K_p \times K_c$$

Where,

ETc = ET from cropped field

ETo = reference crop ET

Kc = Crop co-efficient

E pan = pan evaporation reading

Kp = Pan co-efficient

Random equation for PET estimation

$$PET = 0.6\ E_p \text{ mm/day}$$

Where,

Ep = Evaporation from USWB class A pan in mm/day. The empirical formulae are used to estimate the net amount of water requirement of the crop. With this value, the special water demand like pre plant irrigation, leaching requirement and economically unavoidable irrigation, application losses are to be added for scheduling irrigation.

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 within the group by themselves.

13. IRRIGATION MANAGEMENT TO CROPS

13.1. Rice

Total water requirement is 1100 – 1250 mm.

The daily consumptive use of rice varies from 6-10 mm and total water ranges from 1100 to 1250 mm depending upon the agroclimatic 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 main field irrigation.

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 seeding stage. At the time of transplanting, shallow depth of 2 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 pondnd water. This will result in 30% saving of irrigation water compared to the continuous submergence.

13.2. 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 to 10 days depending upon the soil and climate. During maturity period, the interval is 15 days.

13.3. Finger millet

Total water requirement : 350 mm

Finger millet is a drought tolerant crop. Pre-planting irrigation at 7 & 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.

13.4. Sugarcane

Total water requirement : 1800 – 2200 mm

Formative phase (120 days from planting – germination and tillering phases) 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 irrigation 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.

13.5. Maize

Total water requirement: 500-600

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, tesseling, silking and early dough stages. Crop uniformly requires water in all these stages. Of this, tasseling, silking and early dough stages are critical periods.

13.6. 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 is lost through evaporation than transpiration. As the plant grows., the use of water increases from 3 mm/ day and reaching a peak of 10 mm a day when the plant is loaded with flowers and bolls. 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 stages 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.

13.7. 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 irrigation is given 15 days after 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.

Water requirement of crops:

S.No	Crop	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

14. ESTIMATION OF IRRIGATION EFFICIENCIES

14.1. Water use efficiency

The water utilized by crop is evaluated in terms of Water Use Efficiency. This water use efficiency can be classified into

1. Crop Water Use Efficiency
2. Field Water Use Efficiency
3. Physiological Water Use Efficiency and
4. Irrigation project efficiency

1. Crop Water Use Efficiency

It is the ratio of Crop yield (Y) to the amount of water used by the crop for evapotranspiration (ET).

$$CWUE = \frac{Y}{ET}$$ and expressed as kg/mm/ha

2. Field Water Use Efficiency (FWUE)

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

$$FWUE = \frac{Y}{WR}$$ and expressed as kg/mm/ha

3. Physiological Water Use Efficiency (PWUE)

The physiological WUE is calculated in terms of the amount of CO_2 fixed per unit of water transpired.

$$PWUE = \frac{\text{Rate of Photosynthesis}}{\text{Rate of Transpiration}}$$

4. Irrigation efficiencies of irrigation projects

Many irrigation Projects throughout the World operate with 25 to 40 percent overall efficiency. Thus perhaps one third of the water released at the Project head work is actually beneficially used for evapotranspiration by crops. In many areas increased irrigation efficiency would result in increased irrigation average and production as well as decreased problems with salinity and drainage. The decrease in efficiency can be attributed to losses occurring at various stages. Some of the reasons are:

1. Inadequate design of the project.
2. Inadequate design of the Farm Irrigation System.
3. Lack of maintenance.
4. Inadequate management of the system.

A typical Irrigation System consists of :

1. Head Woks
2. Main canals
3. Field channels.

4. Farm

14.2. Water Application Efficiency (Ea)

The purpose of irrigation is to replenish the available moisture in the root zone depleted by evapotranspiration. Crop water requirement is defined by DOORENBOS AND PRUITT(1977) as "The depth of water needed to meet the water loss through evapotranspiration of a disease free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment".

The application of the least amount of water required to bring the root zone moisture content up to field capacity is considered as efficient irrigation. If on the other hand, the amount of water applied grossly exceeds that actually needed for replenishment, the irrigator application efficiency is very low. To illustrate, consider a field which needs 9 cm depth of water to bring the root zone to field capacity at the time of irrigation. To replace this amount it is necessary to deliver a total or gross depth of 12cm of water to the field. Then the efficiency of application will be.

$$9/12 \times 100 = 75\%$$

$$\text{Application efficiency} = E_a = \frac{\text{Water required to bring soil to FC level}}{\text{Water received at field Inlet}} \times 100$$

Primary factors for low application efficiency are,

1. Improper Irrigation system design, construction.
2. Poor maintenance of system
3. Inadequate farmers knowledge on crop water requirement.

Field Application Efficiency varies with type of soil and method of irrigation. Some observed efficiencies are given below:

Light soil	55%
Medium soil	70%

Heave soil	60%
Graded Border Irrigation	53%
Basin Irrigation	58%
Furrow Irrigation	57%
Sprinkler Irrigation	67%
Drip Irrigation	80%

For Rice cultivation the efficiency is 32%

14.3. Conveyance Efficiency (Ec)

$$Ec = \frac{\text{Water received at inlet to a block of fields}}{\text{Water released at Project Head works}} X100$$

Primary factors affecting conveyance losses are management aspects which cause fluctuations in the supply as well as physical factors such as seepage losses through canal banks and canal outlets.

Some of the observed conveyance efficiencies are,

ii. Continuous supply with no substantial change in flow - 90%

iii. Rotational supply with no substantial change in rotation - 80% areas of 70-300 ha

iv. Rotational Supply in projects more than 7000 ha and less than 10000 ha without effective management and communication - 65%-70% network

14.4. **Project Efficiency (Ep)**

$$EP = \frac{\text{Water made directly available to the crop}}{\text{Water released at Head works.}}$$

The overall project efficiency represents the efficiency of the entire operation between diversion of source of flow and the crop zone.

Water delivery system improvements and farm irrigation improvements would significantly improve the ability of the farmer to apply more uniform and efficient irrigation.

The Project Efficiency can be increased through.

a) Lining of canals in areas of high seepage losses, proper alignment and sectioning of field canals.

b) Maintenance of canals and drains, including an emphasis on farm drains.

c) Inducing scarcity of water by limiting available water per unit area.

d) Ensuring reliability of supply system down to farmers level. Farmers need to know when they can count on water and how much water much they can count on.

e) Design farm systems so that release flow can be handled efficiently by the farmer.

f) Install proper structures at outlets to maintain the flow constant.

g) Encourage efficient design and construction of such system as level basins, contour borders and contour furrows and general land levelling and shaping.

15.IRRIGATION MANAGEMENT UNDER LIMITED WATER SUPPLY

Integration of all water resources like surface, ground water, wastewater, snow, dew etc, is most important to achieve maximum food production per unit quantity of water sued to meet the demand from 1 billion population present. In this juncture, water resources itself become a constraint due to abnormality in distribution and uncertainity it in the occurrence of rainfall. Hence, at present frequent droughts are very common. Under this circumstances a new water saving strategy has to be adopted in irrigation management and in crop production activities. This chapter discusses about water scarce conditions and the ways to overcome it with some drought alleviating methods.

15.1. Water Scarcity conditions

Water scarcity is the term used for poor storage or non-availability of required quantity of water for the purpose of crop production and otherwise due to failure of monsoons. The scarcity will lead to inadequate supply of water to the cropped fields which in turn create a stress in plant community. This degree of stress varies depending upon the frequency of irrigation, nature of the crop, type of soil etc.

In this situation our primary aim is to produce the maximum possible yield per unit quantity of water. The following are some management techniques under stress periods.

1. Assess resource potential

Based on the water potential, optimize the water use by linear programming techniques. This type of exercise should be done by the concerned Department especially Irrigation and Agriculture.

2. Farmer's Attitude

Farmer's or user's behaviors need considerable reorientation to enable them to realize that water is an economic input and conservation of water is their prime responsibility.

3. Improvement in conveyance structure:

A large quantity is lost through conveyance from source to field. It is estimated that about 30-40% of water is lost in conveyance systems. Reducing or totally preventing such losses of water can be made by proper maintenance, lining the channels etc. Conveyance by pipes is often adopted for ground water resource. Such conveyance may be made even at small sluice level in command areas.

4. Conjunctive use of water

Integrating all water resources with water conservation methods is termed as conjunctive use. Optimum use of water from different source is the main aim of conjunctive use. For example, in canal irrigation system the utilization of rainfall and well water optimally to protect the crop without eroding a single resource of water is termed as conjunctive use of water.

15.2. Contingent Plant for Rice.

Rice is a semi-aquatic plant which needs submergence of water for its establishment and better yield. The experimental evidences clearly indicated that 5cm depth of ponding one day after disappearance of previously provided water is superior to higher depths. This was attributed to better aeration and consequently improved root activities.

Yield under different depth of submergence in rice:

Irrigation Practice	Water Applied (mm)	Grain Yield Kg/ha	Water Applied (mm)	Yield (kg/ha)
Continuous submergence of 5. cm	1825	6300	1730	6000
5 cm. One day after disappearance	961	6500	1200	6050
Water saving	47%	-	30%	-

This finding is helpful not only for micro level alone but also to change the water release pattern at macro level too. By this findings, a turn system can be adopted in canal operation system. Further investigation reveals that 2 days dry spell in light textured soil and 2-3 days dry spell in heavy textured soil can be advocated without much yield reduction.

If further scarcity arises, the next management techniques to save the rice crop is to adopt irrigation at critical stages. Different crop growth stages have different response to water stress. In rice crop the most sensitive periods for water stress are.

a. Active tillering
b. Primordial initiation and Flowering and
c. Milky stage.

Dry spell during these periods will drastically reduce the yield.

Other Management Techniques:

1. Summer ploughing reduces runoff by increasing the infiltration and thereby reduces water needed for land preparation.
2. dry nursery with seed hardening technique (1% KCl) can be made which in turn will enhance the drought tolerance capacity.
3. the short duration varieties like ADT 36, IR 36, IR 50, IR 64, J 13 and Co 37 can be chosen.
4. during transplanting it is enough to irrigate to a depth of 2 cm of water in the field.
5. after that maintaining 2.5 cm of water upto 12 days is sufficient.
6. application of Herbicide within 3 to 5 days reduces the weed competition for water which inturn saves water considerably.
7. After 12 days of transplanting, irrigating 5 cm of water one day after the disappearance of ponded water can be adopted not only to save water but also to increase the yield to some extent.
8. Plastering field bunds and plugging of all crevices, rat and crab holes to avoid water loss through seepage.
9. Proper leveling of the field
10. Water should be stopped 10 to 15 days before harvesting.
11. Semidry rice (direct down) saves 30 to 40% water.

12. Application of potassium in 3 split doses as 50% basal 25% at tillering and 25% at panicle initiation.
13. Application of cycocel at the rate of 1000 ppm.

15.3. Drought alleviating methods for some important Irrigated Dry (ID) crops

In ID crops the main objective is to irrigate the crops to meet the requirement of ET need of the crops. Normally the ID crops are irrigated at certain intervals and mostly they are cultivated where conjunctive use of well water is available. So chances for acute drought is very common on complete failure of monsoon. In this situation, adopting irrigation at critical stages save the crops from yield loss. Further, some drought alleviating chemical spray also protects the crops from severe loss.

Contingent plan for sugarcane:

1. Deep planting of sets in 30 cm deep and 30 cm wide trenches.
2. Adopting irrigation at 0.75 and 0.5 IW/CPE ratio during tillering to grand growth and maturity phase, respectively i.e. 8 to 9 days interval during tillering to grand growth and 13 to 15 days interval at maturity phase.
3. Trash mulching to a thickness of 10 cm uniformly 3 days after planting to tide over drought by moisture conservation and to reduce weed incidence.
4. Application of 2 to 3 per cent kaoline spray to mitigate the water loss through transpiration.
5. Alternate furrow irrigation: Irrigate alternate furrows in rotation for each irrigation.
6. Cultivating drought resistant varieties such as COC 85061, COC 8001,COC 671.

Contingent plan for groundnut

1. Regulate water based on growth stages like pegging, flowering and pod development.
2. Adopt the following schedule
   a) Sowing or pre-sowing irrigation
   b) Life irrigation 4-5 days after sowing

c) Irrigate 20 days after sowing
d) At flowering give two irrigations
e) At pegging give one or two irrigations
f) At pod development give 2 to 3 irrigations

3. Spray 0.5% potassium chloride during flowering and pod development stage to mitigate the ill-effect of water stress.
4. Adopt sprinkler irrigation method wherever possible.

Contingent plan for cotton:

The following irrigation schedule can be adopted to overcome water stress.

1. Irrigate immediately after sowing
2. give life irrigation on 5^{th} day of sowing
3. Irrigate on 20^{th} and 35^{th} day at vegetative phase
4. Irrigate copiously at 40,50,60,70,80 and 90 days after sowing which coincide with flowering and boll formation stages.
5. control irrigation during maturity phase from 100 to 150 days after sowing.
6. Stop irrigation after 150^{th} day.
7. Adopt alternate furrow irrigation.
8. Adopt drip irrigation method wherever possible.

15.4. Other management techniques:

1. Summer ploughing has to be done in large scale which is not only a water conservation method but also checks weed growth, facilitate easy puddling etc.,
2. Strengthening of field bunds to minimize the water loss through leakages and to impound rain water to increase the infiltration and soil moisture storage.
3. Adoption of drip or sprinkler irrigation methods wherever it is possible.
4. Proper on-farm development works to reduce the water loss and inturn to increase the water application efficiency.
5. Turn and rotational system of water supply can be introduced

6. Community system of nursery and mass mechanical ploughing can reduce water wastage.
7. Introducing new cropping pattern for effective utilization of available water.
8. Adoption of watershed method and insitu water conservation methods for efficient crop production.
9. Farmers organization and participation appraisal are important extension activities which make the farmers to realize the value of water.

16. WATER MANAGEMENT IN PROBLEM SOILS

When rocks and minerals undergo 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. Accumulation of salts in soil leads to unfavourable soil-water-air relationship and affect the crop production.

16.1. Causes for Salt accumulation

The following are the main causes which lead 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 hectares are salt affected with different degrees of degradation.

2. High subsoil water table

When the water table is within the 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 areas, 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 from canals

The continuous seepage leads to salt accumulation.

16.2. Classification of problem soils

The soil problems can also be divided into

a) Chemical b) Physical

Soil Chemical problems

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

16.3. 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.

16.4. 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. Aluminium sulphate

16.5 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.

16.6. Management practice 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 these problems.

- ❖ The saline soil can be easily improved with leaching of salts by using of good quality water and by providing good drainage system.
- ❖ Application of gypsum would improve the permeability of soil by making good soil aggregates.
- ❖ In acidic soil, 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 sunhemp, daincha and kolinji can be advocated.
- Growing resistant varieties like CoC 771 in sugarcane and Co 43 in rice may be made.
- Adoption of drip irrigation for possible crops is also recommended to overcome soil physical and chemical problems.
- Liberal application of FYM
- Application of green manure
- Excess phosphorous application
- Proper drainage to keep the soil without adverse effect to plant system.

16.7. Soil physical problems:

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

16.8 Water management practice 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, amending the 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 or 50 tones per ha, respectively is advocated.

The encrustation problem could be alleviated by incorporating organic matter and adding montmorilonite clay containing silt.

17. MANAGEMENT OF POOR QUALITY WATER FOR IRRIGATION

17.1. 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, bicabonate and boron are important in determining the quality of irrigation water and its suitability for irrigation purpose. However, other factors such as soil texture, permeability, drainage, types of crop etc., are equally important in determining the suitability of irrigation water. Following are the most common problems that result form 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 ifiltration into the soil profile.

3. Toxicity

When certain constituents of water are taken up by plants which accumulate in large quantities and result 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.

Based on the characteristic features of majority of ground waters in use by the farmers in different agro-ecological regions of the country, the various indices which describe the nature of hazards on soils and crops, irrigation waters have been broadly grouped into good, saline and alkali waters. Depending on the degree of restrictions, the two poor quality waters have been further grouped into three homogenus sub groups as given in the table.

Groups of poor quality ground waters for irrigation

Water quality	Ec (ds/m)	SAR (m.mol/L)	RSC (me/L)
A. Good water	< 2	< 10	< 2.5
B. Saline water			
i. M	2-4	< 10	< 2.5
	>4	< 10	< 2.5
	>4	> 10	< 2.5
	<4	< 10	2.5-4
	<4	< 10	> 4
	Variable	> 10	> 4
ii. S			
iii. H			

C. Alkali water i. Marginally alkali ii. Alkali Highly alkali			

Majority of natural ground waters have pH between 7.2 and 8.5 and are either in equilibrium or even super saturated in respect of calcite and dolomite. Water with pH less than 7.2 seem to be unsaturated in respect of calcite. Water samples with pH > 8.4 invariably have SAR more than 10. High pH is associated with waters containing residual alkalinity and a high carbonate: bicarbonate ratio. Water having residual alkalinity contains carbonate and bicarbonate ions in varying proportions depending on pH. The ratio of CO_3 ions in ground waters generally vary between 1:10 and 1:2, Marginally saline waters have low SAR, the usual range being upto 20. Hardly 10-15 percent of the total ground waters have both high SAR (>20) and high salinity.

Based on some of the quality criteria like EC, pH, concentration of Na, Cl and SAR, suitability of irrigation water is classified into six grades.

Classification of irrigation water quality

Quality of water	EC (m.mhos/ cm)	pH	Na (ppm)	Cl(me/1)	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	75-80	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)

17.2. Factors affecting suitability of water for irrigation

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

1. Chemical composition of water (TSS, pH, CO3, HCO3, Cl, S04, 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 difficulty in extracting enough water from salty solution, thereby affecting the yields adversely.
6. Besides this, total salinity depends on 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 germination and seedling stages are usually more 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.

17.3. 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 pare 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. irrigation the and 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, sugarbeet, Paddy, groundnut, sorghum, corn, sunflower, chillies, tobacco, onion, tomato, garden beans, amaranthus and Lucerne.

17.4. Use of poor quality water

Besides the salinity and alkalinity hazard of water, some industrial effluents and sewage water are also problem waters 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 nutrients 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 (Biological Oxygen Demand. These waste waters when used for irrigation lead to surface and sub surface source of pollution due to horizontal and vertical seepage.

17.5. Projected waste-water Utilization

It is estimated that 2,87,000 million m3 of waste water can be reusable during 2000 A.D. Hence, these waste waters 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.

18. DRAINAGE IN IRRIGATION MANAGEMENT

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 soil contains excess water than that can be accommodated in the pore spaces, it is said the field is water logged.

18.1. 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, lack of outlets.
5. Presence of impervious layer with profile impeding percolation.
6. upward rise of water from shallow ground water table or aquifer.

18.2. Effects of water logging

Direct effects

Replacement of soil air which is the main source of oxygen for the roots as well as soils microbes. Due to high amount of CO2 in soil air, high CO_2 concentration under water logged conditions 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 unavailable due to leaching. Toxic elements will be formed under anaerobic conditions. Decomposition of organic matter under anaerobic condition results in production of organic acids like butyric acid which is toxic to plants.

Reduce the availability of N, Mn, Fe, Cu, Zn, Mb

Reduces soil temperature

Reduces the activity of beneficial microbes

Destruct soil structure

Difficult for cultural operation

Incidence of pest, disease and weeds.

Changes for some elements in water logged condition

Elements	Normal form	Reduced form in water logged soil
Carbon	Carbon Di Oxide	Methane (CH_4) complex aldehyde
Nitrogen	Nitrate (No_3)	Nitrogen (N) and NH2 amides, ammonia
Sulphur	Sulphate (So_4)	Hydrogen sulphide (H_2S)

18.3. 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 conditions.

a) High water table
b) Water ponding on the surface for longer periods.
c) Excessive soil moisture content above FC 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 or intermittent heavy rainfall
f) Flat land with fine textured 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 operations
4. there should be minimum loss of cultivable area.
5. It should intercept or collect water and remove it quickly within shorter period.

18.4. Methods of drainage

There are two methods

1. Surface method
2. Sub surface method

1. 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,

1. slowly permeable clay and shallow soil
2. region of high intensity rainfall
3. to fields where adequate outlets are not available
4. the land with less than 1.5% slope

It can be made by

a) land smoothening
b) making field ditches

The surface drainage can be further classified as

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

a. Lift drainage

To drain from low lying areas or areas having water due to embankment, lift drainage is used. Water to be drained is lifted normally by open devices, unscoops or by pumping or by mechanical means. This method is costly, cumbersome and time consuming.

b. Gravity drainage

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

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.

c. 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 colleted 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.

d. Ditch drainage

Ditches of different dimensions 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 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.

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

2. Sub surface drainage system

Sub surface drains are underground 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 subsurface 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 drainages is mostly needed to the

Medium textured soil
High value crop
High soil productivity

There 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 drainage

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. **Tile drainage:**

This consists 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. The 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 cylindrical 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 beds.

4. **Drainage wells:**

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

18.5. Systems of drainage

There are four systems of drainage

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

1. Random

This is used where the wet areas 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. Herringbone

In this system, the mains are in a narrow depression and the laterals enter the main from both sides at an angle of 45° 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 angels. It is adopted in flat regularly shaped fields. This is an efficient drainage systems.

4. Interceptor

Ditches of different dimensions 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 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.

19. IRRIGATION MANAGEMENT IN COMMAND AREAS

19.1. Irrigation management

Irrigation management (water management) encompasses the process of storage, diversion, conveyance, regulation, measurement, distribution, application of the optimum quantity to crop and removal of excess water from the root zone as drainage.

In Indian states and in Tamil nadu, most of the irrigation projects aim at to meet the need of crop production and power generation. In countries like U.S.A., irrigation management planning includes water for recreation and environmental stability besides power generation and crop production.

19.2. River Command Areas

Vastness

Irrigation management involves large land areas which may cover few sovereign (independent) countries, few states within a country or few districts within a province (state). River Colorado of Southwest of USA flows through seven auto states within USA (Wyoming, Utah, Colorado, Arizona, New Mexico, Navada, California) and Mexico, another nation. River Cauvery originates in Coorg of Karnataka state and irrigates Karnataka, Tamil andu and Pondicherry states. Altogether Karnataka, Kerala, Tamil Nadu and Pondicherry states are involved in Cauvery river system. Usually many river systems are bigger in size (Ganges, Indus, Zambasi). Some of the river projects are meant only for power generation (Zambasi of Zambia and Zimbava). In India, most of the projects are for power generation and irrigation purposes. In big river projects navigation (Ganges) also takes place.

River commands are Complex in Nature

River commands are complex and complicated due to geographical, political and socio-economic scenario peculiar to every project. Hydro-politics (disputes) is a part of the river commands between provinces and countries. Cauvery command of Tamil nadu is unique for historical social, political and economic reasons. During BC 1st Century (speculation upto AD 2nd century), King Karikalacholan built the Grand Anaicut to divert flood water to Cauvery by putting stone embankments in Coleron (Kollidam). This is considered to be the major accomplishment in water management at that time.

The Cauvery system emanates from Kudagu, travels a distance of about 430 km before reaching Bay of Bengal. It is a very well developed delta at the coromandal coast (Cholamandalam coast) in the Tanjavur District of Tamil nadu. Out of the total flow of Cauvery the following are the contributions from different states.

* (for understanding only)

Karnataka - 52.5 percent

Tamil Nadu - 39.3 percent

Kerala - 8.2 percent

Total - 100.0 percent

- Irrigated area in Karnataka, 2.72 lakh hectares
- Irrigated area in Tamil Nadu 11.28 lakh hectares

In Cauvery delta

River courses and branches	:	36 Nos.
Total length of above courses	:	1000 miles
Canals created	:	30000 Nos
Total length of channels	:	15000 miles
A class channels	:	1500 Nos
B class channels	:	9750 nos
C class channels	:	110000 Nos
D class channels	:	53000 Nos.

Government maintains 36 river courses and branches and 138 A class channels and rest are maintained by the farmers.

Cauvery system was once a system of sufficiency and now become a system of deficiency. The main crops grown are Rice, Banana, Sugarcane, Vegetables, Coconut and sylvigronomy crops (tree crops in fields).

There are also trans-basin systems like Periyar-Vaigai of Tamil Nadu. West flowing Periyar river in the Western Ghats has been diverted to Tamil Nadu in opposite direction through tunnels. It was accomplished in 1896 by the Royal Engineer Pennqiuik. This is an unique project in Tamil Nadu of India in which modernization has been taken up.

19.3. Need for modernization of River Commands

- In order to increase the efficiency of the existing system
- To reduce water losses
- To bring additional area under irrigation

Earthern channels were lined with cement concrete on both bottom and sides. Granite stone masonry was also adopted for field water courses. After modernization of main canal and branch channels, efficiency of the water conveyance has increased from 45 to 75 percent.

19.4 Achievement out of modernization in Periyar, Vaigai

- All canals and channels were lined
- Separate outlet facilities were provided up to 10 ha limit
- Operational efficiency has been improved
- Village roads were improved for Agricultural activities
- New link roads were formed
- Functional efficiency were improved
- Water measuring devices were installed
- Irrigated area was increased

Existing area	:	57884 ha	
I state extension		:	10305 ha
II stage extension	:	7208 ha	
Total	:	75395 ha	
			80000 ha(or)
			200000 ac

periyar system has the inbuilt problem of scarcity of water though the systems capability has been increased by modernization. In the recent past, scarcity resulted in crop failure. Proper planning is necessary before water release. In years of scarcity and delayed release for single crop in the entire command was successful as compared to double crops in one area and single crop for another area.

19.5. Operation and Maintenance

Irrigation systems development operation and maintenance are the responsibility of the government agencies. Heavy investment is being made through irrigation development projects. Water from irrigation systems is generally made available to farmers almost free of cost or at lesser cost as compared to pumping from wells with electrical pumps or oil engines.

Besides the normal maintenance of the canals, channels and structural improvement of systems is essential to overcome deficiencies.

This is needed to ensure assured water supply to the farm lands in the command.

Water carrying capacities of the main canals, branch channels, distributaries and water courses are to be checked often to ensure the conveyance of desired quantity. Irrigation system structures should also be maintained for effective operation.

Systematic collection of data during irrigation, documentation and analyses are necessary to enable operation and maintenance. The maintenance staff should find out the operational problems to make mid-term correction if necessary.

System operation and maintenance authorities are to confront many problems especially at the present context of water crisis. Unauthorized pumping, unauthorized extension of head reach farmers, tampering the structures and activities on vested interests are the major problems. Lack of social discipline is the biggest problem in operation and maintenance.

19.6. Water release and water distribution

Water release is usually followed based on operational manuals and established procedures. Water release procedures were evolved based on historical and other considerations based on priorities and water availability.

Water distribution basic principles

- Optimum water supply
- Equity between big and small farmers
- Locational equity (Head, reach, middle reach and tail end farmers)
- Environmental stability
- Less scope for malpractices.

Water distribution methods

1. Flexible methods

- On demand
- Modified demand method

- Continuous flow method (Rice growing systems)

2. Rigid method

- Constant frequency – Constant amount
- Constant frequency – Varied amount
- Variable frequency – constant amount
- Variable frequency – variable amount

3. General methods followed

1. Warabandhi of western India (Rigid system of constant frequency of constant amount)
2. Shejpali system of Maharastra (Irrigation from the end at fixed intervals)
3. Ozarabandhi in UP (Alternate sluices draw water at a time.
4. Continuous flow (during sufficiency for rice, banana, sugarcane) and turn system of Tamil Nadu (Scarcity, variable frequency and variable quantity)

Irrigation system maintenance and operation involve co-operation of the rank and file of the irrigation department. It also needs the co-operation of Agricultural Engineering department, Agricultural Department, Co-operative department and farmers. Farmers are the ultimate users of water. In fact many international, national and state agencies are involved in the form of funding technical input, technical training of different officials and farmers. Policy issues are also playing key role which need political, administrative and social will at different levels.

20. ON-FARM WATER MANAGEMENT

Due to ill distribution, erratic and uncertain nature of rainfall over years and variations are year to year causing management difficulties in predicting the quantity and scheduling irrigation in common 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). These works are otherwise known as On-Farm Development works (OFD)

Conveyance and distribution System

Reservior

▼

Main canal

▼

Minor

▼

Distributory

▼

Sluice / outlet

▼

Field channel

▼

Distribution boxes

▼

Turnout

▼

Checks

20.1. 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 field.
- The number of farmers involved are more
- The influence of Socio-economic constraints

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

20.2. 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 water 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 directions, the junction point becomes widened causing much wastage of land and water.

f) Earthen channels with erosive slopes.

g) Structural deficiencies of essential structures such as channel crossing, small culverts, road crossing with siphon arrangement etc., are to be constructed wherever necessary.

20.3. OFD Measures to overcome the problems

a) Provision of proper earthen field channel network 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 encroachments.

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 crossings, with siphon arrangements, etc., are constructed wherever necessary.

The above details are furnished just to show only some of the problems and relevant OFD measurers. 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 utililzation management. The later is the crop water management at field level.

20.4. Rotational Water Supply (RWS)

RWS is one of the techniques in irrigation water distribution management. It aims at equi-distribution of irrigation water irrestpective 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 within the group by themselves.

Annexure I
Discharge through a 90 V-notch, litres per second

Height of water over V-notch cm	Discharge litres/ sec	Height of water over V-notch cm	Discharge litres/ sec	Height of water over V-notch cm	Discharge litres/ sec
4.0	0.5	13.0	8.6	22.0	31.0
4.5	0.6	13.5	9.5	22.5	34.0
5.0	0.8	14.0	10.5	23.0	35.7
5.5	1.0	14.5	11.3	23.5	38.2
6.0	1.2	15.0	12.3	24.0	40.0
6.5	1.5	15.5	13.3	24.5	42.7
7.0	1.8	16.0	14.5	25.0	44.5
7.5	2.2	16.5	15.6	25.5	46.7
8.0	2.5	17.0	16.7	26.0	48.8
8.5	2.8	17.5	18.3	26.5	51.0
9.0	3.4	18.0	19.4	27.0	53.8
9.5	3.9	18.5	21.7	27.5	56.3
10.0	4.5	19.0	22.3	28.0	58.7
10.5	5.1	19.5	23.5	28.5	61.5
11.0	5.7	20.0	25.5	29.0	64.5
11.5	6.3	20.5	27.0	29.5	66.8
12.0	7.1	21.0	28.3	30.0	69.4
12.5	7.8	21.5	30.3		

Annexure II

Free-flow discharge values for Parshall flumes

Head (Ha)cm	Discharge, litre/sec			
	Throat width			
	7.5 cm	15 cm	23 cm	30 cm
3	0.8	1.4	2.6	3.1
4	1.2	2.3	4.0	4.5
5	1.7	3.3	5.5	7.0
6	2.3	4.4	7.2	9.6
7	2.7	5.4	8.5	11.4
8	3.5	7.2	11.1	14.4
9	4.3	8.5	13.5	17.7
10	5.0	10.2	15.9	21.1
11	5.8	11.6	18.1	23.8
12	6.7	13.5	21.1	27.5
13	7.5	15.0	23.3	31.0
14	8.5	17.3	26.7	35.0
15	9.4	19.2	29.5	38.7
16	10.4	21.2	32.5	42.7
17	11.4	23.2	35.6	46.7
18	12.4	25.3	39.0	51.2
19	13.6	27.8	42.5	55.0
20	14.3	30.0	45.8	59.7
21	15.8	32.7	49.3	64.7
22	17.1	35.2	53.3	69.8
23	18.2	3737	56.8	74.0
24	19.4	40.1	60.5	79.0
25	20.7	42.7	64.5	84.1
26	22.0	45.7	69.3	89.0
27	23.3	48.1	72.4	94.3
28	24.8	51.5	76.7	100.0

29	26.0	54.0	80.7	105.1
30	27.5	57.3	85.2	111.0

Annexure III
Discharge through contracted rectangular weirs (litre/sec)

Head over weir cm	Width of weir			
	30 cm	40 cm	50 cm	60 cm
5.0	6.0	8.0	10.1	12.2
5.5	6.9	9.3	11.6	14.0
6.0	7.8	10.5	13.1	15.9
6.5	8.4	11.8	14.9	17.9
7.0	9.7	13.2	16.6	20.0

7.5	10.7	14.5	18.3	22.1
8.0	11.8	16.0	20.1	24.3
8.5	12.9	17.6	22.1	26.7
9.0	14.0	19.0	24.0	28.9
9.5	15.2	20.7	26.0	31.2
10.0	16.3	22.2	28.0	33.8
10.5	17.5	23.7	30.0	36.2
11.0	18.7	25.3	32.0	37.7
11.5	19.9	27.1	34.3	41.4
12.0	21.3	29.0	36.7	44.4
12.5	22.5	30.7	39.0	47.1
13.0	23.7	32.3	40.9	49.5
13.5	24.8	34.0	43.0	52.2
14.0	26.2	35.8	45.4	55.2
14.5	27.7	37.9	48.2	58.5

Head over weir cm	**Width of weir**			
	30 cm	**40 cm**	**50 cm**	**60 cm**

15.0	28.8	39.5	50.3	60.9
16.0	31.6	43.3	55.2	67.0
17.0	34.3	47.2	60.1	73.0
18.0	37.0	51.0	65.3	79.0
19.0	39.8	55.0	70.2	85.3
20.0	42.8	59.3	75.8	88.8
21.0	45.7	63.3	81.0	99.0
22.0	48.7	67.5	86.7	105.7
23.0	51.3	71.7	92.2	112.3
24.0	54.7	76.5	94.8	120.0
25.0	57	79.8	102.7	125.8
26.0	60.3	84.6	109.2	133.3
27.0	63.5	89.2	115.0	140.8
28.0	66.5	93.7	122.2	148.3
29.0	69.5	98.3	127.0	155.7
30.0	72.3	102.7	133.0	163.3

Annexure IV
Discharge through circular orifice

Height of water over centre of orifice cm	Discharge rate, litres/sec		
	Diameter of orifice		
	2.5 cm	5.0 cm	7.5 cm
1.0	0.13	0.53	1.2
1.5	0.16	0.64	1.4
2.0	0.19	0.40	1.7
2.5	0.21	0.81	1.8
3.0	0.23	0.91	2.1
3.5	0.25	0.99	2.2
4.0	0.26	1.15	2.4
4.5	0.28	1.20	2.5
5.0	0.30	1.21	2.7
5.5	0.31	1.23	2.8
6.0	0.32	1.30	2.9
6.5	0.33	1.34	3.0
7.0	0.35	1.39	3.1
7.5	0.36	1.45	3.3
8.0	0.38	1.50	3.4
8.5	0.39	1.53	3.5
9.0	0.40	1.60	3.6
9.5	0.41	1.62	3.7
10.0	0.42	1.70	3.8
10.5	0.43	1.72	3.9
11.0	0.44	1.75	3.9

Height of water	Discharge rate, litres/sec

over centre of orifice cm	Diameter of orifice		
	2.5 cm	5.0 cm	7.5 cm
11.5	0.45	1.80	4.0
12.0	0.46	1.83	4.1
12.5	0.47	1.87	4.2
13.0	0.48	1.90	4.3
13.5	0.49	1.93	4.4
14.0	0.50	1.96	4.5
14.5	0.51	2.10	4.5
15.0	0.52	2.50	4.6
15.5	0.53	2.80	4.7
16.0	0.54	2.10	4.80
16.5	0.54	2.15	4.83
17.0	0.55	2.20	4.92
17.5	0.56	2.22	5.00
18.0	0.58	2.25	5.13
18.5	0.58	2.31	5.15
19.0	0.59	2.33	5.20
19.5	0.59	2.37	5.30
20.0	0.60	2.40	5.32
20.5	0.60	2.42	5.40
21.0	0.61	2.45	5.47
21.5	0.62	2.50	5.53
22.0	0.63	2.51	5.60
22.5	0.63	2.53	5.65
23.0	0.64	2.57	5.70

Height of water over centre of orifice cm	Discharge rate, litres/sec		
	Diameter of orifice		
	2.5 cm	5.0 cm	7.5 cm
24.0	0.65	2.60	5.83
24.5	0.66	2.62	5.92
25.0	0.66	2.63	5.95
25.5	0.66	2.65	6.00
26.0	0.67	2.67	6.10
26.5	0.68	2.70	6.12
27.0	0.69	2.75	6.18
27.5	0.69	2.80	6.23
28.0	0.70	2.81	6.30
28.5	0.71	2.82	6.37
29.0	0.71	2.83	6.40
29.5	0.72	2.87	6.47
30.0	0.72	2.90	6.53

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GLOSSARY

Absolute Humidity:

Grams of water vapour per cubic metre.

Absolute water requirement:

Also called consumptive use of water. This is the quantity of water in ha-cm per crop season absorbed by the crop together with the evaporation from the crop producing land. It includes the water used by evapo-transpiration and retained in the plant body.

Absorption:

The process by which a substance is taken into and included within another substance, i.e., intake of water by soil, or intake of gases, water, nutrients, or other substances by plants.

Actual crop evapo-transpiration:

Rate of evapo-transpiration equal to or smaller that PET as affected by the level of available soil water salinity field, size, or other causes; mm/day.

Actual vapour pressured:

Pressure exerted by water vapour contained in the air, millibar (mb) or mm of Hg.

Adsorption:

The increased concentration of molecules or ions at a surface, including exchangeable cations and anions on soil particles

Advance curve:

Advance curve is a relationship between distance travelled by a flow of water and unit of time in surface irrigation methods.

Advection:

The process of transport of an atmospheric property (such as heat, water vapour or momentum) solely by the horizontal motions of the atmosphere.

Advective energy:

Advective energy is the energy developed from horizontal heterogeneity in climatic parameters; or in simple words, it is the energy brought by winds. It is an important source of energy especially in tropical hot summers which results in greater evapotranspiration than normally is due to the solar energy.

Aerodynamic:

Refers to forces of moving air acting upon the soil of crop surface.

Aerodynamically rough surface:

Surface whose roughness elements are sufficiently large that the turbulent boundary layer reaches the surface

Aerodynamically smooth surface:

A surface whose roughness elements are sufficiently small to be entirely embedded in the laminar sub-layer

Aggregate:

A single mass or cluster of soil consisting of many soil particles held together, such as a clod, prism, crumb, or granule.

Air capacity:

The quantity of air in the soil when the soil is at field moisture capacity

Albedo:

The ratio of electromagnetic radiation reflected from a soil and crop surface to the amount incident upon it (expressed as per cent). In practice the value is applied primarily to solar radiation.

Alkali soil:

A soil that contains sufficient exchangeable sodium to interfere with the growth of most crop plants, either with or without appreciable quantities of soluble salts.

Alkaline soil:

A soil that has an alkaline reaction, i.e, a soil for which the pH reading of the saturated soil paste is higher than 7

Alkalisation:

The process whereby the exchangeable-sodium content of a soil is increased

Allowable soil water depletion:

Depth of soil water in the root zone readily available to the crop for given soil and climate allowing unrestricted evapo-transpiration as the fraction of total available soil water between field capacity and withing point mm/m

Aquifer:

Water bearing formation in the ground that will yield enough water.

Arid:

A climate that is characterised by low rainfall and high rate of evaporation. Arid climate is usually defined as less than 10 inches (25 cm) of precipitation per year, and semi-arid as between 10 and 20 inches per year.

Atmospheric pressure:

The pressure exerted by the atmosphere as a consequence of the weight of the air lying directly above the unit of area in question. At sea level atmospheric pressure is equal to 76 cm Hg column.

Available soil water:

Depth of water stored in the root zone between field capacity and PWP; mm/m soil depth.

Average intake rate:

Rate of infiltration of water into the soil obtained by dividing the total depth of water infiltrated by the total time, from start to finish, of water application; mm/hour.

Basic intake rate:

Rate at which water will enter the soil when after initial wetting of the soil the rate become essentially constant; which is equal to saturated hydraulic conductivity mm/hr.

Belt of soil water:

The part of the zone of aeration which consists f soil and other materials that lie near enough to the surface to discharge water into the atmosphere in perceptible quantities by the transpiration of plants or by evaporation from the soil.

Berm:

Berm is a narrow strip of land kept between channel section and the bank.

Bowen ratio:

The ratio of energy fluxs upward as sensible heat to latent energy flux in the same direction (negative when the fluxes are in opposite directions)

Bulk density:

Bulk density is the ratio of the mass of water-free soil to its bulk volume. It is expressed in g/cc and is sometimes referred to as "apparent density". When expressed in g/cc, bulk density is numerically equal to apparent specific gravity or volume weight.

Buoyancy:

The upward force exerted on a volume of fluid (or an object in the fluid) by virtue of density difference between the volume of fluid (or the object) and that of the surrounding fluid.

Calorie (cal):

A unit of heats required raising the temperature of 1 g of water from 14.5 to 15.5^{0}C. The international table calorie equals 1.00032 cal.

Capillary fringe:

The zone immediately above the water table in which water is held above the water table by capillary action.

Capillary rise:

The rise of a liquid in a capillary tube may be obtained by computing the pressure exerted by the hanging water column. Water 'hangs' around the permeter of the tube by virtue of adsorption forces between the tube surface and the liquid and the cohesive forces in the liquid surface or surface tension. Capillary rise (h) can be given as:

$$h = \frac{2\sigma}{r\rho g} \quad \text{(or)} \quad h = \frac{2\sigma \cos ;}{r\rho g}$$

Where is the surface tension, r is the radius of the capillary tube, ρ is the density of the liquid and ; is the contact angle between water and soil pore (assumed to be zero).

Capillary potential or Buckingham's potential:

It is a measure of the attraction forces with which water is held by a soil. It is usually expressed in terms of work that must be done to move water against the capillary forces of the soil. Buckingham (1907) who originally losses applied to the soil in one irrigation application and which is needed to bring the soil water content of rootzone to field capacity; mm

Design factor:

Ratio between canal capacity or maximum discharge in m^3/section and the maximum daily supply requirements during the peak water use period in m^3/day.

Dew point:

The temperature at which saturation vapour pressure of the given parcel is equal to the actual vapour pressure of the contained water vapour.

Dielectric constant:

A constant which denotes the non-conductivity to an electric charge of a substance.

Diffusions:

Diffusion is the molecular transfer of gases through a porous media. According to Fick's law, diffusion is a function of the concentration gradient, the diffusion coefficient of the medium, and the cross-sectional area participating in the diffusion.

$$dQ = DA \frac{dc}{dx} dt$$

where dQ is the mass flow (moles) diffusing during time dt across area A (cm^2), dx

$\frac{dc}{}$ is the concentration gradient moles / (cm^3)/cm and D is the proportionality constant or diffusion coefficient (cm^2/section). Soil. Dispersed soils usually have low permeability. They tend to shrink, crack, and become hard on drying and to slake and become plastic on wetting.

Distribution efficiency (Ed) :

Ratio of water made directly available to the crop and that released at the inlet of a block of fields: Ed = Eb/Ea; fraction.

Drainage

(1) The process of the discharge of water from an area of soil by sheet or stream flow (surface drainage) and the removal of excess water from within the soil by downward follow-through the soil (internal drainage)

(2) The means for effecting the removal of water from the surface of soil and from within the soil, i.e., sloping topography or stream channel (surface drainage) and open ditches, underground tile lines, or pumped wells (artificial drainage).

Drainage requirements:

Performance and capacity specifications for a drainage system i.e., permissible depth and modes of variation of the water table with respect to the root zone or soil surface, and the volume of water that the drains must convey in a given time.

Drought year:

When the rainfall is short by more than twice the deviation, the year is said to be drought year for a particular place, e.g if the normal rainfall is 1,000 mm and normal deviation is 150 mm, then if the rainfall received is less than 700 mm, it would be termed as a drought year.

Duty of water:

The total volume of irrigation water required maturing a particular type of crop. It includes consumptive use, evaporation and seepage from ditches and canals, and the water eventually returned to streams by percolation and surface runoff.

Effective rainfall (ER):

Rainfall useful for meeting crop water requirements; it excludes deep percolation, surface runoff and interception; mm/period.

Effective full ground cover:

Percentage of ground cover by the crop when ET crop is approaching maximum - generally 70 to 80 percent of surface area; percentage

Effective rooting depth (D):

Soil depth from which the full-grown crop extracts most of the water needed for evapo-transpiration; m

Efficiency of irrigation:

The fraction of the water diverted from per cent. often applied to whole irrigation systems and takes account of conveyance losses.

Efficiency of water application:

The fraction of the water delivered to the farm that is stored in the root zone for use by the crop, expressed as per cent.

Electrical conductivity (Ec):

Ec is the property of the medium of transferring electric charge. It is the reciprocal of electrical resistively and is expressed in reciprocal of Ohms (mhos0 per cm at 25^0 C.

Equivalent weight:

The weight in grams of an ion or compound that combines with or replaces one gram of hydrogen. The atomic weight or formula weight divided by its valence.

Exchangeable

cation:

A cation that is adsorbed on the exchange complex and which is capable of exchange with other cations.

Exchangeable sodium percentage:

The degree of saturation of the soil exchange complex with sodium. It may be calculated by the formula:

$$ESP = \frac{\text{Exchangeable sodium (meq/100 g soil)}}{\text{Cation -exchange-capacity (meq/100 g soil)}} \times 100$$

Extra-terrestrial radiation (Ra):

Amount of solar radiation received on a horizontal plane at the top of the atmosphere; equivalent evaporation mm/day.

Fetch:

(Also generation area). The length of fetch area, measured in the direction of the wind from the site in question, which is required to eliminate the effect of Advection, etc.

Field application efficiency (Ea):

Ratio of water made directly available to the crop and that received at the field inlet.

Field channel efficiency (Eb): Ratio between water received at the field inlet and that at the inlet of a block of fields; fraction.

Field capacity (Fc):

Depth of water held in the soil in absence of ET after ample irrigation or heavy rain when the rate of downward movement has substantially decreased, usually 1 to 3 days after irrigation, or rain. Soil water content at soil water tension of about 0.1 to 0.3 atmosphere.

Field water balance:

Sum of all gains and losses of water over a given period of time; mm/period.

Fifteen atmosphere percentage:

It is the moisture percentage on dry-weight basis of a soil sample which has been wetted and brought to an equilibrium in a pressure membrane plate apparatus at 15 atm pressure (221 lb/sq. inch). This characteristic moisture value for soil approximates the lower limit of water available for crop growth, which is also referred to as PWP.

Fifty per cent yield-decrement value:

The measured value of the soil salinity or alkali that decreases crop yield by 50 per cent as compared with yields of the same crop on non-saline and non-alkali soils under similar growing conditions.

Free flow:

It is a condition under which the rate of discharge is solely dependent on the length of crest and depth of water at 'Ha' in the converging section of the Parshall flume. At free-flow the ratio of Hb and Ha equals or is less than 0.6.

Full ground cover:

Soil covered by crops approaching 100 per cent when looking downwards.

Gas constant:

The constant factor in the equation of state for perfect gases. The universal gas constant is R = 8.314×10^7 erg mol^{-1}. $^0K^{-1}$.

Global radiation:

The total of direct solar radiation and diffuse sky radiation received by a unit horizontal surface (essentially less than about 3 microns).

Grand growth period:

For a given crop, the period between effective full ground cover and the onset of maturity (i.e., leaves start to discolour or fall off); days.

Gravitational head of water (z):

Gravitational head of water in soil at a given point is the elevation of the point with respect to an arbitrary datum or reference point.

Ground water:

The water that occurs in the zone of saturation, from which wells and springs or open channels are fed. This term is sometimes used to include also the suspended water and is loosely synonymous with sub-surface water, underground water or sub-terranian water.

Ground water table:

Upper surface of free water accumulating in lower depths or saturating the underlying sand or gravel. Furnishes supplies for shallow spring and wells; water table of more than 180-240 cm below the bottom of the root zone is not of much use to the plants.

Hydraulic gradient (I):

The decrease in hydraulic head per unit distance in the soil in the direction of the greatest rate of decrease of hydraulic head.

Hydraulic head (h): the elevation with respect to a standard datum at which water stands in a riser 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 elements is pointed upstream. For nonturbulent 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 (L0.

Hydraulic conductivity (HC):

The proportionality factors in the Darcy flow law, which states that the effective flow velocity is proportional to the hydraulic gradient. Hydraulic conductivity, there fore, is the effective flow velocity at unit hydraulic gradient and has the dimensions of velocity. Saturated hydraulic conductivity for a particular soil is constant, whereas unsaturated hydraulic conductivity is a function of soil water content.

Hydraulic equilibrium:

Hydraulic equilibrium is the condition for zero flow rate of water film in soil.

Hydraulic pressure:

The pressure in a fluid in equilibrium which is due solely to the weight of fluid above.

Hydroscopic coefficient:

It is the amount of moisture in dry soil when the same is in equilibrium with some standard relative humidity near a saturated atmosphere 9 about 98 per cent) expressed in terms of percentage on the basis of oven-dry soil.

Hygroscopic water:

Hygroscopic water is that which is absorbed from an atmosphere of water vapour as a result of attractive forces in the surface of particles.

Hysteresis:

The curve obtained by progressive lowering of moisture content and progrssively increasing the moisture content are known as 'disorption' and 'adsorption' curves, respectively. The two curves generally do not coincide. The phenomenon is called 'hysteresis'.

Indicator plant:

Indicator plant is one which reflects specific growing conditions either by its presence or character of growth. Such as plant indicates water stress earlier than main crop plants.

Infiltration:

The downward entry of maximum rate at which a soil under a given condition and at a given time can absorb water when there is no divergent flow at borders.

Infrared radiation:

Electromagnetic radiation lying outside the red band with wavelength between about 0.8 μm.

Initial intake rate:

Rate at which water will enter the soil when water is first applied; mm/hr.

Intake rate or infiltration velocity:

It is the rate of water entry into the soil expressed as depth of water per unit of time. It involves no restrictions on area of application or divergence of flow in the soil.

Intermediate belt:

Zone that lie between the belt of soil water and the capillary fringe.

Intrinsic permeability:

Intrinsic permeability is the factor k in the equation V = k dgi/,η where V = flow velocity, d = density of liquid, g = scaler value of acceleration due to gravity, I = hydraulic gradient and η = viscosity of fluid.

Irrigation:

Artificial application of water to land.

Irrigation efficiency:

The ratio of the volume of water required for a specific beneficial use as compared to the volume of water delivered for this purpose. It is commonly interpreted as the volume of water stored in the soil for evapo-transpiration compared to the volume of water delivered for this purpose.

Irrigation interval:

Time between the start of successive field irrigation applications on the same field; days.

Irrigation requirement:

Refers to the quantity of water, exclusive of precipitation, required for crop production. this amounts to net irrigation requirement plus other economically unavoidable losses. It is usually expressed in depth for a given time.

Irrigation response:

Irrigation response is the rate of increase in crop yield per unit of increase in water applied.

Isobar:

A line of equal pressure.

Isohyet:

A line of equal precipitation

Isotach:

A line of equal wind speed

Isotherm:

A line of equal temperature

Laminar flow:

A flow in which fluid moves smoothly in streamlines in parallel layers or sheets (nonturbulent flow).

Latent heat:

The heat released or absorbed, per unit mass, by a system during a change of phase. In metrology, at 0^0C the latent 600, 80, and 680 cal/g, respectively.

Leaching requirement;

The fraction of the water entering the soil that must pas through the root zone in order to prevent soil salinity from exceeding a specified value. Leaching requirement is used primarily under steady-state or long time average conditions.

Leaching efficiency:

The ratio of the average salt concentration in drainage water to an average salt concentration in the soil water of the root zone when near field capacity.

Leaf area index:

The area of one side of leaves per unit area of land surface.

Levee:

A bank of earth used to hold irrigation water within certain limits. So that uniform irrigation of the entire field is obtained. An earthen dam placed at varying distance from the banks of a river to serve as barrier to adjacent low lying land during floods.

Long-wave radiation:

Electromagnetic radiation with a wave-length greater than 0.8 microns.

Maximum number of bright sunshine hours, (N):

Number of bright sunshine hours for a 24 hr day with no cloud cover; hr

Method of irrigation:

Method of operating an irrigation system to convey water from the source of supply and to distribute it according to crop requirements to each field served by the system.

Microclimate:

The pattern of variation in temperature, moisture, etc., over a small area, i.e., the sequence of atmospheric changes with a very small region.

Mixing ratio:

The ratio of the mass m_γ of water vapour to the mass m_α of dry air with which the water is associated $r = m_\gamma / m_\alpha$

Moisture percentage:

1) **dry weight basis :** The weight of water per 100 units of weight of material dried to constant weight at a standard temperature

2) **depth basis:** The equivalent depth of free water per 100 units of depth of soil.

Numerically this value approximates the volume of water per 100 units of volume of soil.

Mole:

A unit of mass numerically equals to the molecular weight of the substance.

Mulch:

Mulch is natural or artificially applied layer of plant residues or other material on the surface of the soil with the object of moisture conservation, temperature control, prevention of surface compaction of crusting, reduction of run off and erosion, improvement in soil structure or weed control.

Net irrigation requirement:

Depth of water required for meeting evapo-transpiration minus contribution by precipitation, ground-water, stored soil water; does not include operation losses and leaching requirements; mm/period.

Net longwave radiation (Rnl):

Balance between all outgoing and incoming longwave radiation; almost always a negative value, equivalent evaporation; mm/day.

Net radiation (Rn):

Balance between all incoming and outgoin short and longwave radiation; Rn = Rns + Rnl; equivalent evaporation; mm/day.

Nonsaline alakali soil:

A soil that contains sufficient exchangeable sodium to interfere with the growth of most crop plants and does not contain appreciable quantities of soluble salts. The exchangeable sodium percentage is greater than 15 and the electrical conductivity of the saturation extract is less than 4 m mhos/cm (at 25^0 C). The pH reading of the saturated soil paste is usually greater than 8.5.

Oasis effect:

Effect of dry fallow surrounds on the micro-climate of a relatively small acreage of land, where an air mass moving into an irrigated area will give up sensible heat. For small field, this may result in a higher ET crop as compared to predicted ET crop using a climatic data collected inside the irrigated area; conversely ET crop predictions based on weather data collected outside the irrigated fields may over-predict actual evapo-transpiration losses.

Osmotic pressure:

The equivalent negative pressure that influence the rate of diffusion of water through a semipermeable membrane. It's direct experimental value for a solution is the pressure difference required to equalise the diffusion rates between the solution and pure water across a semipermeable membrane.

Pan:

Pan is a layer formed by accumulation of materials such as salts, clay etc., and which impedes free drainage. In a clay pan, there is accumulation of clay washed down from upper layers Dissolved salts like silica, calcium carbonate, etc., on precipitation, from a hard pan.

Pan coefficient (Kp):

Ratio between reference evapo-transpiration ET_0 and water loss by evaporation from an open water surface of a pan; k = ET_0 / E pan fraction.

Pan evaporation (E pan):

Rate of water loss by evaporation from an open water surface of a pan mm/day.

Particle density (real density):

Real density or the particle density is the density of oven dry soil particles when air is excluded.

Peak or maximum supplies (V max)

Average daily supply requirement during the peak water use period for given crop or cropping pattern and climate; m^3 / day.

Peak supply period:

Water use period for a given crop or cropping pattern during the month or period there of highest water requirements; mm / day.

Pellicular zone:

The maximum depth from the natural surface up to which the evaporation can have its effects.

Perched water or perched ground water:

Ground water of a limited aquifer embedded in different depths on small impermeable or relatively impermeable layers.

Percolation:

Movement of water through a column of soil in response to the force of gravity generally under-saturated or near saturated conditions.

Permanent wilting point:

Permanent wilting point is the moisture content in percentage of a soil at which nearly all plants wilt and do not recover in a humid dark chamber, unless water is added from an outside source. This is the lower limit of available moisture range for plant growth. Below the wilting point, extraction of moisture continues for some time but growth ceases completely. The force with which moisture is held by the soil at this point corresponds to 15 atm.

Permeability:

1) The readiness with which air, water or plant roots penetrate into or pass through the soil pores.
2) The quality or state of a porous medium relating to the readiness with which it conducts or transmits fluids.
3) The rate of readiness with which a porous medium

transmits fluid under standard conditions.

pF:

Is the logarithm of height in cm of a column of water, which represent the totals stress with which water is held by a soil.

Piezometer:

It is a hallow pipe with opening at the bottom used to measure pressure of ground water at the point of entry.

Porosity:

Porosity of a soil 9N) is defined, as the percentage of soil volume not occupied by the soil particles. It is obtained from particle density (dp) and bulk density (bd) by the relationship.

$$N = \frac{bd}{dp} \times 100$$

Potential evaporation:

It represents evaporation from a large body of free water surface. It is a assumed that there is no effect of advective energy. It is primarily a function of evaporative demand of climate.

Potential evapo-transpiration (PET):

It is amount of water evapo-transpired in unit time from a short uniform green crop growing actively and covering an extended surface and never short of water.

Potassium-adsorption-ratio (PAR):

A ratio for soil extract and irrigation waters used to express the relative activity of potassium ions in exchange reactions with soil.

$$PAR = \frac{K+}{(Ca^{++} + Mg^{++})/2}$$

where the ionic concentration are expressed in meq/litre.

Precipitation:

Total amount of precipitation (rain, drizzle, snow, hail, fog, condensation, hoar, frost and rime) expressed in depth of water which would cover a horizontal plane if there is no runoff, infiltration or evapo-transpiration; mm/day.

Pressure gradient:

The rate of decrease of pressure in space at a given time.

Project efficiency, (Ep):

Ratio between water made directly available to the crop and that released at project head works; Ep = Ea. Eb. Ec; fraction.

Psychrometer:

Device to measure air humidity; normally consisting of two standard thermometers, one of whose bulb is surrounded by a wet muslin bag and is called wet-bulb thermometer; both should normally be force-ventilated and shielded against radiation (Assmann type).

Psychrometric chart:

A homograph for graphically obtaining relative humidity and dew point from wet-and dry-bulb thermometer readings.

Psychrometric constant:

The ratio of specific heat of air to the latent heat of evaporation of water.

Radiation:

The process by which electromagnetic radiation is propagated through free space as distinguished from conduction and convection.

Recession curve:

It is the relationship between the time at which water has completely receded from the soil surface and distance along the run in a surface irrigation system.

Reference crop evapo-transpiration (ET_0):

Rate of evapo-transpiration from an extended surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water; mm/day.

Reflection coefficient:

The ratio of amount of solar radiation reflected by a body to the amount incident upon it.

Relative humidity:

The dimensionless ratio of actual vapour pressure of the air to saturation vapour pressure, commonly expressed in per cent.

Saline alakali soil:

A soil containing sufficient exchangeable sodium to interfere with the growth of most crop plants and containing appreciable quantities of soluble salts. The exchangeable sodium percentage is greater than 15 and the electrical conductivity of the saturation extract is greater than 4 m mhos per cm (at 25^0C). The pH reading of the saturated soil is usually less than 8.5.

Saline soil:

A non-alkali soil containing soluble salts in such, the quantities that they interfere with the growth of most crop plants. 4 m mhos per cm 9at 25^0 C) and the exchangeable sodium percentage is less than 15. The pH reading of the saturated soil is usually less than 8.5.

Salinisations:

The process of accumulation of soluble salts in soil at or when air is saturated at given air temperature; millibar (mb) or mm of Hg.

Saturated air:

Moist air in a state of equilibrium with a plane surface of pure water or ice at the same temperature and pressure. In such a state the relative humidity is 100 per cent and the amount of water vapour is maximum for the given temperature.

Saturation deficit: (also called vapour pressure deficit):

The difference between the actual vapour pressure and the saturation vapour pressure at the existing temperature.

Saturation extract:

The solution extracted from a soil at its saturation percentage.

Saturation percentage:

The moisture percentage of a saturated soil expressed on a dry-weight basis.

Sensible heat (H):

The energy utilised to heat the air.

Seepage:

The slow movement of water through small cracks, pores, interestices etc., in the surface of unsaturated material into or out of a body of surface or sub-surface water.

Semipermeable membrane:

A membrane that permits the diffusion of one components of a solution but not the other. In biology, a septum which permits the diffusion of water but not the solute.

Short-wave radiation:

A term used loosely to distinguish solar and diffuse sky radiation from long - wave radiation.

Slick spots:

Slick spots are wet spots with high exchangeable sodium occurring generally in salt affected areas.

Sodium adsorption ratio:

A ratio for soil extracts and irrigation waters used to express the relative activity of sodium ions in exchange reactions with soil.

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{++} + Mg^{++})/2}}$$

Where the ionic concentrations are expressed in milliequivalents (me) per litre.

Soil extract:

The solution separated from a soil suspension or a soil at particular moisture content.

Soil specific gravity (As):

Ratio of the weight of water - free soil to its volume; also called bulk density; g/cm^3.

Soil structure

Arrangement of soil particles into aggregates, which occur in a variety of, recognised shapes, sizes and strengths.

Soil texture:

Characterization of soil in respect of its particle size and distribution.

Soil water stress:

Sum of soil water tension and osmotic pressure to which water must be subjected, to be in equilibrium with soil water; also called soil water potential; atmosphere or bar.

Soil water tension:

Force at which water is held by the soil or negative pressure or suction that must be applied to bring the water in a porous cup into static equilibrium with the water in the soil; soil water tension does not include osmotic pressure; also called matric potential; atmosphere or bar.

Solar constant:

The rate at which solar radiation is received out side the earth's atmosphere on a surface normal to the incident radiation. (2 cal/cm^2 per minute).

Soluble sodium percentage (SSP):

A term used in connection with irrigation waters and soil extracts to indicate the proportion of sodium ions in solution in relation to the total cation concentration. It may be calculated by the formula

$$SSP = \frac{\text{Soluble sodium concentration (meq/1)}}{\text{Total cation concentration (meq/1)}} \times 100$$

Specific heat:

The heat capacity of a system per unit mass

Specific humidity:

The ratio of the mass of water vapour in a volume of moist air to the total mass of the volume of moist air.

Specific surface:

The surface area per unit weight of soil, commonly expressed as square metres per gram of soil (m^2/g).

Stefan-Boltzmann law:

One of the radiation laws which states that the amount of energy radiated per unit time from a unit surface area of an ideal black body is proportional to the fourth power of the absolute temperature of the black body; $R = \sigma T^{4.}$

Stored soil water (wb):

Depth of the water stored in the root zone from earlier rains, snow or irrigation applications which partly or fully meets crop water requirements in following periods; mm.

Stream lines:

Stream lines are definite paths through which water flows in a soil.

Stream size:

Flow selected for supply to field inlet or irrigation block; 1/sec. or m^3+/sec.

Submerged flow:

The flow in which there is a backpressure as a result of which the discharge is lower than the free flow.

Sunshine hours (n):

Number of hours of bright sunshine per day, also sometimes defined as the duration of traces of burns made on a chart by Campble Stocks recorder; hours.

Tensiometer:

A device for measuring the tension of soil water in the soil consisting of a porous, permeable ceramic cup connected through a tube to a manometer or vacuum gauge.

Transpiration:

The process by which water in plants is transferred as water vapour to the atmosphere.

Turbulence:

A state of fluid flow in which instantaneous velocities exhibits irregular and apparently random fluctuations.

Vapour pressure:

The partial pressure of water vapour in the atmosphere.

Water potential:

The capability of soil water to do work compared with free-water. The water potential at the surface of free water is taken as zero.

Water requirement (WR):

Also referred as water need. It is defined, as the water needed for raising a crop in a given period. It includes consumptive use and other economically unavoidable losses and that applied for special operation such as land preparation, transplanting leaching etc,. it is usually expressed as depth of water for a given time.

Watershed:

Watershed is the area above a given point on a stream that contributes water to the flow at that point. Catchment basin or drainage basin are synonymous with it.

Wet - bulb depressing:

Difference between simultaneous readings of wet-and dry bulb thermometers; degree Celsius

Wet bulb temperature:

Temperature recorded on a thermometer whose bulb is surrounded by a wet muslin bag, thus lowering the temperature by loss of latent heat through evaporation; degree Celsius.

Wet land:

Pertaining to soils flooded for at least several weeks each year or to crop grown in such soils.

Wet year:

If the rainfall exceeds twice the normal deviation at a particular place, that year is said to be a wet year.

Windspeed (U_2):

Speed of air movement at 2m above ground surface in unobstructed surrounding. Means in m/section over the period considered, or total wind run in km/day.

Wind vane:

An instrument used to indicate wind direction.

Zero-plane displacement:

An empirically determined constant introduced into the logarithmic velocity profile to extend its applicability to very rough surfaces or to take into account the displacement of a profile above a dense crop.