Water Management including Micro Irrigation

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Lesson No.	Lesson Title
Lesson 1	Definition of irrigation; History of irrigation in India; Water resources -their exploitation; Scenario of irrigation in India-canal, tank, well and lift irrigation systems
Lesson 2	Soil water relations; Introduction to basic terms in water management & irrigation; study of moisture constants and hydro dynamic relations
Lesson 3	Measurement of soil moisture-different direct and indirect methods
Lesson 4	Expressions of soil moisture and their mutual relations
Lesson 5	Plant water relations-critical stages; meaning and impact of water stress
Lesson 6	Water availability and its relationship with nutrient availability and losses
Lesson 7	Water management of crops-its definition, meaning, and relevance in crop production
Lesson 8	Concept of evapotranspiration and its measurement
Lesson 9	Factors affecting water requirement; Study of water requirement of field crops and horticultural crops
Lesson 10	Methods of irrigation-surface, subsurface, sprinkler and drip; their types and efficiencies; constraints and advantages of different methods
Lesson 11	Efficiency of irrigation; methods to measure them
Lesson 12	Quantitative estimation of irrigation water-direct and indirect methods; expressions of flowing water and their mutual relations

Lesson 13	Concept of water use efficiency, its relevance and factors affecting it-methods to improve WUE
Lesson 14	Assessment of irrigation requirement. Scheduling of irrigation-approaches and methods to schedule irrigation
Lesson 15	Development of irrigation plans for individual farms and micro and macro commands
Lesson 16	Suitability of irrigation water for irrigation-quality of water & its impact on growth, development and yield of crops
Lesson 17	Irrigation control and water conveyance methods-their advantages & disadvantages
Lesson 18	Concept of drainage-surface and subsurface methods of drainage
Lesson 19	Irrigation practices of important field and horticultural crops

Course Name	**Water Management including Micro Irrigation**
Lesson 1	**Definition Of Irrigation; History Of Irrigation In India; Water Resources -Their Exploitation;**
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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Objective

1. To learn about history of irrigation development and its current scenario in India
2. To learn annual water budget and various water resources.
Terminology

Irrigation: Irrigation is be defined as artificial application of water to the plant root zone to supplement the water available from rainfall, ground water and stored soil moisture in crop root zone.

Wadi: A ravine or valley which is dry except in the rainy season. It may also refer to a stream running through such a valley. In-between the irregular floods, they are either dry or carry scanty base flow.

Command area: The area that can be irrigated from an irrigation canal or canal system by gravity flow due to its location higher than the surrounding canal.

Catchment area, River basin, Drainage basin, Watershed: The area from which a river, stream or reservoir receives surface flow which originates as precipitation.

Gross irrigated area: Land area irrigated in a year (2 irrigation seasons counted as two).

Net irrigated area: The land area that actually receives irrigation in a year, irrespective of no. of crop seasons (Ex.- 2 or 3 irrigation seasons in a year are counted as one).

Water basin: A hydrologically delineated area that is drained by a river system.

Watershed: A hydrogeological unit that drains into a river or stream through a common point.

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Watershed management: A process of planning and implementing a course of action that involves a region's natural and human resources and taking into account social, political, economic, environment and institutional factors operating within a watershed and surrounding river basin and other relevant regions to achieve the social goal.

Culturable command area (CCA): It is the portion of the gross command area (GCA) which is culturable or cultivable.CCA= GCA–unculturable area in the GCA.

Cultivable area: Area of land potentially fit for cultivation. May or may not include part or all of the forests and permanent pastures.

Cultivated area: Area under annual and permanent crops it refers to the area actually cultivated and does not include land which is fallow.

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 objectives, without eroding the environment is called management.

1.0 Irrigation Management

Management of water based on the soil and crop environment to obtain better yield by efficient use of water without any damage to the environment. Management of water, soil, plants, irrigation structure, irrigation reservoirs, environment, social setup and it's inter liked relationship are studied in the irrigation management.

For this we have to study

- The soil physical and chemical properties
- Biology of crop plants
- Quantity of water available
- Time of application of water
- Method of application of water

- Climatological or meteorological influence on irrigation and
- Environment and its changes due to irrigation

1.2 Importance of Irrigation management

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

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

1.3 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.

✓ First century A.D. to middle of 20th century: mainly developed in southern

India. Pandya, Chera, Chola, Pallava, Chalukya and Rashtrakutadyanasty were major contributors in irrigation projects. Grand Anicut in Kaveri delta is an outstanding example for the irrigation work by a Chola king the great KarikalaCholan and the first major irrigation system in Indian sub-continent.

✓ Gupta era (300 A.D. to 500 A.D.): Dikes, embankments and canals were reported.

✓ Pallava kingdom: Tank irrigation in Tamil Nadu. The Kaveripak tank had a 6.4 km long earth dam and is still functional.

✓ Gupta era (985 A.D. to 1205 A.D.): practiced irrigated agriculture.

✓ Irrigation development in Northern and Eastern India during the 9th to 12th century A.D.:Anantarajasagar tank in Andhra Pradesh from Vijayanagar Kingdom (1336 to 1500 A.D.). FerozshahTughlag built Western Yamuna Canal in A.D. 1355.

✓ Irrigation development in 19th century A.D.: Irrigation projects like Kaveri delta system in Tamil Nadu, Godavari anicut in Andhra Pradesh. Arthur Cotton contributed immensely to irrigation of cotton in India.

✓ Upper Ganga canal in Uttar Pradesh and Odisha canal system on Mahanadi are few more to name. The Triple Canal Project now in Pakistan is the 1st large scale trans basin diversion of water from one river to another. Periyar Dam is diverts water to rain shadow Madurai district of Tamil Nadu.

1.3.1 Irrigation Development during five year plans

Table 1 Cumulative Irrigation Potential Created and Utilized for Each Five-Year Plan

(In million hectares)

Plan	Potential Created					Potential Utilized				
	Major & Medium	Minor			Total	Major & Medium	Minor			Total
		Surface Water	Ground Water	Total			Surface Water	Ground Water	Total	
Pre- Plan up to 1951	9.70	6.40	6.50	12.90	22.60	9.70	6.40	6.50	12.90	22.60
I Plan (1951-56)	12.20	6.43	7.63	14.06	26.26	10.78	6.43	7.63	14.06	25.04
II Plan (1956-61)	14.33	6.45	8.30	14.75	27.08	13.05	6.45	8.30	14.75	27.80
III Plan (1961-66)	16.57	6.48	10.52	17.00	33.57	15.17	6.48	10.52	17.00	32.17
Annual Plan (1966-69)	18.10	6.50	12.50	19.00	37.10	16.75	6.50	12.50	19.00	35.75
IV Plan (1969-74)	20.70	7.00	16.50	23.50	44.20	18.69	7.00	16.50	23.00	42.19
V Plan (1974-78)	24.72	7.50	19.80	27.30	52.02	21.16	7.50	19.80	27.30	48.46
Annual Plan (1978-80)	26.61	8.00	22.00	30.00	56.61	22.64	8.00	22.00	30.00	52.64
VI Plan (1980-85)	27.70	9.70	27.82	37.52	62.22	23.57	9.01	26.24	35.25	58.82
VII Plan (1985-90)	29.92	10.99	35.62	46.61	76.53	25.47	9.97	33.15	43.12	68.59
Annual Plan (1990-92)	30.74	11.46	38.89	50.35	81.09	26.32	10.29	36.25	46.54	72.86
VIII plan (1992-97)	32.96	12.09	50.31	53.30	86.26	28.44	7.73	39.58	48.80	77.24
IX Plan (1997-2002)	37.08	13.02	53.01	56.90	93.98	31.03	8.27	41.80	49.05	86.80
X plan (2002-07) Target	47.02			63.71	110.73					

(Source: http://117.252.14.242/rbis/india_information/irrigation%20demands.htm)

1.3.2 CLASSIFICATION OF IRRIGATION PROJECTS

The irrigation projects can be classified as-

1.3.2.1 Based on cultural command area (CCA), financial limits or expenditure:

1. Major – more than 50 million Rupees: It covers cultural command area of more than 10,000 hectares. These are essentially surface water projects.

2. Medium – 2.5 million to 50 million Rupees: It covers cultural command area of 2000 – 10,000 hectares. Surface and few lift irrigation schemes.
3. Minor – less than 2.5 million Rupees: It covers cultural command area of 2,000 hectares. It consists of a) surface water minor irrigation schemes, b) groundwater minor irrigation schemes.

1.3.2.2 The Major and Medium Irrigation (MMI) projects are further classified into two types based on irrigation method adopted.

1. Direct irrigation method:
➢ Water is directly diverted from the river into the canal by the construction of a diversion structure like weir or barrage across the stream without attempting to store water.
➢ This method is practiced where the stream has adequate perennial supply.
➢ Direct irrigation is usually practiced in deltaic tracts that is, in areas having even and plane topography.

2. Indirect or Storage Irrigation Method:
➢ In this system, water is stored in a reservoir during monsoon by construction of a dam across the river.
➢ The stored water is diverted to the fields through a network of canals during the dry period.
➢ Indirect irrigation is adopted where the river is not perennial or flow in the river is inadequate during lean period.

1.3.2.3 Based on the Way of Water Application

The Irrigation schemes are classified into two types based on way of water application.
1. Gravity/Flow Irrigation Scheme: This is the type of irrigation system in which water is stored at a higher elevation so as to enable supply to the land by gravity flow. Such irrigation schemes consists head works across river to store the water and canal network to distribute the water. The gravity irrigation scheme is further classified as:

a. Perennial Irrigation Scheme: In this scheme assured supply of water is made available to the command area throughout the crop period to meet irrigation requirement of the crops.

b. Non-Perennial Irrigation (Restricted Irrigation) Scheme: Canal supply is generally made available in non-monsoon period from the storage.

2. Lift Irrigation Scheme: Irrigation systems in which water has to be pumped to the field or canal network form lower elevations are categorised as lift irrigation schemes.

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

Table 2 Major irrigation projects of India

Name	River	State	CCA, ha	Year of completion
Bhakra Nangal Project	Sutlej	Punjab and Himachal Pradesh	0,00,000	1963
Beas Project	Beas River	Punjab, Haryana and Rajasthan	1,00,000	1974
ndira Gandhi Canal	Harike (Satlej and Beas)	Punjab	5, 28,000	1965
Koshi Project	Kosi River	Bihar and Nepal	8.48,000	1954
Hirakud Project	Mahanadi	Odisha	0,00,000	1957
Tungabhadra project	ungbhadra -Krishna	AP-Karnataka	5,74,000	1953
NagarjunaSagar Project	Krishna	AP	3,13,000	1960

Chambal Project	Chambal	Rajasthan and Madhya Pradesh	5,15,000	1960
Damodar valley project	Damodar	Jharkhand, West Bengal	8,23,700	1948
Gandak project	Gandak	Bihar-UP	6,51,700	1970
Kakrapar project	Tapti	Gujarat	1,51,180	1954
Koyna Project	Koyna- krishna	Maharashtra		1964
Malprabha project	Malprabha	Karnataka	2,18,191	1972
Mayurakshi Project	Mayurakshi	West Bengal	2,40,000	1956
Kangsabati project	Kangsabati and Kumari river	West Bengal	3,48,477	1956

Source: http://dilipkumar.in/india/rivers/dams.php

1.4 Sources of water

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

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

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

1.5 Rain fall

Seasons of rainfall can be classified as follows

1. Winter (Cold dry period) - January – February
2. Summer (Hot weather period) - March – May
3. Kharif (South-West monsoon) - June – September
4. Rabi (North-East monsoon) - October – December

1.5.1 South-west monsoon

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

1.5.2 North East monsoon

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

1.5.3 Winter

It comprises of the month of January and February. It contributes very littlerainfall.

1.5.4 Summer

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

1.5.5.1 Characteristic features of Indian rainfall

- Annual Average rainfall is 1190 mm
- There is wide variation in the quantity of rainfall received from place to place. Highly erratic, undependable, variation in seasonal rainfall either in excess or deficit is the nature of Indian rainfall. For example a place in Rajasthan receives practically nil rainfall at the same time Cherapunji about 3000 mm rainfall.
- Rainfall is not uniformly distributed throughout the year. It is seasonal,

major quantity is in the South West Monsoon, (SWM alone contributing 70% of total rainfall) i.e. in the month of June to September followed by North East Monsoon (NEM) from October to December. It summer and winter the amount of rainfall is very little.

- Within the season also the distribution is not uniform. A sudden heavy downpour followed by dry spell for a long period is common occurrence.
- Rainfall distribution over a large number of days is more effective than heavy down pour in a short period, but it is in negative trend in India
- Late starting of seasonal monsoon
- Early withdrawal of monsoon and
- Liabilities to failure are the freakish behavior of Indian rainfall.
- Timely and uniform distribution of rainfall is important for better crop planning and to sustain crop production.

1.6 India's water budget

Table 3 Water budget of India

otal geographical area	28M.ha.
verage annual rainfall	190mm
million hectare m	190 x 328 = 392 M ha m
ontribution from snowfall	M ha m
otal	00 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 orground water.

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

✓ There are on an average 130 rainy days in a year in the country out of which the rain during 75 days considered as effective rain. The remaining 55 days are very light and shallow which evaporates immediately without any contribution to surface or ground water recharge.

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

1.7 Surface run-off

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

a) Total surface run off 180 M ha m

b) Rain fall contribution 115 M ha m

c) Contribution from outside the country through streams and rivers 20 M ha m

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

e) Total 180 M ha m

1.7.1 Disposal of surface runoff

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

a) Total surface run off = 180 M ha m

b) Stored in reservoir and tanks = 15 M ha m

c) Flow in the river = 165 M ha m

d) Utilization from the river by diversion tank and direct pumping = 15 M ha m

e) Water goes to sea as waste = 150 M ha m

f) On full development work expected utilization = 45 M ha m

g) Water flows to sea = 105 M ha m

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1.8 Water resources exploitation

1.8.1 The major concern of water resources are as follow:

1. Water is a precious, finite, and in view of growing demand, ultimately scarce natural endowment.
2. The optimum availability for different purposes, drinking, food production, livestock, as well as for power generation, commercial and domestic uses are equally important.
3. The declining per capita availability and the pollution of water through human intervention are major area of concern.
4. India, which has 2.45% of the world's land resources, has only 4% of the world's fresh water resources, whereas the 16% of the world's population.
5. Most of the rainfall, around 76% of it as occurs during southwest monsoon between June-September, while rest of rainfall during occurs during northeast monsoon between October-November in the State of Tamil Nadu.
6. More than 50% of precipitation takes place in about 15 days and less than 100 hours altogether in a year.
7. India has gross irrigated area of 96.46 Mha, net irrigated area 68.38 Mha.
8. The Canal irrigated area was 8.3 million hectares and it currently (2014-15) stands at 16.18 million hectares. Canal irrigation has come down to 24% in 2014-15 from 40% in 1951.
9. On the other hand, the well and tube well accounted for 29% total irrigated area in 1950-51 and now they share 63% of the total irrigated area.
10. Irrigated area under canals and tank has been declining since 2009-10 but area under underground sources are on rise, which is a matter of concern.

Table 4 Water Resources in India Distribution of irrigated area in '000 hectares

Canal	Tanks	Wells	Other
12,776	4,123	12,034	2,601

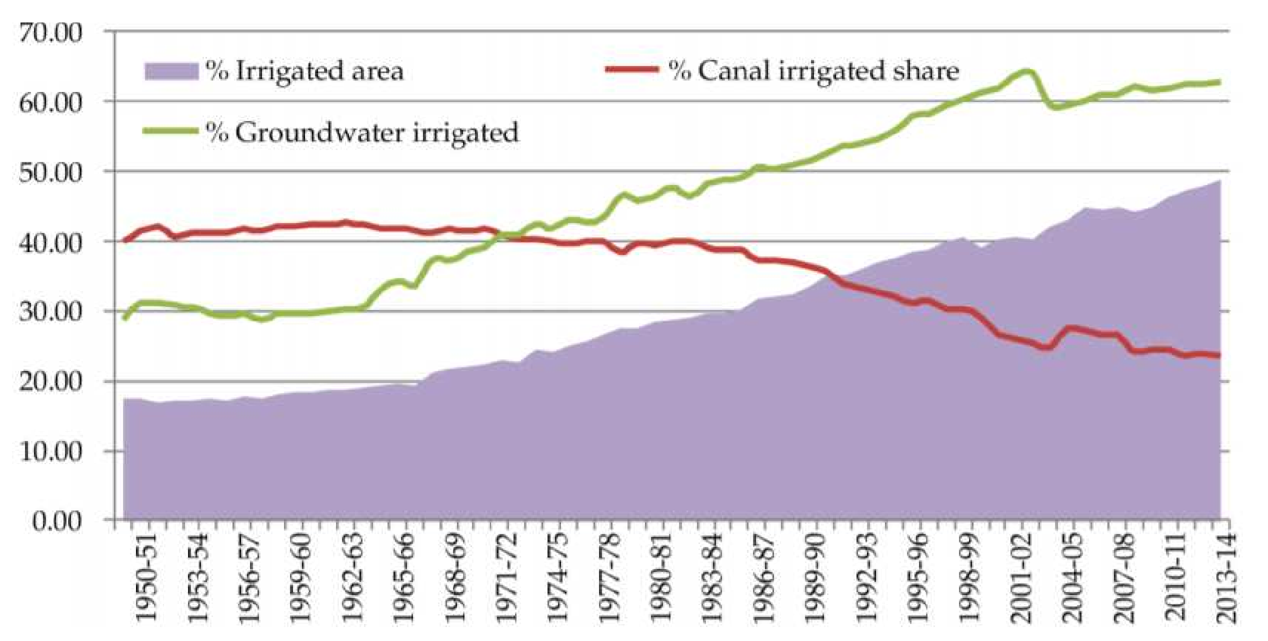

Fig. 1 Percent net irrigated to net sown area and per cent canal irrigated & per cent groundwater irrigated to net irrigated area

(*Source: based on data from DES, 2017-18*); NIA %: Net Irrigated area to net sown area, GW %: Groundwater share in net irrigated area, SW %: Surface water share in net irrigated area

1.8.2 Spatial variation among different sources of irrigation

1. Well Irrigation is common in alluvial plains of the country except the deserts of Rajasthan. Plains of UP, Bihar, Gujarat, Karnataka and Tamil Nadu are the states which are more prominently under the well irrigation.

2. Canals are second most important source of irrigation after wells and tube wells. The plains of North India are mostly canal irrigated. Other parts are coastal low lands and some parts of Peninsular India. The major states irrigated through canal are: Andhra Pradesh, Assam, Haryana, Jammu & Kashmir, West Bengal, Punjab Rajasthan, Bihar, Karnataka, Tamil Nadu and Uttar Pradesh.

3. The Tank irrigation is more in the rocky plateau area of the county, where

the rainfall is uneven and highly seasonal. The Eastern Madhya Pradesh, Chhattisgarh, Orissa, Interiors of Tamil Nadu and some parts of Andhra Pradesh have more land under tank irrigation.

4. India invested nearly 4,000 million US dollars in public canal systems during 1991-2007 (Dhawan, 2017).

5. Yet the canal-irrigated area decreased by 38 lakh hectares during that period, as infrastructure is old, water supply is unreliable, further there are no incentives.

6. This implies that "despite of heavy public expenditure on canals, our governments have not been able to reduce the groundwater depletion".

7. The key reason is widening gap between irrigation potential created and actually utilized.

8. States with the highest dependency on ground water for irrigation include Punjab (79% of the area irrigated is by tube-wells and wells), Uttar Pradesh (80%) and Uttarakhand (67%).

9. According to the CGWB, around 39% of the wells are showing a decline in groundwater level. Out of 6,584 assessment units in the country, 1,034 units (in 15 states and 2 union territories) have been categorized as "over exploited" based on the stage of groundwater withdrawal as well as long term decline in groundwater level (CGWB, 2017).

1.8.3 Exploitation of water resources

- India has only about 4 per cent of the world's renewable water resources. Home to nearly 18 per cent of the world's population.
- It receives an average annual precipitation of 4,000 billion cubic metres (BCM) which is the principle source of fresh water in the country.
- India has about 20 river basins. Due to increasing demand for domestic, industrial and agriculture uses, most river basins are water stressed.
- Increasing demand from a growing population, coupled with economic

activity, adds pressure on already stressed water resources.

- Per capita annual water availability reduced from 1816 cubic metre in 2001 to 1544 cubic metre in 2011.
- There is high variation in per capita water availability ranging from 263 cubic metre in the Sabarmati basin to 2013, 6 cubic metre in Ganga-Brahmaputra-Meghna system.
- Groundwater caters to about 85 per cent of rural demand, 50 per cent urban requirements and more than 60 per cent of our irrigation needs.
- Unregulated groundwater extraction has led to overuse in many parts of the country, causing the groundwater table to plummet, drying springs and aquifers.
- According to the CWG Report 2011, the annual groundwater draft is 245 BCM, which is account for about 62 per cent of the net water available.
- Of this, 91 per cent was used for irrigation. However, the effects on ground water in different regions of the country have not been uniform.
- Groundwater exploitation exceeds the replenishment. States like Haryana, Punjab and Rajasthan now draw more water than is annually replenished. Several places in Rajasthan and Haryana have high salt concentration in groundwater, which makes it not potable.
- India experiences both floods and droughts periodically. Nearly a third of the country's geographical area is drought-prone whereas 12 per cent of the area is prone to floods.
- The effect of global warming further intensifies temporal and spatial variations in precipitation, melting of snow and water availability.
- Water Pollution on the other hand, a CPCB report indicated that organic pollution (biological oxygen demand and coliform bacteria) continues to be predominant polluters in rivers, lakes, ponds, tanks and groundwater resources.
- Untreated waste water from urban settlements and industrial establishments are main reasons for pollution. In River Ganga, discharge of untreated waste along the entire stretch of the river, is the main cause of pollution despite the centrally funded Namami Gange project.

- National Water Policy 2012 stresses that "low consciousness about the overall scarcity and economic value of water results in the wastage and inefficient uses".
- Most of the water supplied for domestic uses and irrigation use is highly subsidised, providing little incentive for users to be efficient. Further, the water revenue recovery in India is also poor.
- Water conflict between several states and water demand for meeting domestic, industrial and agricultural needs within each state has gone up significantly.
- Agriculture sector consumes the largest amount (over 90 per cent) of India's water. Consumption of water would escalate further with pressure from industrialisation and urbanisation.
- It has been estimated that by 2050, more than half of India or an estimated 800 million people will be living in urban India. Most urban areas will have to import water from further distances unless measures are taken to improve water use efficiency, reduce leakages, adoption of appropriate water tariff, rehabilitate and recharge local water bodies considering many parts of rural and urban areas suffer from insufficient water for daily use .

Table 5 Source wise created utilized and ultimate irrigation potential

Source	**Irrigation potential (million ha)**			
	After independence	Up to 2007-12		UltimateIrrigation potential
	Created and utilized	Created	Utilized	
Major and medium (surface water)	9.7	47.97	34.95	58.5
Minor (surface water)	6.4	NA	NA	17.3
Minor (surface and ground water)	12.9	65.56	52.5	81.4

Total (major, medium, minor)	22.6	113.53	87.86	139.9

Source: CWC (2015); DES, GoI (2017)

Table 6 Net Irrigated area from various sources and their relative contribution

Source	2009-10		2014-15	
	et irrigated area (million ha)	Contribution (%)	Net irrigated area (million ha)	Contribution (%)
Canal	16.967	26.40	16.18	23.66
Tank	1.638	2.59	1.72	2.52
Wells	39.042	61.72	42.96	62.82
Others	5.880	9.30	7.52	11.00
Total	63.257	100	68.38	100

Source: DES, MoA&FW, GoI (2018)

References and Suggested Readings:

1. https://krishi.icar.gov.in/jspui/bitstream/123456789/34362/1/irrigation_rajni_preprint.pdf

2. Directorate of Economics and Statistics, Government of India 2018. Latest updates on Land use data- [https://eands.dacnet.nic.in/LUS_1999_2004.htm.2018]

Course Name	**Water Management including Micro Irrigation**
Lesson 2	**Soil Water Relations; Introduction To Basic Terms In Water Management**
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Objective:

To learn about how water is held and movement in soil-plant system

To study about moisture constants and hydrodynamic relations

Terminology:

Available water: Soil moisture between field capacity and permanent wiltingpoint is referred to as readily available moisture.
Gravitational water: It is the excess water above field capacity in a soil moving down under the influence of gravity.
Hydraulic conductivity: Hydraulic conductivity is the proportionality factor k in Darcy's law (V=ki, in which v is the effective flow velocity and ki is the hydraulic gradient). It is, therefore, the effective flow velocity at unit hydraulic gradient and has the dimensions of velocity (LT-1).
Hydraulic equilibrium of water in soil: It is the condition for zero flow rate of liquid or film water in the soil. This condition is satisfied when the pressure gradient force is just equal and opposite of the gravity force.
Hydraulic gradient: Hydraulic gradient is the rate of change of piezometric or hydraulic head with distance.
Hydraulic head: Hydraulic head is the elevation with respect to a standard datum at which water stands in a riser pipe or manometer connected to the point in question in the soil. This will include elevation head, pressure head, and also the velocity head.
Hysteresis: it is the lag in one of the two associated processes or phenomenon during reversion in soil moisture absorption and desorption process i.e. difference in moisture content at a given suction.
Infiltration capacity or soil infiltrability: It is the flux which the soil profile can absorb through its surface where it is maintained in contact with water at atmospheric pressure and there is no divergent flow at the borders.

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Infiltration rate: The rate of water entry into soil expressed as a depth of water per unit time and expressed in inches per hour or feet per hour. Infiltration rate changes with time during irrigation.

Infiltration: The process of water entry into the soil generally through the soil surface and vertically downward.

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

Irrigation: Artificial application of water to soil to help crop growth and production especially can be during stress periods.

Percolation: It is the downward movement of water through saturated or nearly saturated soil in response to the force of gravity. Percolation occurs when water is under pressure or when the tension is smaller than ½ atmospheres.

Permeability: (1) Qualitative. It is the characteristic of a pervious medium relating to the readiness with which it transmits fluids. (2) Quantitative. The specific property governing the rate or readiness with which a porous medium transmits fluids under standard conditions.

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

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

2.0 SOIL WATER RELATIONS

The physical properties of the soil and water, which influence the movement, retention and use of water by the plants that must be considered to plan for an efficient irrigation system. This system also called SPAC for soil plant atmosphere continuum.

2.1 Kinds of soil water

2.1.1 Hygroscopic water: When water is held tightly as thin film around soil particles by adsorption forces and no longer moves in capillary pores it is called hygroscopic water (held by a force of -1000 bars).

- Forms very thin films around soil particles hence not available to the plant.
- Held on the particle surface.
- Held very tightly, by forces of adhesion resulted into not available to the plant

2.1.2 Capillary water: Water retained by soil in capillary pores against gravity, by forces of surface tension as continuum film around soil particles is called capillary water (held by a force of -1/3 to - 31 bars).

- Found in the micro pores only.
- Most of this water is available for plant growth.
- Held in the soil against the force of gravity (cohesion and adhesion)
- Amount of water held is a function of the pore size and pore space.

2.1.3 Gravitational water: Water in macro pores that moves freely under the influence of gravity beyond the root zone (held by a force of < - 1/3 bars).

- It moves through the soil due to the force of gravity.
- Found in the macro pores only.
- Not considered to be available to plants.
- Drains out of the soil in 2-3 days

2.2 SOIL MOISTURE CONSTANTS

Water contents under certain standard conditions are referred to as soil moisture constants. Under field conditions water content of the soil changing constantly with time and depth of soil due to pressure gradient and vapour pressure differences.

2.2.1 Saturation capacity or maximum water holding capacity: When the all pores (macro and micro) are filled with water, the soil it said to be at its maximum water holding capacity or saturation capacity. The soil moisture tension at MWHC is zero and almost equal to free water surface.

2.2.2 Field capacity: When supply of water is stopped, water continues to drain from large pores for a day or two and becomes negligible thereafter. The macro pores are again filled with air and micro pores are filled with water and it moves because of capillary force. This water called capillary water. Soil moisture tension which is varies from soil to soil, generally ranges from 1/10 to 1/3 atm. FC is called upper limit of water availability to plants.

2.2.3 Moisture equivalent: It is amount of water is retained by initially saturated soil after being subjected to a centrifugal force of 1000 times that of gravity for an hour is called moisture equivalent. Values of FC and moisture equivalent are nearly equal in medium textured soils. In sandy soils, FC exceeds ME. In clayey soil FC is lower than ME.

2.2.4 Permanent wilting point: The concept of permanent wilting point (PWP) was proposed by **Briggs and Shantz** in 1912. Permanent wilting point is also called wilting coefficient is the moisture content of the soil at which plants can no longer enough moisture to meet the transpiration requirements and remain wilted unless water is added to the soil. At this point, the plant wilts during daytime to conserve moisture and become normal at night. The plants are not dead but remain in wilted condition. Soil moisture tension at PWP ranges from 7 to 32 atm. depends on soil texture, soluble salts, environment and kind of plant. Therefore, the commonly used average value is 15 atm. for PWP.

Table 1 Available soil water at various soil texture at FC and PWP

Soil	**FC %**	**PWP%**	**ASM%**
Clay	40	20	20
Clay loam	30	15	15
Silt loam	22	12	10
Sandy loam	14	6	8
Loamy sand	10	4	6

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Sand	6	2	4

Source; Reddy, (1999)

2.2.5 Available water: The soil moisture held between field capacity to permanent wilting point is called available water. The fine texture soil have a wide range of water content at FC to PWP than coarse texture soils.

2.2.6 Hygroscopic coefficient at soil water potential of -30 bars water is held so tightly that much of it can move only in vapour phase. Moisture content of soil at this point termed as hygroscopic coefficient

2.2.7 Ultimate wilting point at -60 bars plants cannot absorb the moisture and die eventually. Soil moisture content at which plants die is called ultimate wilting point.

Table 2 Soil moisture tension and PF value of Soil at various soil moisture constants

Soil moisture constants	Soil moisture tension (bars)	PF value
MWHC	0	_
FC	-1/10 to 1/13	2.53
PWP	-15	4.10
HC	-30	4.50
UWP	-60	_

Source; Reddy sr (1992), Sunda NR and Kaswan SL (2018)

2.3 SOIL MOISTURE POTENTIAL

- Soil moisture tension or soil moisture potential is a measure of the tenacity with which water is retained in the soil and shows the force per unit area that must be exerted to remove water from a soil.

- It measures the potential energy of water in the soil with respect to free water. It is usually expressed in atmospheres, the average air pressure at sea level.
- The term soil moisture potential, soil moisture suction and soil moisture tension are often used synonymously.
- 1 atmosphere = 1036 cm of water or 76.39 cm of mercury.
- 1 bar = 10^{-6} dynes / cm2 = 1023 cm of water column.

pF Value: The term pF value given by Schofield (1935). It is the logarithm of centimetre height of a water column to give the necessary suction. Expressed in centimetre of water (based on the height of a water column above free water level in cm).

$$pF = \log_{10}{}^{h}$$

h = soil moisture tension in cm of water

2.3.1 Total soil water potential

Total soil water potential is defined as the amount of work per unit quantity of pure water that must be done by external forces to transfer reversibly and isothermally an infinitesimal amount of water from the standard state to the soil at the point under consideration. It expressed as given below:

$$\psi_{soil} = \psi_g + \psi_m + \psi_p + \psi_o$$

Where,

ψ_g= gravitational potential

ψ_m = metric potential

ψ_p = pressure potential

ψ_o = osmotic potential

2.3.1.1 Gravitational potential: It is amount of work that a unit quantity of water in an equilibrium soil water or plant water system is a capable of doing when it moves to another equilibrium system identical in all aspects that it is reference level. It results from elevation with respect to reference level.

2.3.1.2 Metric potential/ Capillary potential: It is amount of work that a unit quantity of water in an equilibrium soil water or plant water system is a capable of doing when it moves to another equilibrium system identical in all aspects except that there is no matrix present. It results from interaction of soil particle surfaces with water. Unsaturated soil has only metric potential. In saturated soil metric potential is zero

2.3.1.3 Pressure potential: It is amount of work that a unit quantity of water in an equilibrium soil water or plant water system is a capable of doing when it moves to another equilibrium system identical in all aspects except that it is at reference pressure. In unsaturated soil pressure potential is zero.

2.3.1.4 Osmotic potential / solute potential: It is amount of work that a unit quantity of water in an equilibrium soil water or plant water system is a capable of doing when it moves to another equilibrium system identical in all aspects except that there are no solutions. It results from solutes dissolved in soil water.

Soil water potential usually measured with tensiometer, pressure plate apparatus and thermocouple psychrometer

2.4 SOIL MOISTURE CHARACTERISTICS

Moisture extraction curves, also called moisture characteristic curves, describes the relationship between soil-water pressure potential and volumetric water content, show the amount of moisture a given soil holds at various tensions. A moisture characteristic curve is affected by soil texture, structure and other characteristics of soil. The shape of clay soil curve is almost straight line with bends at ends while it is L shaped in case of sandy soils.

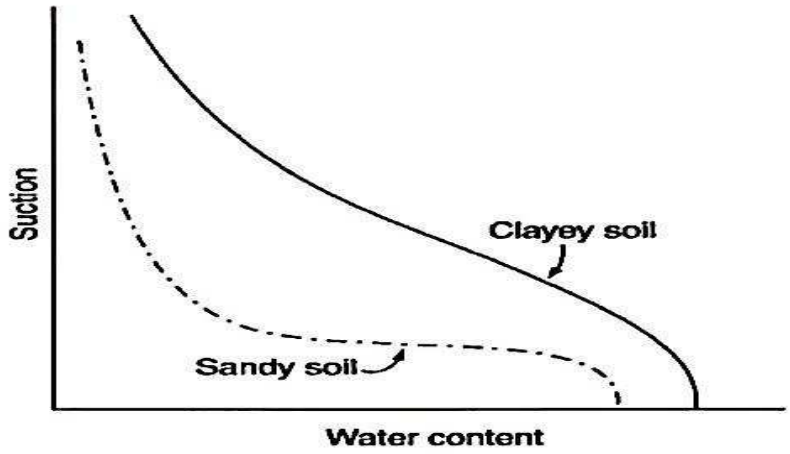

Fig. 1 Effect of soil texture on soil water retention

2.4.1 Hysteresis: It is the lag in one of the two associated processes or phenomenon during reversion in soil moisture sorption (wetting) and desorption (drying) process i.e. difference in moisture content at a given suction. Hysteresis effect may be due to geometric non uniformity of individual pores, entrapped air or swelling and shrinkage of the soil.

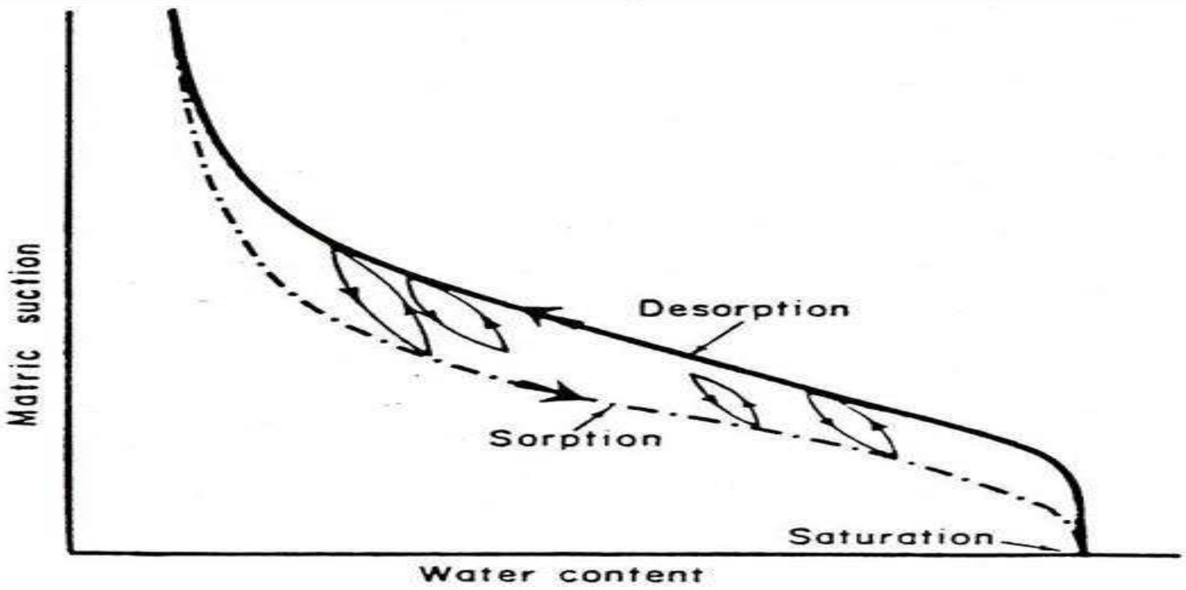

Fig. 2 Difference in moisture content at a given suction

2.5 HYDRODYNAMICS

Hydrodynamics is the study of movement of water in soil. It is useful to know how much applied/naturally received water can readily reach the desired zone of soil and how much time it is retained there.

Hydrodynamics terms

- The process of water entry into soil through the soil profile and vertically downward is termed **Infiltration.**
- **Percolation:** is the downward movement of water through saturated or nearly saturated soil in response to the force of gravity. Percolation occurs when water is under pressure or when the tension is smaller than ½ atmosphere
- **Interflow**: Interflow is the lateral seepage of water in a relatively pervious soil above a less pervious layer. Such water usually reappears on the surface of the soil at a lower elevation.
- **Seepage:** Seepage is the infiltration (vertically) downward and lateral movements of water into soil or substrata from a source of supply such as a reservoir or irrigation canal

4.6 INFILTRATION

- The process of water entry into soil through the soil profile and vertically downward is termed Infiltration. Rate of water entry into soil expressed as a depth of water per unit time and expressed in inches per hour or feet per hour.
- An infiltration rate change with time during irrigation is called infiltration rate or soil intake rate.
- The actual rate at which water enters the soil at any given time is called infiltration velocity.
- The nearly constant rate that reaches after some elapsed time from start of irrigation is termed as basic infiltration rate or steady state of infiltrability.
- The cumulative infiltration is the total amount of water enters the soil in a given time.

4.6.1 Measurement of infiltration

1. Use of cylinder infiltrometers (commonly used method)
2. Subsidence of free water in large basin
3. Estimation of cumulative infiltration from water front advance data

4.6.2 Factors influencing the infiltration rate

1) Conditions and characteristics of soil

2) Hydraulic conductivity
3) Tillage and crop management practices
4) Vegetative cover
5) Organic matter content in soil
6) Depth of water passing over the soil
7) Duration of irrigation and intensity of rainfall.
8) Viscosity of water

4.7 WATER INTAKE-TIME RELATIONS

Relationship between water intake and time elapsed is important in the design of sprinkler and surface methods of irrigation.

The intake rate is very high at start of irrigation or rainfall and soon declines rapidly. After some elapsed time from the start of irrigation, the intake rate approaches a constant rate.

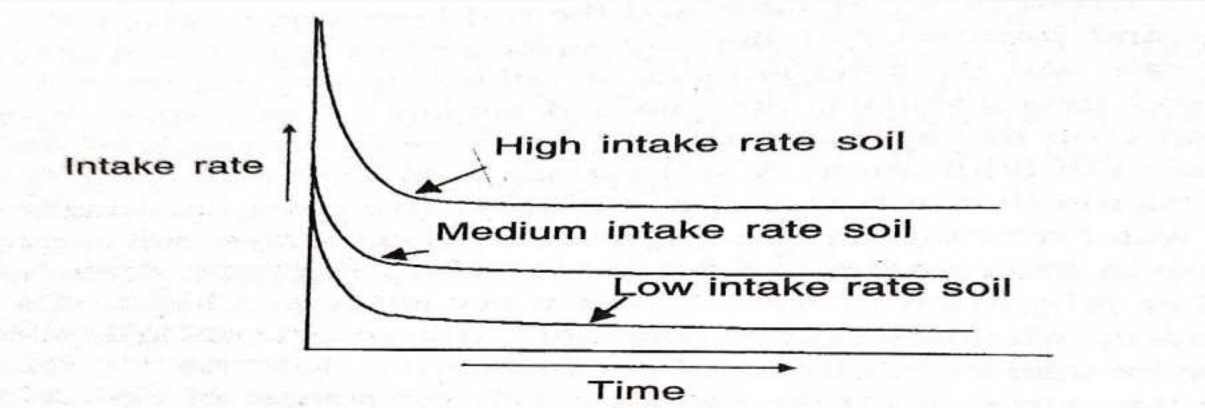

Fig.3 Water Intake-Time Relations

Three textured different soils are same nearly nature of intake-time curves but they differ in their relative positions.

4.8 SOIL WATER MOVEMENT

4.8.1 Movement of water under saturated conditions

In saturated soils water movement occurs through macro pores. Under saturated condition when all soil pores are completely filled with water, the movement called saturated flow. Major force in driving water in saturated soil is gravity and naturally major direction is downward. Water in saturated soils is not under any tension and the flow follows either Poiseuille's or Darcy's law

4.8.1.1 Poiseuille's stated that the flow is direction proportional to fourth power of radius of pore. The Poiseuille's explain the water flow in a narrow tube. Generally, rate of flow in soils of various textures is in following sequences:

Sand >Loam >Clay

Expressed as

$$\mathbf{QA = \pi r4 \Delta P / 8 \mu L}$$

Where,

Q= volume of flow passing through a unit area per unit time, cm^3/s

r= radius of tube, cm

ΔP= Pressure difference between two ends of the tube, $dynes/cm^2$

L= length of the tube, cm

μ= viscosity of liquid, $dynes/cm^2$

4.8.1.2 Darcy's law state that velocity of water flow is directly proportional to the difference of hydraulic heads and inversely proportional to the flow length.

$$\mathbf{Q = AV = KA\Delta H/L}$$

Q = volume of water flow per unit time, cm^3/s.

A = cross-sectional area of flow, cm^2

K= hydraulic conductivity, cm/s

V = velocity of flow, cm/s

ΔH= difference of hydraulic heads between two points, cm

L = flow length, cm

Darcy's law is the most fundamental equation describing water flow in saturated porous media only.

4.8.1.3 Hydraulic conductivity: Hydraulic conductivity is the proportionality factor k in Darcy's law (V=ki, in which v is the effective flow velocity and ki is the hydraulic gradient). It is, therefore, the effective flow velocity at unit hydraulic gradient and has the dimensions of velocity (LT-1). The values of k depend on the properties of the fluid with the porous medium, such as swelling of a soil. A soil that has high porosity and coarse open texture has a high hydraulic conductivity value.

4.8.1.4 Moisture movement under unsaturated conditions

Unsaturated movement is in micro pores. The major force driving is metric potential. Unsaturated flow is more important from crop production point of view. The range of unsaturated flow in soils of various textures is in the following order:

Sand < loam < clay

4.8.1.5 Water vapour movement

When soil becomes dry, water form micro pores is also emptied and water mainly present in form of water vapour. Water vapour moves from moves from one zone to another due to vapour pressure gradient. Temperature is also influence the water vapour movement. Water vapours move from higher temperature region to cooler region.

Table 4 Water movement in soil

Particulars	Saturated flow	Unsaturated flow	Vapour movement
Major force	Gravitational	Metric	Vapour pressure
Water form	Liquid	Liquid	Vapour
Major direction of flow	Downward	Lateral	All directions
Pore space	All pore filled with water	Micro pores filled with water	All the pores are empty
Rate of flow (cm/day)	Fast (1-100)	Slow (0.01-0.00001)	_
Quantity of water (kg in 15cm depth of soil)	Large quantities (375000)	Small (100000)	Negligible (15)

Source; Reddy, (1999)

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Water Management including Micro Irrigation

Lesson 3

Measurement Of Soil Moisture-Different Direct And Indirect Methods

Content

DESIGNED AND DEVELOPED UNDER THE AEGIS OF
NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications
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Course Name	**Water Management including Micro Irrigation**
Lesson 3	**Measurement Of Soil Moisture-Different Direct And Indirect Methods**
Content Creator	**Dr. Hardev Ram**
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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
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Objective: To learn about various direct and indirect methods of soil moisture estimation

Terminology:

Bar: A unit commonly used in irrigation scheduling to express soil-water tension.

Matric potential: It is the portion of water potential that is attributable to the more or less solid colloidal matrix of the soil or the plant system. It is the amount of that a unit quantity of water in an equilibrium soil-water (or plant-water) system is capable of doing when it moves to another equilibrium system identical in all respect except that it is no matrix present.

Moisture release curve/ soil moisture characteristics curve: It is the functional relationship between soil moisture tension and soil moisture content at a range from FC to PWP.

Moisture tension: The equivalent negative pressure to which water must be subjected in order to be in hydraulic equilibrium through a porous permeable membrane or wall, with water in soil. Gives the relationship between amounts of water remaining in the soil at equilibrium as a function of matric suction.

Osmotic potential: The amount of work that must be done per unit quantity of water in order to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water at a specific elevation and atmospheric pressure to another equilibrium solution identical in all respect that it has solutes.

Osmotic Pressure: the pressure developed due to unequal concentrations of salts separated by semi permeable membrane or plant cell wall. Water will from low salt concentration to high salt concentration. The pressure exerted by water is called osmotic pressure.

Pressure plate apparatus: Instrument that measures water held by soil at FC (1/3rd atm) to PWP (15 atm). It gives us the water retention capacity of the soil.

Pressure potential: it is the portion of water potential that results from an overall pressure, which is different from reference pressure. It is the amount of that a unit quantity of water in an equilibrium soil-water (or plant-water) system is capable of doing when it moves to another equilibrium system identical in all respect except that it is at a reference pressure.

Saturation: Condition in which all soil pores are filled with water. At saturation, soil-water tension is zero.

Tensiometer: a device for measuring the negative pressure or tension of water in soil in situ, consisting a porous permeable ceramic cup connected through a tube to a manometer or vacuum gauge. It is used in scheduling irrigation.

Tension, Suction: A measure of the adsorptive forces by which soil retains water. Tension is a measure of negative pressure (suction) relative to the prevailing atmospheric pressure of zero.

Soil moisture measurements are important in scheduling of irrigation and to estimate the amount of water applying each irrigation. Soil moisture is estimated by both direct and indirect method. Direct methods involve the determination of moisture in the soil while indirect methods estimate amount of water through the properties of water the soil (stress or tension).

3.1 Direct method (Thermo-gravimetric method)

3.1.1 Oven drying method

Soil sample is collected in a moisture can and wet weight of the sample is recorded. The soil sample is dried in hot air oven at 105°C until constant weight is obtained and dry weight of the sample is recorded.

Moisture content (on weight basis) = Wet weight-Dry weight X 100
Dry weight

Volumetric moisture content = Wet weight-Dry weight X 100 X Bulk density
Dry weight

Moisture content (on depth basis) = Wet weight-Dry weight X 100 X Bulk density X Soil depth
Dry weight

Advantages

- Standard method mainly used in experiment work
- Simple
- Calibration not required
- Inexpensive

Limitations

- Tedious and time consuming
- In heterogeneous soil profile, representative moisture content is difficult
- Destructive method at site
- Difficult to determine moisture in case of rocky surface or at a specific depth

3.1.2 Volumetric method

Soil sample is taken with a core sample or with a tube auger whose volume is known. The amount of water present in the soil sample is estimated by drying in the oven. The volumetric moisture content can also be estimated from the moisture content estimated on dry weight basis.

3.1.2.1 Alcohol burning method

1 ml alcohol per gram of soil at FC and 0.5 ml at PWP is used to evaporate soil moisture. Sample should be small. Not recommended for soils with high organic matter.

3.1.2.2 Hot air drying

Hot air at 110°C is passed on a screen with weighed moist soil samples. Soil moisture evaporates. It is quite expensive.

3.1.2.3 Gypsum sorption plugs

Gypsum plugs comes into equilibrium with surrounding soil moisture. Then these are removed and weighed. It is necessary to calibrate the plugs with moisture content of various soils.

3.1.2.4 Infrared Balance

A 250 watt infrared lamp, torsion balance and auto transformer, all housed in an aluminum cabinet. Soil moisture is evaporated with infrared radiation in 5 minutes. The instrument is directly calibrated in percent moisture.

3.1.2.5 Feel and appearance method

Though not a method of soil moisture measurement, it is often discussed under direct method.

3.2 Indirect methods

3.2.1 Tensiometer

Tensiometer measures soil water suction (negative pressure), which is usually expressed as tension. It measures the metric or capillary potential and also used to estimate the soil moisture content. This suction is equivalent to the force or energy that a plant must exert to extract water from the soil.

How it works? Tensiometer is a sealed, airtight, water-filled tube (barrel) with a porous tip on one end and a vacuum gauge on the other, as shown in Figure 1. The instrument must be installed properly so that the porous tip is in good contact with the soil, ensuring that the soil-water suction is in equilibrium with the water suction in the tip. The suction force in the porous tip is transmitted through the water column inside the tube and displayed as a tension reading on the vacuum gauge. Soil-water tension is commonly expressed in units of bars or centi bars. One bar is equal to 100centibars (cb).

Principle: The suction at the tip is transmitted to the vacuum gauge because of the cohesive forces between adjacent water molecules. As the suction approaches approximately 0.8 bar (80 cb), the cohesive forces are exceeded by the suction and the water molecules separate. When this occurs, air can enter the tube through the porous tip and the tensiometer no longer functions correctly. This condition is referred to as breaking tension.

Range: 0 to 0.8 bar. The suction scale on the vacuum gauge of most commercial tensiometer reads from 0 to 100 bar.

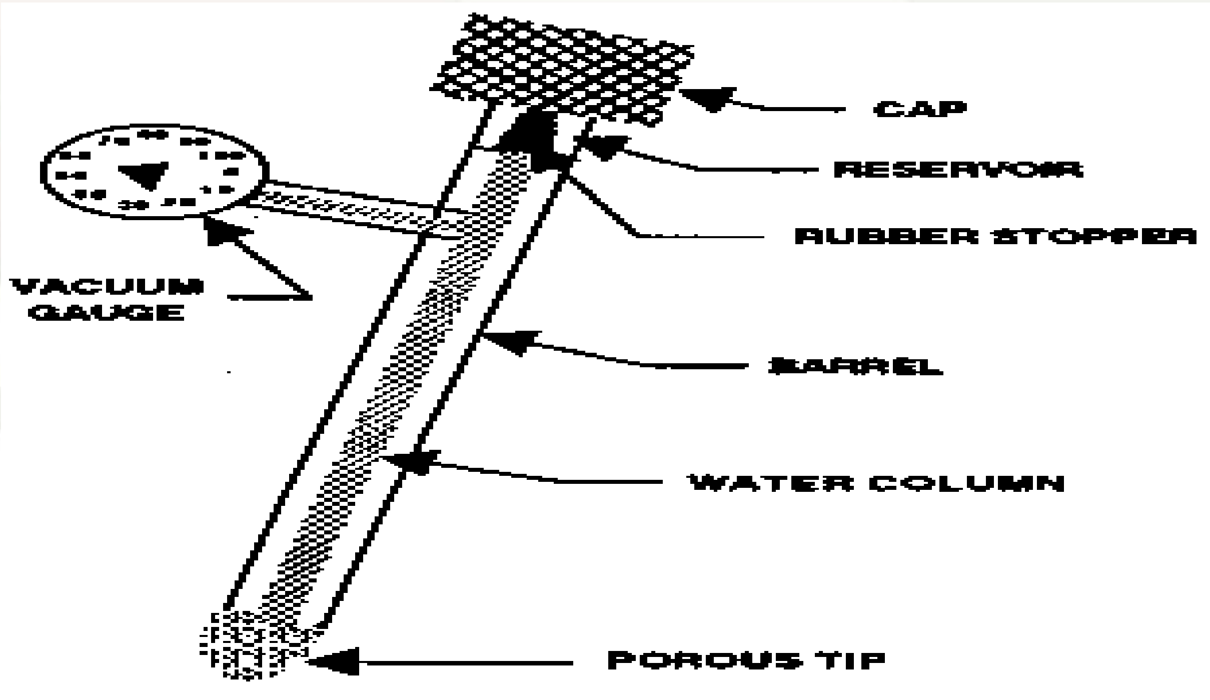

Fig 1 Tensiometer (Source: https://content.ces.ncsu.edu/media/images/ag4522-1.gif)

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Applicability:

- Tensiometer is best suited for use in soils that release most of their plant-available water at soil-water suctions between 0 and 80 cb.
- Soil textures in this category are those that consist of sand, loamy sand, sandy loam, and the coarser-textured range of loam and sandy clay loam.
- Tensiometer is not recommended for clayey and silty soils unless irrigation is to be scheduled before 50 percent depletion of the plant-available water, which is the normal practice for some vegetable crops.

Advantages

- Direct measure the metric or capillary
- Best suited for sandy soil
- Less maintenance
- Inexpensive
- Not affected by soil salinity (salts move freely across porous cap).

Limitations

- Suction <1 bar
- Slow response time
- Proper contact of porous cap with soil is required
- Requires frequent refilling in hot dry weather

3.2.2 Gypsum block or Electrical resistance blocks

Electrical resistance blocks consist of two electrodes enclosed in a block of porous material, as shown in Figure 2. The block is often made of gypsum, although fiberglass or nylon is sometimes used. Electrical resistance blocks are often referred to as gypsum blocks and sometimes just moisture blocks. The electrodes are connected to insulated lead wires that extend upward to the soil surface.

Principle: Resistance blocks work on the principle that water conducts electricity. The water suction of the porous block is in equilibrium with the soil-water suction of the surrounding soil. As the soil moisture changes, the water content of the porous block also changes. The electrical resistance between the two electrodes increases as the water content of the porous block decreases. The block's resistance can be related to the water content of the soil by a calibration curve. To make a soil water reading, the lead wires are connected to a resistance meter containing a voltage source. The meter normally reads from 0 to 100 or 0 to 200. High readings on the scale indicate high levels of soil-water, whereas low meter readings indicate low levels. Because of the pore size of the material used in most electrical resistance blocks, particularly those made of gypsum, the water content and thus the electrical resistance of the block does not change dramatically at suctions less than 0.5 bar (50 cb).

Working range: 400-600 ohms at FC and 50,000-75,000 ohms at PWP.

Fig 2 Gypsum block

(Source: https://crops.extension.iastate.edu/files/resize/article/watermark-400x339.jpg)

Applicability

- Resistance blocks are best suited for use in fine textured soils such as silts and clays that retain at least 50 percent of their plant available water at suctions greater than 0.5 bar.
- Electrical resistance blocks are not reliable for determining when to irrigate sandy soils where over 50 percent of the plant-available water is usually depleted at suctions less than 0.5 bar.

Advantages

- Easy installation
- No maintenance
- Simple and inexpensive
- Quick response time
- Suitable for fine textured soils (ASM between 1-15 atm)
- Can be used for deficit irrigation

Limitations

- Cannot measure moisture at near saturation (0-0.3 atm)
- Block properties may change with time sue to gypsum dissolution and soil deposition
- Does not work for sandy soil
- Not suitable for shrinking, swelling and salt affected soils

3.2.3 Neutron moisture meter

This meter scans the soil about 15cm diameters around the neutron probe in wet soil and 50 cm in dry soil. It consists of a probe and a scalar or rate meter. This contains a fast neutron source which may be a mixture of radium and beryllium or americium and beryllium; and boron tri fluoride or lithium tri fluoride as detector. Access tubes are aluminum tubes of 50-100 cm length and are placed in the field when the moisture has to be estimated. Neutron probe is lowered in to access tube to a desired depth.

Principle: Fast neutrons are released from the probe which scatters in to soil. When the neutrons encounter nuclei of hydrogen atoms of water, their speed is reduced. The scalar or the rate meter counts of slow neutrons which are directly proportional to water molecule. Moisture content of the soil can be known from the calibration curve with count of slow neutrons. If soil is dry, the cloud of neutrons will be less dense and extend further from the probe. If soil is wet, the neutron cloud will be denser and extend a shorter distance.

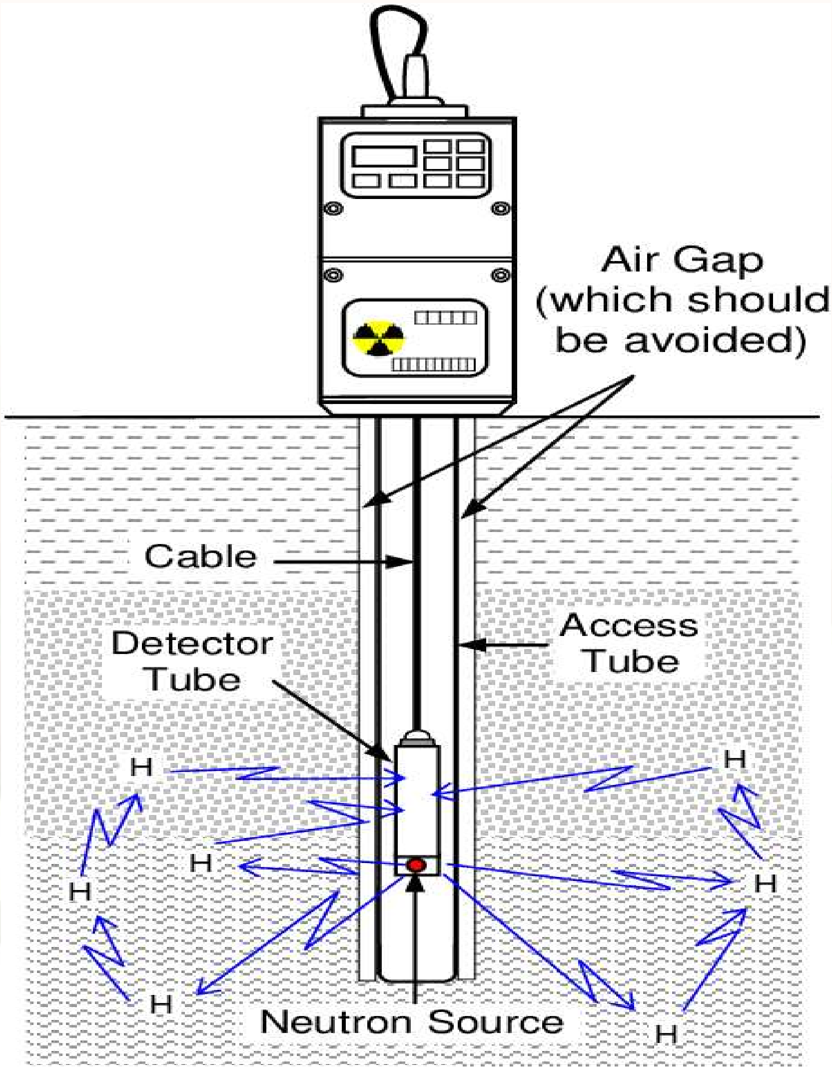

Fig.4 Neutron moisture meter (Source:https://d3i71xaburhd42.cloudfront.net/96b4be39dafc8fce33980b60c6244629e59f7bd5/250px/19-Figure1-1.png)

Advantages

- Robust and accurate to measure water balance
- A large number of measurements can be made at different points with the same instrument (inexpensive per location)

- Different depths can be made with single probe
- Large soil sensing volume (10.2 to 40.6 cm radius)
- Not affected by salinity or air gaps

Limitations

- Safety hazard
- Needs soil specific calibration
- Expensive instrument
- Long response time
- Readings close to soil surface is not accurate and difficult

3.2.4 Pressure membrane and pressure plate apparatus

Pressure membrane and pressure plate apparatus is generally used to estimate field capacity, permanent wilting point and moisture content at different pressure in laboratory. The apparatus consists of an air tight metallic chamber in which porous ceramic pressure plate is placed. The pressure plate and soil samples and saturated and are placed in the metallic chamber.

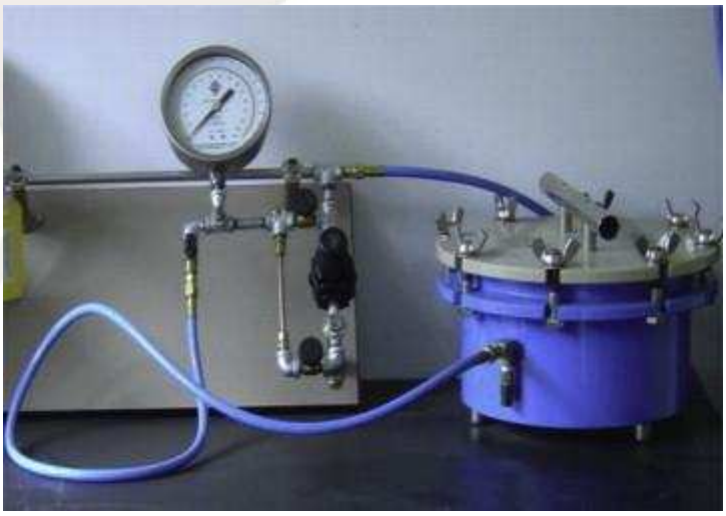

Fig 5 Pressure plate apparatus
(Source: https://ars.els-cdn.com/content/image/1-s2.0-S1674775515000153-gr3.jpg)
The required pressure of 0.33 or 15 bar is applied through a compressor. The water from the outlet till equilibrium against applied pressure is

achieved. After that, the soil samples are taken out and oven- dried for determining the moisture content.

3.2.5 Phene Cell

Principle: The Phene cell works on the principle that a soil conducts heat in relation to its water content. By measuring the heat conducted from a heat source and calibrating the conductance versus water content for a specific soil, the Phene cell can be used reliably to determine soil-water content.

Because the Phene cellis placed at the desired soil depth, a separate cell is needed for each depth at each location to be monitored. For irrigating small acreages, the total cost of using the Phene cell is less than that of the neutron probe. For large acreages, the neutron probe may be more cost effective.

3.2.5 Time Domain Reflectometer

The time domain reflectometer (TDR) is a new device developed to measure soil-water content. Two parallel rods or stiff wires are inserted into the soil to the depth at which the average water content is desired. The rods are connected to an instrument that sends an electromagnetic pulse (or wave) of energy along the rods.

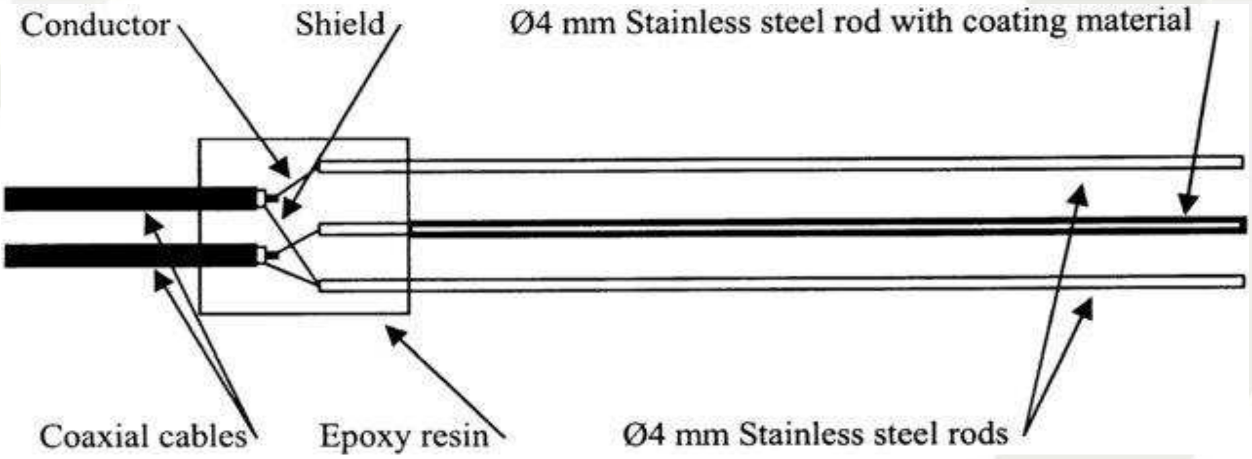

Fig 6 Schematic design of the time-domain reflectometer (TDR) coated-uncoated probe (CUP).

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(Source:https://www.researchgate.net/profile/Magnus_Persson4/publication/242363082/figure/fig1/AS:650152721272832@1532019896502/Schematic-design-of-the-time-domain-reflectometry-TDR-coated-uncoated-probe-CUP-The_W640.jpg)

Principle: The rate at which the wave of energy is conducted in to the soil and reflected back to the soil surface is directly related to the average water content of the soil.

$t = 2L/v$

Where;
t = time between reflections (s)
v = pulse velocity (m/s)
L = length of probe needles (m)
$V = c/K^{-1/2}$;
Where;
c = velocity of light in space (m/s)
$K = (ct/2L)^2$

One instrument can be used for hundreds of pairs of rods. This device, just becoming commercially available, is easy to use and reliable.

Advantages

- High accuracy
- Soil specific calibration is not required
- Variety of probe configuration
- Minimum soil disturbance
- Not sensitive to low salinity
- Can provide simultaneous measurement of soil conductivity

Limitations

- Expensive
- Limited application under high salinity and heavy clay soils
- Calibration required for soils with high organic matter content and

volcanic soils

Suggested reading and references

Majumdar, D.K. 2013. Irrigation Water Management Principles and Practices, PHI learning Private Limited. New Delhi.

Michael, A. M. 1978.Irrigation theory and practice, Vishal Publishing House Private Limited. New Delhi.

Reddy, S. R. 1999. Principles of agronomy. Kalyani publications, Ludhiana, New Delhi.

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Course Name	Water Management including Micro Irrigation
Lesson 4	Expressions Of Soil Moisture And Their Mutual Relations
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University	NDRI - National Dairy Research Institute
Course Reviewer	Prof. Ummed Singh
University	Agriculture University Jodhpur, Jodhpur

Objective:

To understanding the soil-moisture relationship for the design of efficient irrigation system.

Terminology:

Available water: Soil moisture between field capacity and permanent wilting point is referred to as available water.
Bulk Density: The mass (weight) of unit soil divided by the total volume occupied. An ideal soil has a bulk density of about 1.25 g cm^{-3}. Bulk density is the total soil porosity. Compacted soils have a bulk density of 1.5 g cm^{-3} or higher.
Capillary water: Water in micro-pores space that moves very slowly up, down, or sideways under the influence of capillary forces.
Field Capacity: It refers to the relatively constant soil water content reached after 48 hours drainage of water from a saturated soil.
Gravitational water: It is the excess water above field capacity in a soil moving down under the influence of gravity.
Macro-pores: Large spaces (>0.06mm) between soil particles or spaces within the soil structure those are large enough to allow water to move under the influence of gravity.
Micro-pores: Small spaces (<0.06mm) around and between soil particles that hold the water by surface tension and capillary action against the force of gravity.
Permanent wilting point: It refers to the water content of a soil that has been exhausted of its available water by a crop, such that only non-available water remains. The crop then becomes permanently wilted and cannot be revived when placed in a water-saturated atmosphere. At this point the soil feels nearly dry or only very slightly moist.

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Porosity: The volume of voids divided by the total volume of soil. In an ideal soil, the total pore space should be about 50% (composed of air and water) while the solid phases (sand, silt, clay, and organic matter) make up the other 50% of soil volume.

Saturation: It refers to a soil's water content when practically all pore spaces are filled with water. This is a temporary state for well-drained soils, as the excess water quickly drains out of the larger pores under the influence of gravity, to be replaced by air.

Soil Structure: Combination or arrangement of primary soil particles into secondary particles, or groups of aggregates. Soils with good structural stability typically have more macro-aggregates and macro-pores while soils with poor structural stability have more micro-aggregates and micro-pores. Compacted soils have poor structure and more micro-aggregates and micro-pores.

Soil Texture: Relative portion of sand, silt, and clay in a given amount of soil. A soil is described as coarse, medium and fine texture depends on the predominant particle size.

The physical properties of the soil and water, which influence the movement, retention and use of water by the plants that must be considered to plan for an efficient irrigation system. Irrigation or rain water after infiltration into soil, stored in macro and micro-pores of the soil constitutes soil water. Therefore, an understanding of the relationship between soil-water is a prerequisite for the most profitable use of water for crop production.

4.0 Soil

- Soil is a three phase system consists of solid, liquid and gaseous phases.
- The solid phase comprises minerals, organic matter and various chemical compounds.
- The liquid phase contains all the dissolved substances i.e. soil moisture or soil water or soil solution.
- The gaseous phase consists of soil air and it occupies those spaces between the soils particles which are not filled with water.

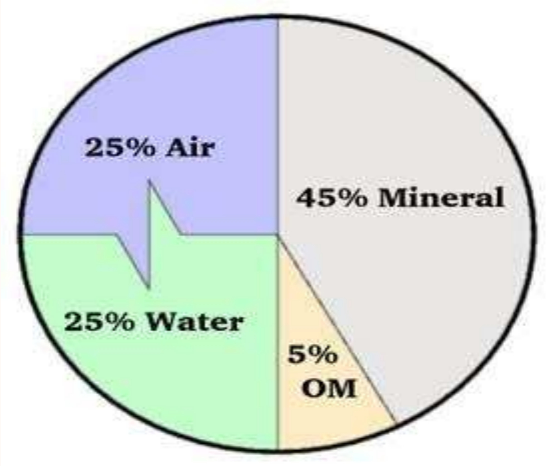


Figure 1 Approximate composition of soil

Source:

https://www.ctahr.hawaii.edu/mauisoil/images/a_comp_clip_image002.jpg

In a completely dry soil, all of the pore spaces are filled with air, and in a completely wet soil (waterlogged soil) all of the pores are filled with water. However, in most of the field situations the pore spaces are filled with both air and water. Volumes of these soil components vary widely and a typical soil consists of approximately 45% mineral, 5% organic matter, 25% water, and 25% air.

4.1.1 Soil texture

It refers to the relative proportion of sand, silt and clay in a given soil. A soil is described as a coarse, medium or fine textured depending on the predominant particle size. The soil texture not manipulated with tillage and other soil management practices and remains constant.

Table 1 USDA textural classes of soils

Common names of soils (General texture)	Sand	Silt	Clay	Textural class
Sandy soils (Coarse texture)	86-100	0-14	0-10	Sand
	70-86	0-30	0-15	Loamy sand
Loamy soils (Moderately coarse texture)	50-70	0-50	0-20	Sandy loam
Loamy soils (Medium texture)	23-52	28-50	7-27	Loam
	20-50	74-88	0-27	Silty loam
	0-20	88-100	0-12	Silt
	20-45	15-52	27-40	Clay loam

Loamy soils (Moderately fine texture)	45-80	0-28	20-35	Sandy clay loam
	0-20	40-73	27-40	Silty clay loam
Clayey soils (Fine texture)	45-65	0-20	35-55	Sandy clay
	0-20	40-60	40-60	Silty clay
	0-45	0-40	40-100	Clay

(Source: FAO: accessed on Jan 23, 2021)

The water holding capacity, permeability and infiltration rate of soil depends on the soil texture. A fine textured soil (clay soil) has relatively higher water holding capacity and slow movement of water resulting in poor drainage and aeration. On the other hand, coarse texture soil (sandy soil) have very low water holding capacity and have large volumes of macro-pores that encourages the rapid drainage and aeration. Therefore, the loamy soils have intermediate properties clay and sand soils are ideal for growing most crops due to providing good drainage, high available water and nutrients.

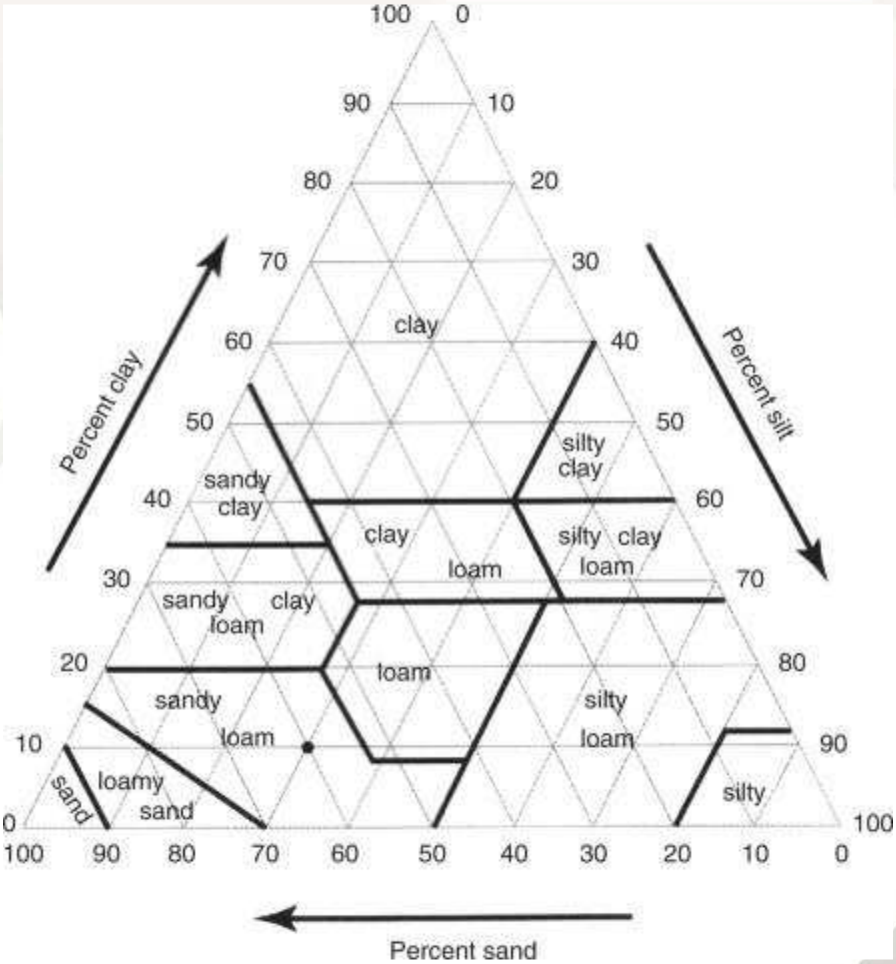


Fig 2 Soil texture triangle based on USDA particle-size classification

(Source: https://ars.els-cdn.com/content/image/3-s2.0-B978012064477350014X-f12-01-9780120644773.jpg?)

4.1.2 Soil Structure

The structure of a soil refers to the combination arrangement of primary soil particles into secondary particles, or groups of aggregates. Soil structure has important role in water movement, plant root penetration, air movement etc.

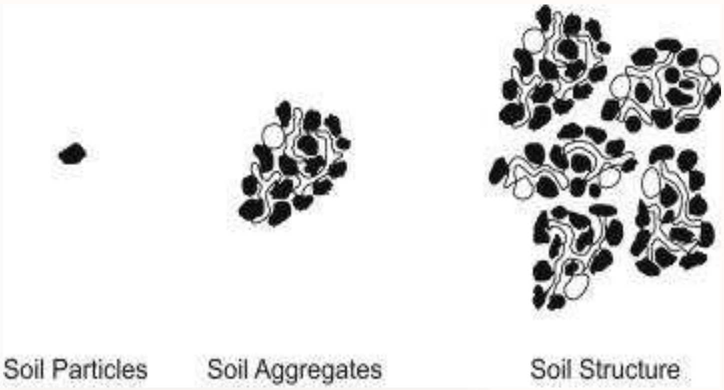


Figure 2 Soil structure

(Source: https://ars.els-cdn.com/content/image/3-s2.0-B9780128117484000170-f17-02-9780128117484.jpg?)

4.2 Soil Moisture

Soil moisture has commonly divided into four classes

4.2.1 Hygroscopic water: When water is held tightly as thin film around soil particles by adsorption forces and no longer moves in capillary pores it is called hygroscopic water (held by a force of -1000 bars).

- Forms very thin films around soil particles hence not available to the plant.
- Held on the particle surface.
- Held very tightly, by forces of adhesion resulted into not available to the plant

4.2.2 Capillary water: Water retained by soil in capillary pores against gravity, by forces of surface tension as continuum film around soil particles is called capillary water (held by a force of -1/3 to - 31 bars).

- Found in the micro pores only.
- Most of this water is available for plant growth.

- Held in the soil against the force of gravity (cohesion and adhesion)
- Amount of water held is a function of the pore size and pore space.

4.2.3 Gravitational water: Water in macro pores that moves freely under the influence of gravity beyond the root zone (held by a force of < - 1/3 bars).

- It moves through the soil due to the force of gravity.
- Found in the macro pores only.
- Not considered to be available to plants.
- Drains out of the soil in 2-3 days

4.2.4 Water vapour:

- Water occurring in the soil atmosphere.
- It is also unavailable water to plants.

4.3 SOIL MOISTURE CONSTANTS

Water contents under certain standard conditions are referred to as soil moisture constants. Under field conditions water content of the soil changing constantly with time and depth of soil due to pressure gradient and vapour pressure differences.

4.3.1 Saturation capacity or maximum water holding capacity: When the all pores (macro and micro) are filled with water, the soil it said to be at its maximum water holding capacity or saturation capacity. The soil moisture tension at MWHC is zero and almost equal to free water surface.

4.3.2 Field capacity: When supply of water is stopped, water continues to drain from large pores for a day or two and becomes negligible thereafter. The macro pores are again filled with air and micro pores are filled with water and it moves because of capillary force. This water called capillary water. Soil moisture tension which is varies from soil to soil, generally ranges from 1/10 to 1/3 atm. FC is called upper limit of water availability to plants.

4.3.3 Moisture equivalent: It is amount of water is retained by initially saturated soil after being subjected to a centrifugal force of 1000 times that of gravity for an hour is called moisture equivalent. Values of FC and moisture equivalent are nearly equal in medium textured soils. In sandy soils, FC exceeds ME. In clayey soil FC is lower than ME.

4.3.4 Permanent wilting point: The concept of permanent wilting point (PWP) was proposed by **Briggs and Shantz** in 1912. Permanent wilting point is also called wilting coefficient is the moisture content of the soil at which plants can no longer enough moisture to meet the transpiration requirements and remain wilted unless water is added to the soil. At this point, the plant wilts during daytime to conserve moisture and become normal at night. The plants are not dead but remain in wilted condition. Soil moisture tension at PWP ranges from 7 to 32 atm. depends on soil texture, soluble salts, environment and kind of plant. Therefore, the commonly used average value is 15 atm. for PWP.

Table 1 Available soil water at various soil texture at FC and PWP

Soil	**FC %**	**PWP%**	**ASM%**
Clay	40	20	20
Clay loam	30	15	15
Silt loam	22	12	10
Sandy loam	14	6	8
Loamy sand	10	4	6
Sand	6	2	4

Source; Reddy, (1999)

4.3.5 Available water: The soil moisture held between field capacity to permanent wilting point is called available water. The fine texture soils have a wide range of water content at FC to PWP than coarse texture soils.

4.3.6 Hygroscopic coefficient: At soil water potential of -30 bars water is held so tightly that much of it can move only in vapour phase. Moisture content of soil at this point termed as hygroscopic coefficient

4.3.7 Ultimate wilting point: At -60 bars plants cannot absorb the moisture and die eventually. Soil moisture content at which plants die is called ultimate wilting point.

Table 2 Soil moisture tension and at various soil moisture constants

Soil moisture constants	Soil moisture tension (bars)
MWHC	0
FC	-1/10 to 1/13
PWP	-15
HC	-30
UWP	-60

Source; Reddy (1992)

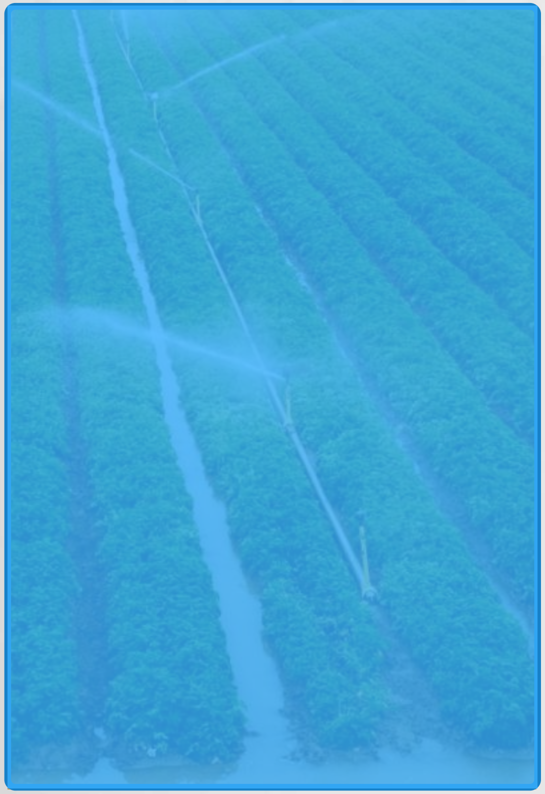
Suggested reading and references

Majumdar, D.K. 2013. Irrigation Water Management Principles and Practices, PHI learning Private Limited. New Delhi.

Michael, A.M, 1978. Irrigation theory and practice, Vishal Publishing House Private Limited. New Delhi.

Reddy, S. R. 1999. Principles of agronomy. Kalyani publications, Ludhiana, New Delhi.

Sunda N.R. and Kaswan S. L. 2018. Basic agriculture, Surahee publications, Jaipur.



Course Details	
Course Name	Water Management including Micro Irrigation
Lesson 5	Plant Water Relations-Critical Stages; Meaning And Impact Of Water Stress

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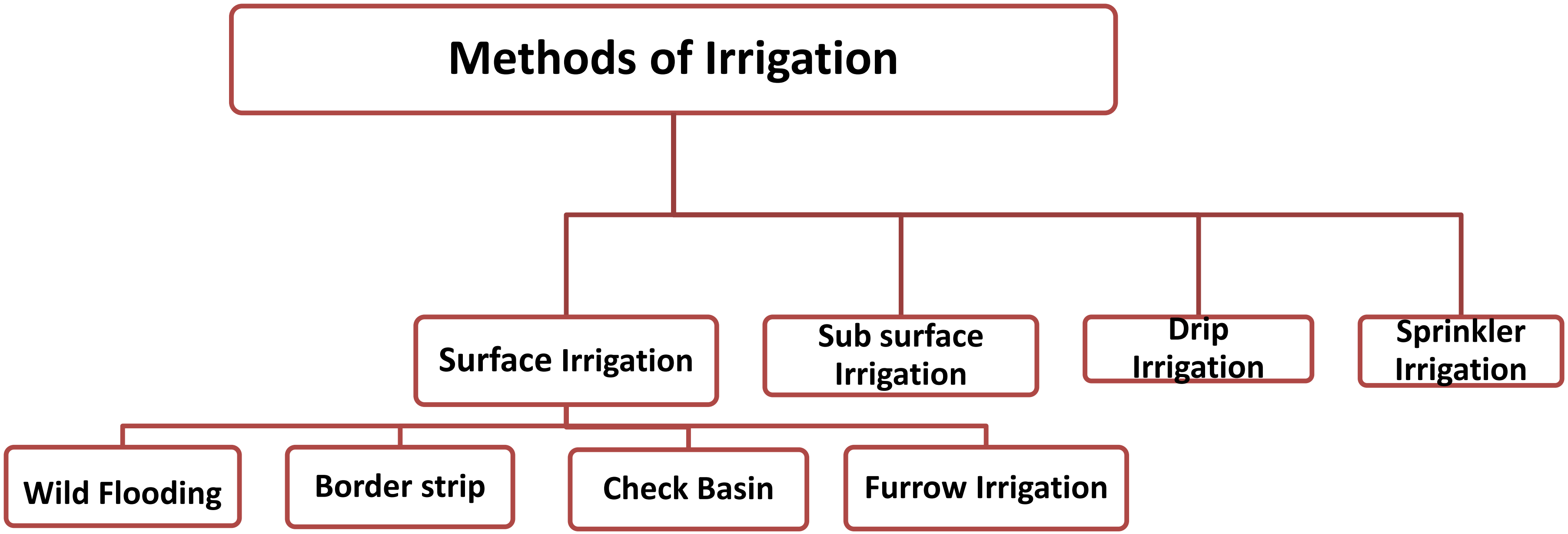
Classification of different method of irrigation



Surface irrigation

1. Uncontrolled Flooding/Free Flooding

Refers to the irrigating fields that are relatively flat and level by allowing water from supply channels to flow over land along the natural slope

Size of stream, flow depth, land slope and water intake rate influence greatly the efficiency and uniformity of water application.

Suitability: Field should be relatively smooth and slope (~0.05%) gradually and uniformly towards natural drainage.

Crops: grasses, fodder, close-growing grain crops, rice, pasture

Advantages

Don't require precise land leveling, application is easy and cheap, Don't require skilled labour

Disadvantages

- Non-uniform wetting of soil and accumulation of water in lower spots
- Loss of water through percolation and runoff
- Water application efficiency is very low
- Poor crop performance due to uneven distribution of water

2. Border irrigation

- The land is divided into several long parallel strips (3-15 m wide and 60-300 m long) called borders and these borders are separated by low ridges.
- The strip has a uniform longitudinal gentle slope of 0.2-04 %.
- Border slope should be minimum 0.05% to provide drainage and maximum 2% to limit soil erosion problem
- Each strip is irrigated independently by turning the water in the upper end.
- The water spreads and flows down the strip in a sheet confined by the border ridges.
- Width of border strip: It varies from 3-15 m Border length: 60-300m

Recommended safe limit of slope and border length under different soil

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

Suitability: Soils having moderately low to moderately high infiltration rates. Not suitable in coarse sandy soils (very high infiltration rates) and heavy soils having (very low infiltration rate).

Crop: Close-growing crops like wheat, barley, fodder crops and legumes and upland rice, not suitable for rice.

Advantages

1. Border ridges can be constructed with simple farm implements
2. Labour requirement low as compared to conventional check basin method.
3. Uniform distribution of water and high application efficiencies.
4. Large irrigation streams can be efficiently used.
5. Adequate surface drainage is provided if outlets are available.

3. Check basin irrigation

- It is the most common method and widely practiced in India. (specially irrigated rice)
- Here the field is divided into smaller unit areas so that each has a nearly level surface.
- Bunds or ridges are constructed around the area forming basins within which the irrigation water can be controlled.
- The water applied to a desired depth can be retained until it infiltrates into the soil.
- The size of the basin varies from 10 m^2 to 25 m^2 depending upon soil type, topography, stream size and crop.

Suitability: Small gentle and uniform land slopes, soils having moderate to slow infiltration rates.

Crops: Both row and close growing crop, grain (wheat, maize etc.)and fodder crops in heavy soils.

Advantages

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

Limitations

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

4. Furrow irrigation

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

Suitability: Suitable to most soils except sandy soil

Crops: Wide spaced row crops including vegetables, Suitable for maize, sorghum, sugarcane, cotton, tobacco, groundnut, potatoes

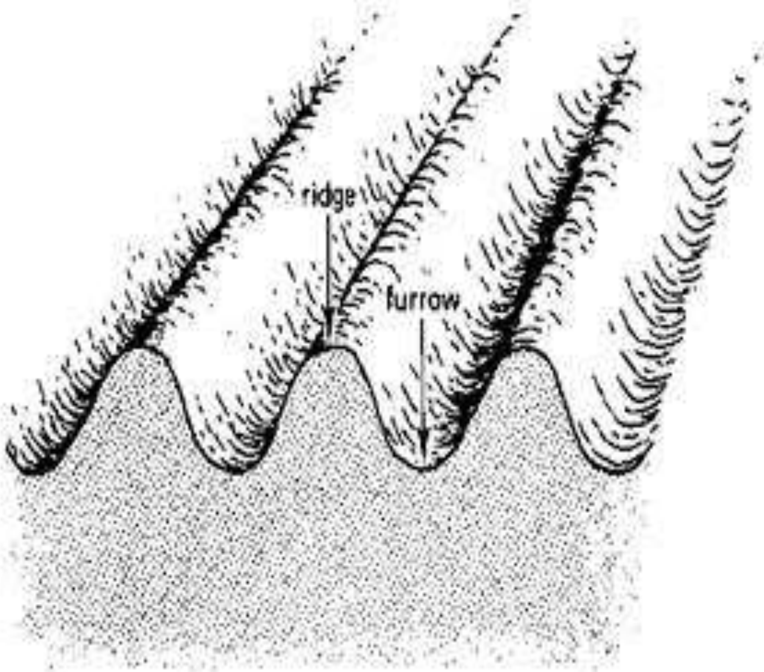


Fig: Top view and cross-section of furrows and ridges

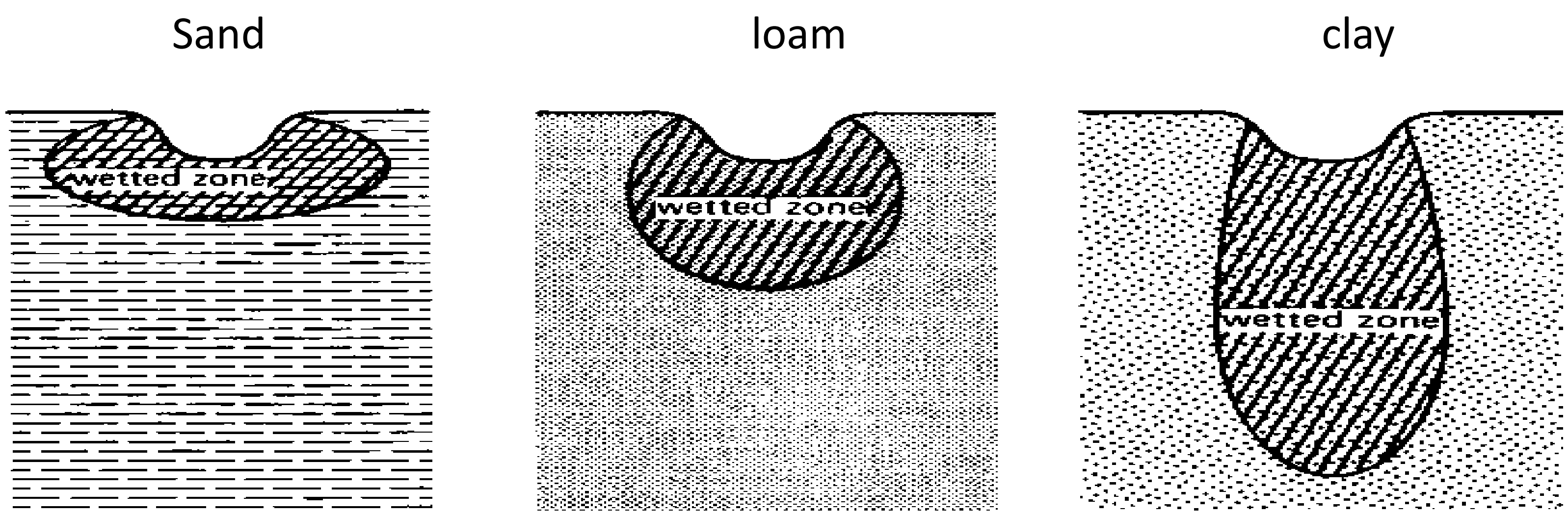
Fig: Furrow irrigation in field

Advantages

1. Water in furrows contacts only one half to one fifth of the land surface.
2. Labour requirement for land preparation and irrigation is reduced.
3. Compared to check basins there is less wastage of land in field ditches
4. Helpful in lands with high salt content as salts accumulate on the upper part

Disadvantages

1. Land requires precise grading to a uniform slope
2. High labour requirement 3. This method is unsuitable for light irrigation



(Source: http://www.fao.org/3/S8684E/s8684e04.htm)

Wetting pattern in furrows in different soil type

Types of furrow irrigation

Based on alignment of furrows

1. **Straight furrows:** Furrows are made level and straight throughout its length. Suited to soil having low IR and high WHC.
2. **Contour furrows:** Adopted in area having an uneven and rolling topography. When the longitudinal slope exceeds the safe limits for graded furrows, furrows are constructed along the contour.

Based on irrigation:

1. **All furrow irrigation:** Water is applied evenly in all the furrows and are called furrow system or uniform furrow system.
2. **Alternate furrow irrigation:** It is not an irrigation layout but a technique for water saving. Water is applied in alternate furrows for eg. During first irrigation if the even numbers of furrows are irrigated, during next irrigation, the odd number of furrows will be irrigated.
3. **Skip furrow irrigation:** Normally adopted during the period of water scarcity and to accommodate intercrops. In the skip furrow irrigation, a set of furrows are completely skipped out from irrigation permanently. The skipped furrow will be utilized for raising intercrop.

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

CORRUGATION

- This is a partial surface flooding method of irrigation
- These are miniature furrows adopted for irrigated close growing crops such as grain, forage and pasture crops.
- This method is used for fine to moderately coarse soils, especially soils that bale and form crusts.
- Corrugations are about 6-8 cm deep and 40-75cm apart depending on the physical properties soil and spacing of crops.
- Crops: Wheat, Setaria, Groundnut

Sub-surface irrigation/ Sub-irrigation

- Water is applied beneath the ground by creating and maintaining an artificial water table at some depth, usually 30-75 cm below the ground surface.

- Moisture moves upwards towards the land surface through capillary action,

- Water is applied through underground field trenches laid 15-30 m apart.
- Open ditches are preferred (relatively cheaper and suitable to all types of soil),

- The irrigation water should be of good quality to prevent soil salinity.

Advantages

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

Disadvantages

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

Drip irrigation system

- Drip or trickle irrigation is one of the latest methods of irrigation.
- It is suitable for water scarcity and salt affected soils.
- Water is applied in the root zone of the crop
- Discharge rate: <12 lph

Components

- ♦ A drip irrigation system consists of a pump or overhead tank, main line, sub-mains, laterals and emitters.
- ♦ The mainline delivers water to the sub-mains and the sub-mains into the laterals.
- ♦ The emitters which are attached to the laterals distribute water for irrigation.
- ♦ The mains, sub-mains and laterals are usually made of black PVC (poly vinyl chloride) tubing. The emitters are also made of PVC material
- ♦ The other components include regulator, filters, valves, water meter, fertilizer application components, etc.

Components of drip irrigation

Pump: The pump creates the pressure necessary to force water through the components of the system.

Centrifugal pump operated by engines or electric motors are commonly used. The laterals may be designed to operate under pressures as low as 0.15 to 0.2 kg/cm^2 and as large as 1 to 1.75 kg/cm^2.

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

Filter: It is an essential part of drip irrigation system. It prevents the blockage of pipes and drippers/emitters.

Emitters: Drip nozzles commonly called drippers or emitters are provided at regular intervals on the laterals. They allow water to emit at very low rates usually in trickles.

The discharge rate of emitters usually ranges from 2 to 12 lph.

Advantages

1. Water saving - losses due to deep percolation, surface runoff and transmission are avoided.
2. Brackish water can be used more safely
3. Localized fertilizer application can be made with this system
4. Uniform water distribution
5. Suitable for wide spaced row crops, like cotton, sugarcane and horticulture
6. Soil erosion is reduced, better weed control, land saving and less labour requirement.

Disadvantages

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

Sprinkler irrigation

- It refers to the application of water to crop in form of spray from above the crop like rain.
- Also called as overhead irrigation.
- Highest area under sprinkler irrigation in Rajasthan.(2018)

Suitability:

Sandy soil or soil having high infiltration rate, undulation topography

Shallow soil that do not allow proper land levelling

Water scarce area

Layout of sprinkler irrigation system

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

A sprinkler system usually consists of the following parts.

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

Other accessories / fittings

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

Types of sprinkler system

Based on arrangement for spraying irrigation water

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

Based on the portability

1. **Portable system:** It has portable mainlines and laterals and a portable pumping unit
2. **Semi portable system:** A semi portable system is similar to a fully portable system except that the location of the water source and pumping plant are fixed.
3. **Semi permanent system:** A semi permanent system has portable lateral lines, permanent main lines and sub mains and a stationery water source and pumping plant. The mainlines and sub-mains are usually buried, with risers for nozzles located at suitable intervals.
4. **Solid set system:** A solid set system has enough laterals to eliminate their movement. The laterals are placed in the field early in the crop season and remain for the season.
5. **Permanent system:** It consists of permanently laid mains, sub-mains and laterals and a stationary water source and pumping plant. Mains, sub-mains and laterals are usually buried below plough depth. Sprinklers are permanently located on each riser.

Advantages

1. Water saving to an extent of 35-40 % compared to surface irrigation
2. Saving in fertilizers - even distribution and avoids wastage.
3. Suitable for undulating topography (sloppy lands)
4. Reduces soil erosion
5. Suitable for coarse textured soils (sandy soils)
6. Frost control - protect crops against frost and high temperature
7. Drainage problems eliminated and no wastage of land
8. Fertilizers and other chemicals can be applied through irrigation water

Disadvantages

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

Irrigation efficiency (%) under different irrigation methods

Irrigation Efficiency	Surface	Sprinkler	Drip
Conveyance efficiency	40-70	100	100
Application efficiency	60-70	70-80	90
Evaporation loss	30-40	30-40	20-25
Overall efficiency	30-35	50-60	80-90

(Source: Reddy and Reddy, 2016)

Some other irrigation system

Low Energy Precision Applicators (LEPA)

The LEPA is modifications of centre pivot or linear move sprinkler systems. The sprinkler heads on such systems are replaced by closely spaced drops pipes releasing water at pressures of 7-35 KPa few centimeters above the soil surface. Water can be applied at a rate to meet crop requirements as dikes are constructed in such a way that a few furrows row crops are accommodated in small basins. The irrigation efficiency is high as runoff is checked and irrigation requirement can be reduced.

Control Conduit gravity system

A buried corrugated plastic pipe distributes water between each two rows of trees. From this pipe a much smaller (< 10mm inside diameter) tube conveys water to each individual tree. The end of this tube is elevated several centimeters above the ground surface, but is left open without any emitter, etc. Since this system applies water at rates greater than the soil intake capacity, small dikes are formed around each tree to hold applied water until it infiltrates.

Course Name	**Water Management including Micro Irrigation**
Lesson 6	**Water Availability And Its Relationship With Nutrient Availability And Losses**
Content Creator	**Dr. Hardev Ram**
University	**NDRI - National Dairy Research Institute**
Course Reviewer	**Prof. Ummed Singh**
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Objective: To understand how soil-water available to plants and how it affects the nutrient availability and losses in the rhizosphere.

Terminology:

Available water (AW): Water contained in soil between field capacity (FC) and permanent wilting point (PWP) is known as available water. It is also referred as available soil moisture (ASM). AW or ASM = FC - PWP

Management allowable depletion (MAD): It is the degree to which water in the soil is allowed to be depleted by management decision. It is also expressed as depletion of available soil moisture (DASM). MAD = Allowable depletion % of TAW

Readily available water (RAW): It is the fraction of TAW that a crop can extract from root zone without suffering water stress is the readily available water.

Total available water (TAW): It is the amount of water which will be available in the root zone for plant use. It is the difference in volumetric moisture content at FC and PWP multiplied by root zone depth (RD).

TAW = AW x RD or (FC – PWP) x RD

6.0 Introduction:

Soil water plays a dominant role in nutrient uptake due to its direct involvement in nutrient transport to roots, nutrient solution equilibrium, and microbial activity. Soil water and nutrient have synergistic effect on crop growth and yields. Plant nutrient uptake is the result of complex interactions among soil-plant-atmospheric continuum (SPAC). Optimum soil moisture content will improve uptake of nutrients by diffusion and root interaction, and also increase organic matter decomposition, which releases N, P, and S. However, low soil moisture can result in the formation of insoluble nutrient-containing compounds resulted in to unavailability of nutrient to plant.

6.1 Importance of soil water

The soil moisture is important to know because:

- Water is essential for life including soil organisms and plants
- Soil water serves as a solvent and carrier of nutrients for plant growth
- The yield of crop is determined by the amount of water available in soil followed by availability of other nutrients
- Soil water acts as a nutrient itself
- Soil water regulates soil temperature
- Microorganisms requires water for metabolic activities
- Soil forming processes and weathering depend on soil water
- Soil water helps in chemical and biological activities of soil

6.2 Concept of soil-water availability to plants

Three classical hypotheses have been put forth for the relative availability of soil water in the available range. This was given by **'Veihmeyer and Hendrickson'**.

- Water availability and consequently the crop growth is equal and uniform over the entire range from the field capacity to the permanent wilting point. This holds good generally for perennial crops such as orchard and tree crops whose dense root mass permeates the soil matrix thoroughly.
- Water availability and crop growth proceed uniformly from the field capacity to a certain critical point beyond which crop growth decreases rapidly till the permanent wilting point is reaches. This view holds good for most of the seasonal field crops maturing up to the seed stage.
- The availability of water and the rate of crop growth decrease gradually as the soil water content decreases from the field capacity to the permanent wilting point. This holds good generally for most of the forage crops and those grown vegetatively.
- 'Veihmeyer and Hendrickson' claimed that soil water is equally available throughout a definable range of soil wetness from an upper limit (FC) to a lower limit (PWP), both of which are characteristic and constant for a given soil. They postulated that plant functions remain unaffected by any decrease in soil wetness until PWP is reached, at which plant activity is curtailed, often abruptly.

- 'Richards and Wadleigh' produced evidence indicating that water availability to plants actually decreases with decreasing soil wetness and that a plant may suffer water stress before wilting point is reached.

6.2.1 Factors affecting water availability

The amount of available water is influenced by a number of factors like plant, climatic and soil factors.

1. **Plant factors:**
   - Rooting habits of plants
   - Drought tolerance
   - Stage and rate of growth of the plant
2. **Climatic factors:**
   - Air temperature
   - Humidity
   - Wind velocity and turbulence
3. **Soil factors:**
   - Moisture suction relations (matric and osmotic)
   - Soil depth
   - Soil stratification or layering

6.3 Nutrient uptake by plants

Water is key factor in nutrient uptake by plants through mass flow, diffusion and root interception.

6.3.1 Mass flow: It is the movement of dissolved nutrients with water flow to the root as the plant absorbs water for transpiration. Some mass flow can also occur in response to evaporation and percolation of soil water. Mobile nutrients like nitrate-N (NO_3-N), sulfate (SO_4), calcium (Ca) and magnesium (Mg) are transported to the roots by mass flow.

6.3.2 Diffusion: It is the movement of nutrients to the root surface in response to a concentration gradient. Nutrient ions move from higher concentrations to the lower concentration area in the soil solution. Mainly phosphorus (P) and potassium (K) are transport through diffusion. The rate of diffusion depends partly on the soil water content. Therefore, with thicker water films or with a higher nutrient content, nutrients diffuse more readily.

6.3.3 Root interception: It is one of the mechanisms of ion absorption by which the absorption of nutrient ions are enhanced by the growth of new roots throughout the soil mass. Calcium and magnesium transport through root interception.

However, **n**utrient absorption is directly affected by the level of soil moisture, as well as water use for metabolic activity of the plant, soil aeration, and the salt concentration in the soil solution. Micronutrients generally supplied to plant roots by diffusion in soil. Therefore, low soil moisture conditions reduce the micronutrient uptake. Under higher soil moisture conditions, iron (Fe) and zinc (Zn) deficiencies are frequently occur in such conditions.

6.4 Effect of soil-water on nutrient utilization

Organic matter and minerals in soil contain plant nutrients. These nutrients become available to the plant through mineralization of organic matter and weathering of minerals. Fertilizer applied to soil can be changed into either available or unavailable form. Among various factors affecting availability of soil nutrients, soil water is the most important factor. In soil-plant continuum water plays various roles in nutrient transformation, transportation and utilization in following ways.

6.4.1 Nutrient availability

- Water affects nutrient transformation in soil turning unavailable into available forms. It also affects the rate of transformation of fertilizers added to the soil.
- It affects absorption of nutrients, total nutrient uptake and nutrient composition of plants.
- Under water stress situation, both availability and uptake of nutrients declines. Thus, total plant growth or net assimilation is reduced more seriously than nutrient uptake.

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- Rate of mineralization of N is governed by soil water availability and proportionally related to the increase in soil water content.
- Water content in aerobic soils directly affects nitrification of ammonium-N and ammonium-N from both soils as well as fertilizer gets quickly transformed into nitrate-N. Thus, large amount of nitrate-N often accumulates in soil profile as compared to ammonium-N with sufficient water availability.
- Water content also changes root distribution pattern and affect nutrient uptake from soil. Nutrient uptake from lower profile depth is always higher under limited water supply, whereas with sufficient water supply it is generally from top layer.

6.4.2 Nutrient movement

- Nutrients dissolved in soil water also move with water, leading to a decrease of nutrient concentration gradient and water influences nutrient uptake by plants directly or indirectly.
- Some nutrients such as Ca, Mg and N are transformed by mass flow, whereas P and K mostly transformed by diffusion.
- Water deficit does not only affect nutrient amount in solution, but also the rate of movement of mass flow and diffusion. The effect of water deficit on mass flow depends on the degree of decline in soil-water potential, whereas diffusion largely depends upon the water potential changes.

6.4.3 Nutrient use efficiency

- Water deficit cause water stress to the plants which inhibits plant root growth, reduces absorbing volume and capacity of plant roots, increase the viscosity of sap and thereby, decreases nutrient uptake and transfer.
- Under excess water availability, reduces N recovery by means of NO_3-N leaching e.g. continues submergence of rice field showed more nitrate-N loss than intermittent submergence. Application of excessive N dose further increases the nitrate-N loss beyond the root zone.

6.4.4 Nutrient distribution in plants

- Soil-water content also influences nutrient movement from roots to above ground parts of plants.
- The influence of water deficit on nutrient distribution in plant parts varies with the crop. For example, in cereals and leguminous crops, water deficit at later stage reduces transfer of photosynthesis product from leaves, but N transformed to seed and storage proteins are hardly influenced.

6.5 Interaction of soil-water and nutrients on crop yield

- Water and nutrients have intense interaction and change in one brings change in another, which ultimately affects the yield and nutrient or water use efficiency. Therefore optimum combination of water and nutrient use is essential.
- Over supply of water and N may delay crop maturation by encouraging vegetative growth, weakening stems that lead to lodging along with wastage of water and over consumption of N.
- Excessive water supply lead to nutrient losses by leaching, while shortage of water supply may bring high nutrient concentration in soil which causes difficulties for crops to take up water and nutrients and even plants die before grain filling referred as **'haying-off effect'**. Therefore rational combination of water and nutrients is beneficial to crop plants.

6.5 Soil moisture and nutrient availability

6.6.1 Nitrogen

- Under drought or moisture stress condition, organic matter decomposition declines and N mineralization is reduced which affect the availability of N and its uptake.
- Excess soil moisture results downward movement of nitrate-N in the soil profile referred as 'leaching' and it moves even below the root zone under extreme case.

6.6.2 Phosphorous

- Lower the soil moisture, greater is the response to P.

- In low-P soils having limited soil moisture, yield response to P fertilization is always higher, whereas under the sufficient water availability situations yield gains are more with other nutrients than P.

6.6.3 Potassium

- Generally, lower the soil moisture content, greater is the response to K.
- Most of the K absorbed moves to the roots by diffusion through the water films and with low water content K diffusion is reduced. Therefore, K fertilization increases the K content in the water films and increases the diffusion.
- In wet soil, the K response can also be large, but it is related to soil aeration.
- As far as % K saturation of CEC increases, K availability increases and crop performance also improves even in soil moisture stress conditions. Thus, adequate K availability reduces the effect of water stress.

6.6.4 Micronutrients

- The most of the micronutrients are transported to the plant roots by diffusion or mass flow, lower soil-moisture content reduces micronutrient uptake.
- Temporary boron (B) deficiency occurs during moisture deficit condition due to reduced mineralization. B deficiency also occurs with excessive moisture condition due to its leaching beyond root zone.
- Lower soil moisture can also induce deficiencies of manganese (Mn) and molybdenum (Mo), although iron (Fe) and zinc (Zn) deficiencies are often associated with high soil moisture.

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Course Name	**Water Management including Micro Irrigation**
Lesson 7	**Water Management Of Crops-Its Definition, Meaning, And Relevance In Crop Production**
Content Creator	**Dr. Hardev Ram**
University	**NDRI - National Dairy Research Institute**
Course Reviewer	**Prof. Ummed Singh**
University	**Agriculture University Jodhpur, Jodhpur**

Objective

To learn about how to manage irrigation water and its relevance to crop production

Water management is a broader term which includes development, application and utilization of water resources, water conservation, drainage, water quality and other aspects such as participatory irrigation management.

Irrigation water management is defined as the integrated process of intake, conveyance, regulation, measurement, distribution, application and use of irrigation water to farms and drainage of excess water, with proper amounts and at right time, for the purpose of increasing crop production and water economy in conjunction with improved agricultural practices.

Irrigation water management is the act of timing and regulating irrigation water applications in a way that will satisfy the water requirement of the crop without the waste of water, soil, plant nutrients, or energy. It means applying water according to crop needs in amounts that can be held in the soil available to crops and at rates consistent with the intake characteristics of the soil and the erosion hazard of the site.

Management is a prime factor in the success of an irrigation system. Large quantities of water, and often large labour inputs, are required for irrigation. The irrigator can realize profits from investments in irrigation equipment only if water is used efficiently.

7.1 Components of water management

There are two major components of water management (The detail discussion about irrigation and drainage see chapter 1 and 18):

1. **Irrigation:** Irrigation is as artificial application of water to the plant root zone to supplement the water available from rainfall, ground water and stored soil moisture in crop root zone.

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2. **Drainage:** The removal of excess surface or ground water from land by means of surface or sub-surface drains.

7.2 Importance of water management

- The proper management of water resources for the purpose of crop production and other activities such as industrialization, power generation etc.,
- Proper regulate the water resources for further use or non-season use.
- Allocation the water based on area and crop under cultivation.
- Minimize the conveyance and other losses viz., percolation and seepage.
- To utilize the water considering cost-benefit.
- To distribute the available water without any social problem.
- To protect the environment from overuse or misuse of water.
- Minimize pumping costs.
- Maintain or improve quality of ground water and downstream surface water.
- Increase crop biomass yield and product quality

7.3 Water management at various levels

Water management is required at scheme level, and at farm level and improving policies at national and international level (FAO).

7.3.1 Improving management -at scheme level

- Protective to productive irrigation
- A supply-oriented to service-demand approach
- A centralised to a decentralised irrigation management
- Allocation of land and water resources to users
- Power and responsibilities to the users.

7.3.2 Improving management at farm level

- Improving water use efficiency

- Crop diversification (Rice to non-rice crops)
- Investment in water saving technologies
- Improved market opportunities and credit.

7.3.3 Improving management and policies -at national and international level

- Ensuring fair and equitable access
- Secure water rights
- Water management at the river basin
- Provide incentives to conserve water to reduce losses
- Recognising the full value while protecting the poor
- Regulations for protection of aquifers, rivers, lakes and wetlands.

7.4 Efficiently irrigation water management

- Reduce conveying losses of water from the source to the field
- Follow right source, method, time and quantity of irrigation water
- Selecting right crop, varieties and cropping pattern
- Selection of crop that require less water in areas where availability is scarce
- Adoption of resource conservation techniques (RCTs) and land configuration to reduce evaporation losses and higher water productivity
- Application of right amount of fertilisers and plant protection measure
- Adoption of water conservation techniques and consecutive use of water.

7.5 Relevance of water management in crop production:

Water is a critical input for agricultural production and plays an important role in food security. Currently, agriculture accounts about 70% of all freshwater withdrawals globally and in India, it account about 90%.

Irrigated agriculture represents 20% of the total cultivated land and contributes 40% of the total food produced worldwide. In India, irrigated agriculture occupies 35% net sown area, contributing 56% of food grains and supporting 60% of the population. The average productivity of irrigated agriculture is almost three times as compared to rainfed agriculture.

Therefore, judicious water management help in the spatial and temporal distribution of water, so as to optimise crop growth and yield and to enhance the economic efficiency of crop production. It is not necessarily to obtain higher yields per unit area of land or per unit volume of water, but to maximise the net returns in long run.

Increasing population growth, urbanization, and climate change, competition for water resources is expected to increase, with a particular impact on agriculture. In India, population is expected to increase to over 1.5 billion by 2030, and whether urban or rural, this population will need food and fiber to meet its basic needs.

However, future demand on water by all sectors will require as much as 25 to 40% of water to be re-allocated from lower to higher productivity and employment activities, particularly in water stressed regions.

7.8 Possible options for better water management

- Technologies such as conservative agriculture should be popularized, as it is known to increase water use efficiency.
- Improvements main system (off-farm) with appropriate incentives for on-farm investments
- Improved water delivery systems to provide adequate on-demand service as well as use of advanced technologies to improve efficiency and productivity of water in agriculture.
- Water pricing for the agriculture sector should be reviewed and revised.

- Watershed development must be planned to pave way to safeguard the surface and ground water recharge mechanisms.
- Increase awareness to increase water use efficiency in the agriculture sector.
- Developed efficient pressurised irrigation and fertigation techniques for crops to achieve more output from per drop of water.
- Increasing water productivity in challenging environment like waterlogged and rainfed areas.
- Ensuring sustainable financing/subsidies to ensure that existing public irrigation infrastructure is maintained.

Suggested reading and references:

https://www.oav.de/fileadmin/user_upload/5_Publikationen/5_Studien/170118_Study_Water_Agriculture_India.pdf

The World Bank. 2020. Water in agriculture. https://www.worldbank.org/en/topic/water-in-agriculture

Course Name	Water Management including Micro Irrigation
Lesson 8	Concept Of Evapotranspiration And Its Measurement
Content Creator	Dr. Hardev Ram
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Course Reviewer	Prof. Ummed Singh
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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
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Objectives: To assess the evapotranspiration in relation to plant growth

Terminology:

Actual transpiration: rate of evapotranspiration equal to or smaller than evapotranspiration as affected by the level of available water, soil water, salinity, field size and other causes.

Consumptive use: It is sum of total water transpired and used for carrying out metabolic activities and building-up plant body by vegetation and the water evaporated from unit area of vegetation. It is expressed in cm depth of water per unit area.

Crop coefficient: Refers to the ratio between crop evapotranspiration and reference crop evapotranspiration
Crop water requirements: The depth of water needed to meet the water loss through evapotranspiration (ETcrop) 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.

Evaporation: The process of conversion of liquid into vapour form

Evapo-transpiration: It is the total amount of water lost due to transpiration by crop and evaporation from the soil surface during a specified time from a particular area.

Lysimeter: A device used for measuring percolation and leaching losses from a column of soil under controlled condition.

Pan coefficient: A ratio between reference evapotranspiration and water loss from open water surface

Potential evapotranspiration (Reference transpiration): The evapotranspiration from an extensive surface of green grass of uniform height (8-15cm), actively growing, completely shading the ground with an albedo of 0.23 and not short of water is called reference crop evapotranspiration and is denoted by ETo.

8.0 Concept of evapotranspiration

Agriculture is major sector of water use in the global (70%) as well as India (>90%). The concept of ET is highly useful for irrigation scheduling. ET based irrigation scheduling is getting wider applications as a means to improve water productivity due to rising concern on water conservation. The environmental demand for water regulates the water requirement of the crops. The process is controlled by other factors like amount of ground coverage by the crops and its geometry, growth stage of the plant, nature and characteristics of the ground surface etc., apart from the meteorological parameters.

- Water can exist in the natural environment in three different forms or states - solid (ice), liquid and gas. The process by which water changes from a liquid to a gas is known as evaporation**.**
- Transpiration is process by which water vapour leaves the living plant body and enters the atmosphere.
- The cycle of water in field consists of its entry into soil, redistribution, downward drainage within the soil, uptake of by the plants and its return to the atmosphere in twin processes of transpiration and evaporation.
- The ET process serves as significant contributor of moisture back in to the atmosphere (hydrological cycle) and it is responsible for 15% of atmosphere water vapour.

8.1 Consumptive use (CU) – CU is used to designate the losses due to ET and water that is used for its metabolic activities of plants thus CU exceed ET by the amount of water used for photosynthesis, transport of minerals and photosynthates, structural support and growth. Since this difference is usually less than 1%, ET and CU are normally assumed to be equal. But both (CU & ET) terms are used simultaneously.

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- The amount of water consumptively used during 24-hour period is called **daily consumptive use**.
- The average daily water use rate during the few days (usually 6 to 10 days) of highest consumptive use in a season is called **peak period-consumptive use**. It is useful in planning an irrigation system.
- The total amount of water consumptively used by a crop during the entire growing season is called **seasonal consumptive**.

Table 1 Maximum rates of soil moisture use by crops under different climate conditions

Climatic conditions	Peak rate of soil moisture removal (mm/day)
Cool, humid	3
Cool, dry	4
Moderate, humid	4
Moderate, dry	5
Hot, humid	5
Hot, dry	8

(Source: Michael, 2008)

8.2 Factors affecting ET

- Weather parameters

1. Solar radiation
2. Air temperature
3. Humidity
4. Wind speed

- Crop characteristics

1. Difference in resistance to transpiration
2. Crop height
3. Crop roughness

4. Reflection
5. Crop rooting characteristics
- Management and environmental factors
1. Cultivation practices (tillage, inter cultivation, time and method of fertilizer application, plant protection measures)
2. Time and method of irrigation.
3. Soil and moisture conservation practices

8.3 Potential evapotranspiration (Reference transpiration): The evapotranspiration from an extensive surface of green grass of uniform height (8-15cm), actively growing, completely shading the ground with an albedo of 0.23 and not short of water is called reference crop evapotranspiration and is denoted by ETo.

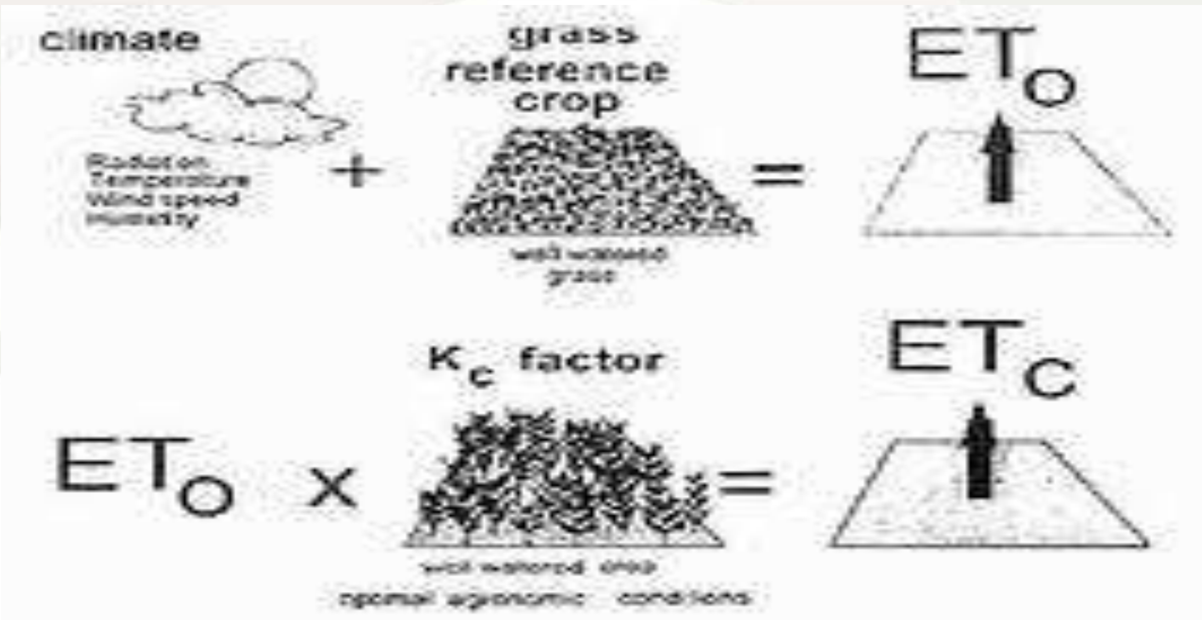

Fig.1 ET and crop coefficient

Source:https://tse4.mm.bing.net/th?id=OIP.yk2bkFI1E2iVd2TLlEr1oQAAAA&pid=Api&P=0&w=213&h=163

Actual transpiration; rate of evapotranspiration equal to or smaller than evapotranspiration as affected by the level of available water, soil water, salinity, field size and other causes.

8.4 Determination of evapotranspiration

8.4.1 ET computed from meteorological data (by using empirical formulas)

a. Blaney-Criddle method

$$ET_0 = C[P(0.46T+8)]$$

Where:

ETo = Reference crop evapotranspiration in mm/day for the month considered

T = Mean daily temperature on Cover the month considered

P = Mean daily percentage of total annual daytime hours obtained for a given month & latitude

c = Adjustment factor which depend on minimum relative humidity, sunshine hours and day time wind estimates

Application & Limitations of Blaney-Criddle method

a) Widely used for estimation of PET, only require air temperature and day light hour's data.

b) Not recommended for equatorial regions, small islands and coastal areas at high altitudes and in climates with a wide variability.

b. Radiation method

$$ET_0 = C(W.R_s)$$

Where:
ETo = Reference crop evapotranspiration in mm/day for the period considered

Rs = Solar radiation in equivalent evaporation in mm/day

W = Weighting factor which depends on temperature and altitude

c = Adjustment factor which depends on mean relative humidity and day time wind conditions.

Application & Limitations of Radiation method

a) Recommended for areas where measured climatic data include air temperature and sunshine, cloudiness or radiation, but not measured wind and humidity

b) Knowledge of general levels of humidity and wind is required

c) It is reliable than Blaney - Criddle method in which possible error of this method is 20%

but possible error of Blaney - Criddle method is 25%.

c. Pan evaporation method

$$ET_o = K_P . E_{pan}$$

Where:
ETo = Reference crop evapotranspiration in mm/day for the period considered

Epan = Pan evaporation in mm/day and represents the mean daily value of the period considered

Kp = Pan coefficient

Applications and Limitations

1) Simple, fairy reliable and inexpensive.
2) Possible error of this method is 15%

d. Modified Penman method

$$ETo = c\ [W.\ R_n + (1-W).\ f\ (U)\ (ea-ed)]$$

Where:

ETo = Reference crop evapotranspiration in mm/day

W = Temperature related weighing factor

Rn = Net radiation in equivalent evaporation in mm/day

f(u) = Wind related function

(ea – ed) = Difference between the saturation vapour pressure at Tmean 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

Applications and Limitations

1) Fairy accurate method possible error is around 10%
2) Widely used in irrigation development and management project
3) Complicated method

Table 2 Meteorological data required

Method	T	Rh	Wv	Ss	Ra	E	Environment
Blaney-Criddle	*	0	0	0	-	-	0
Radiation	*	0	0	*	(*)	-	0
Pan evaporation	-	0	0	-	-	*	*

Modified Penman	*	*	*	*	(*)	-	0

Source; Reddy, (1999)

*= measured data, 0= estimated data, Ra= solar radiation, (*) = used if available, E= open pan evaporation

8.4.2 Field water balance method

ΔS = (P+I+U) – (R+D+ET)

ΔS = Change in soil moisture storage in root zone

P = Precipitation

I = Irrigation

U = Upwind capillary flow of water from below to root zone

R = Run off

D = Downward drainage out of the root zone

ET = Evapotranspiration from soil and plants.

8.4.3 Lysimeter

Lysimeter is a multifaceted instrument used in a variety of investigations. It is widely used for the measurement of percolation of water beneath the vegetation root zone and water use through evaporative processes. Lysimeter is direct measurement of water flux from vegetative surface (for details see lesson 14).

8.4.4 Evaporimeter

The standard USWB Class-A pan evaporimeter is the most widely used to measure evaporation from the free water surface. It consists of a 121.5 cm diameter and 25.4 cm deep pan made of 20gauge galvanized iron sheet with a stilling well. A vertical pointer is provided in the stilling well to show the level of water maintained in the pan. Sharma and Dastane (1968) developed the sunken screen pan evaporimeter that provides evaporation values closer to crop ET values than the USWB Class-A pan evaporimeter.

Fig. 2 USWB Class-A pan evaporimeter

Source: https://images.app.goo.gl/BSkfvALVR6mFiqiA6https://images.app.goo.gl/2nxCBbVHe1kfP8r19

8.5 ET and Crop Yield

Evapotranspiration and crop growth are directly related in several crops. The relationship between dry matter of crop and ET is linear but relationship between ET and crop yield depends on crops. It is linear in case of cereals and quadrate in case of several leguminous.

8.6 Crop coefficient

Crop coefficient refers to the ratio between crop evapotranspiration and reference crop evapotranspiration. Crop coefficient depends on crop type, climate, soil evaporation and crop growth stages.

Crop coefficient curve is constructed by dividing crop growing period into four growth periods and placing straight line segments through each of these periods with the lines through the initial and mid-season periods being horizontal. The four growth stages of crop growing period are as follows:

a) Initial period – planting to 10% ground cover
b) Crop development – 10% ground cover to effective cover i.e., flowering

c) Mid-season – Effective cover to start of maturity i.e., senescence of leaves
d) Late season – Start of maturity to harvest.

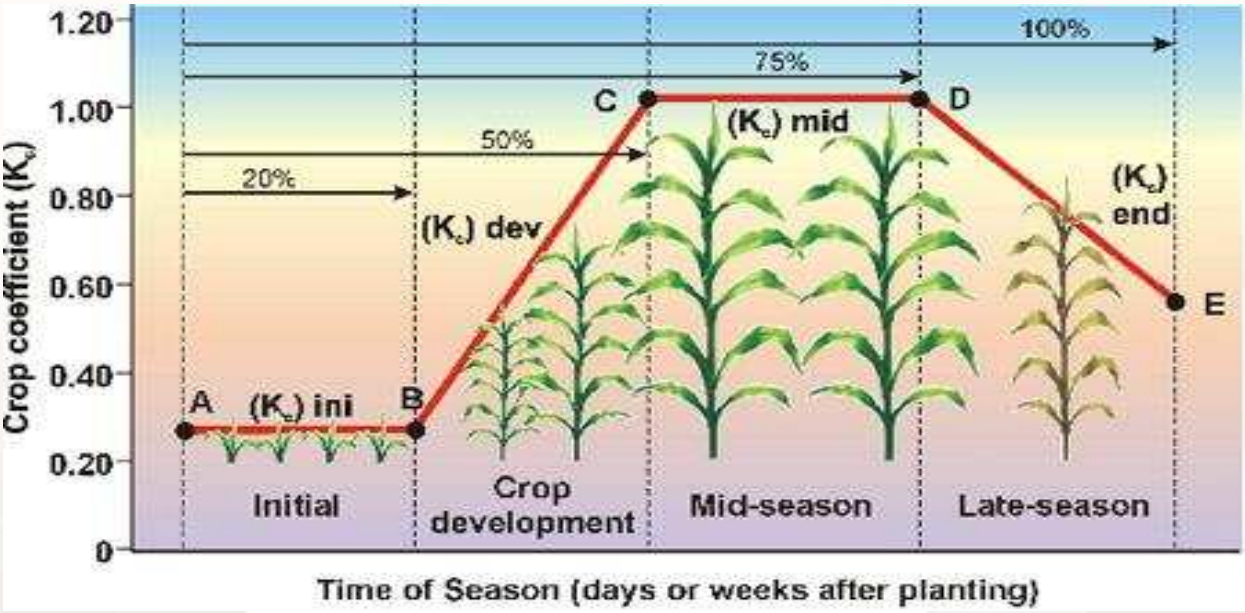

Fig.3 Crop coefficient and growth stages

Source: https://cropwatch.unl.edu/image/883897-version%3D1.0%26t%3D1248286069000.jpg

8.9 Factors considered estimating crop coefficient

- In general Kc is higher in hot, windy and dry climates than in cool, calm and humid climates.
- Most of crops the crop coefficient value for total growing period is between 0.85 to 0.90 with the exception of a higher value for rice and banana.
- The Kc values vary among crops due to differences in reflectivity, crop height and roughness, degree of ground cover and canopy resistance to transpiration.

- Annual crops K_c typically increases from a low value at seedling emergence to a maximum when the crop reaches full ground cover,

- continues at that value during the stage of full activity and declines as the crop matures.

Table 3 Crop coefficient for important crops at different stages of development is given below

Crop	Seedling	Vegetative	Reproductive	Maturity
Rice	1.1-1.2	1.1-1.4	1.1-1.3	0.9-1.0
Wheat	0.3- 0.4	0.7-0.8	1.0-1.2	0.6-0.8
Sorghum	0.3 – 0.4	0.7-0.8	1.0-1.1	0.7-0.8
Maize	0.3 – 0.5	0.7-0.8	1.0-1.2	0.8-0.9
Cotton	0.4 – 0.5	0.7-0.8	1.0-1.2	0.8-0.9

Source: (Reddy, 1999)

References and suggested reading

Majumdar, D.K. 2013. Irrigation Water Management Principles and Practices, PHI learning Private Limited. New Delhi.

Michael, A.M, 1978. Irrigation theory and practice, Vishal Publishing House Private Limited. New Delhi.

Reddy, S.R. 1999. Principles of agronomy. Kalyani publications, Ludhiana, New Delhi.

Course Name	**Water Management including Micro Irrigation**
Lesson 9	**Factors Affecting Water Requirement; Study Of Water Requirement Of Field Crops And Horticultural Crops**
Content Creator	**Dr. Hardev Ram**
University	**NDRI - National Dairy Research Institute**
Course Reviewer	**Prof. Ummed Singh**
University	**Agriculture University Jodhpur, Jodhpur**

Objective:

The study the water requirement of crops for planning of farm and irrigation project

Terminology:

Base Period (B): This is the period in days during which irrigation water is supplied to a crop. Normally it is equal to the period between the first and last irrigation applied to a crop

Delta (Δ): This the total depth of water required by a crop during the crop season to meet its requirements. It is expressed in mm or cm. This does not have any relevance to the area of the cropped field.

Duty of Water (D): This is defined as the area irrigated by one cusec or cumec discharge of water during the crop period. It is equal to twice the base divided by delta. It is expressed as ha/cumec or ha/cusec.

Effective rainfall: The fraction of total precipitation that forms the soil water reserve for consumptive use of crop or that becomes available for crop production.

Gross Irrigation Requirement: The total amount of water applied through irrigation to meet the soil water depletion from field capacity, inclusive the losses, which in other words in net irrigation requirement plus application and other losses. GIR=NIR/Irrigation efficiency.

Irrigation interval: Time between the start of successive field irrigation application on the same field, in days.

Irrigation period: The number of days that can be allowed for applying one irrigation to a given design area during the peak consumptive use period of the crop being irrigated. It is the basis for designing the capacity of an irrigation project.

Irrigation requirement: It is a part of total water requirement of a crop, exclusive of effective rainfall and soil moisture stored in the root zone or that contributed from the shallow ground water table. It expressed as; IR=WR-(ER+S), where, IR is Irrigation requirement, WR is Water requirement, ER is Effective rainfall and S is soil moisture stored in the root zone.

Net Irrigation Requirement: The depth of irrigation water required to bring the soil water level to field capacity in the effective root zone depth i.e., difference between the field capacity and the soil moisture content in the root zone before application of irrigation water. It excludes precipitation, carry over soil moisture or ground water contribution.

Water requirement: Water requirement may be defined as the quantity of water, regardless of its source, required by a crop in a given period of time for its normal growth under field conditions at a place. Water requirement includes the losses due to ET (or CU) plus the unavoidable losses during the application of irrigation water and water required for special operations such as land preparation, puddling, leaching etc.

9.0 Water Requirement

Water is mainly needed to meet the demands of evapo transpiration (ET) and the metabolic activities of plant, both together known as consumptive use (C or U). Since the water used in the metabolic activities of the plant are negligible, ET is practically considered equal to Cu.

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

Water requirement includes the losses due to ET (or CU) plus the unavoidable losses during the application of irrigation water and water

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required for special operations such as land preparation, puddling, leaching etc. It may express as:

WR= ET or CU + application losses + special needs.

Based on the sources of water supply to meet the water requirement, numerically it is represented as,

WR=IR+ER+S

Where;

IR, Irrigation water

ER, Effective rainfall

S, Soil profile contribution.

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

9.1 Needs of determination of water requirement

1. To decide the cropping pattern in a farm or area
2. Effective use of available water
3. Plan and design an irrigation project
4. Asses the irrigation requirement in an area
5. Management of water supply from sources

9.2 Factors affecting water requirement of crops

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

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Table 1 Effect of major climatic factors on crop water needs

imatic factor	**op water need**	
	gh	**w**
nshine	nny (no clouds)	oudy (no sun)
mperature	ɔt	ɔol
ımidity	w (dry)	gh (humid)
ind speed	indy	tle wind

(Source: http://www.fao.org/3/s2022e/s2022e02.htm**)**

9.2.1 Crop factors

a) Variety

b) Growth stages

c) Duration of crops

d) Plant population

e) Crop growing season

9.2.2 Soil factors

a) Structure

b) Texture

c) Depth

d) Topography

e) Soil chemical composition

f) Hydraulic conductivity,

g) Water holding capacity

9.2.3 Climatic factors

a) Temperature

b) Sunshine hours

c) Relative humidity

d) Wind speed

e) Rainfall

9.2.4 Agronomic management factors

a) Irrigation methods used

b) Frequency of irrigation and its efficiency

c) Tillage and other cultural operations like weeding, mulching, intercropping etc

Based on all these factors, average crop water requirement for various crops have been worked out

9.3 Irrigation requirement

It is a part of total water requirement of a crop, exclusive of effective rainfall and soil moisture stored in the root zone or that contributed from the shallow ground water table. It expressed as;

IR=WR-(ER+S),

Where,

IR, Irrigation requirement,

WR, Water requirement,

ER, Effective rainfall and

S, Soil moisture stored in the root zone.

9.4 Net irrigation requirement

The depth of irrigation water required to bring the soil water level to field capacity in the effective root zone depth i.e., difference between the field capacity and the soil moisture content in the root zone before application of irrigation water. It excludes precipitation, carry over soil moisture or ground water contribution.

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

Where;

d = Net irrigation water to be applied (cm)

Mfci = FC in ith layer (%)

Mbi = Moisture content before irrigation in ith layer (%)

Ai = Bulk density (g/cc)

Di = depth (cm)

n = number of soil layer

9.5 Gross irrigation requirement

The total amount of water applied through irrigation to meet the soil water depletion from field capacity, inclusive the losses, which in other words in net irrigation requirement plus application and other losses.

Gross irrigation requirement = $\frac{\text{Net irrigation requirement}}{\text{Field irrigation efficiency}}$

9.6 Irrigation frequency

Irrigation frequency is the number of days between irrigation during crop periods without rainfall. It depends upon the rate of uptake of water by plants and soil moisture supply capacity to plant and soil moisture available in the root zone. Hence it is a function of crop, soil and climate.

Design frequency (days)

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

9.7 Irrigation period

The number of days that can be allowed for applying one irrigation to a given design area during the peak consumptive use period of the crop being irrigated. It is the basis for designing the capacity of an irrigation project.

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

9.8 Steps involved to estimation of irrigation and water requirement

(Source: http://www.fao.org/3/x5648e/x5648e0e.htm)

The main steps in estimating crop water and irrigation requirements are as follows:

i. Set out a cropping calendar of 10 or 30-day for land preparation, planting, (draining the wetland rice field), harvesting, etc.

ii. Calculate 'reference crop evapotranspiration' (ETo) for each 10-day or weekly period.

iii. Select crop coefficients (kc); (kc = ETm/ETo for different stages of crop development);

iv. Obtain the maximum crop evapotranspiration (ETm) by multiplying ii. and iii- (ETm = ETo.kc) for different stages of crop development. This assumes no water shortages occur;

v. Add in water requirements for wetting the soil initially if it is dry, and for land preparation; also that for draining rice fields for weeding, etc.;

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vi. Subtract water requirements supplied by residual soil moisture towards the end of the growing season (if appropriate);

vii. Add in estimates of losses from run-off, seepage and percolation, or gains from run-on or groundwater;

viii. Calculate the leaching requirement;

ix. Deduct the contribution from precipitation or rainfall in farmers' fields (effective rainfall) from the irrigation water requirement;

x. Convert the above requirements in mm, into volumes of water per irrigated area (i.e. mm x 10 x ha = m^3;

xi. Add on the conveyance losses between source of water and the field;

xii. On the basis of the irrigation application technique, decide on irrigation schedules in terms of frequency, rate and duration of water application;

xiii. Determine peak water requirements in terms of flow rates (litres per sec per ha, l/s/ha);

xiv. Match supply and requirement profiles by review and iteration.

9.9 Water requirement of annuals and biennials

The vegetable crops are mostly annuals and their duration extends from two to five months or a single season.

Some may be biennial and the season may get extended.

The vegetable crops are sensitive to water stress.

The water requirement is normally expressed for the entire period of the crop in the field.

The crop water requirements are worked out for the period.

The requirement could be estimated by different methods.

9.10 Water requirement of perennial crops

Fruit crops are mostly perennials.

When an orchard is first established, transpiration is very low because of the small crop canopy.

Most water lost from the soil is by evapotranspiration from among the trees. With the increase in years the trees grow and a large canopy is established.

The water is expressed for one year or daily basis.

The water requirement of perennial crop through lysimeter is not a practical proposition.

Hence other methods may be used to assess the water requirements.

Table 2 Approximate values of seasonal crop water needs

Crop	Crop water need (mm)
Alfalfa	800-1600
Banana	1200-2200
Barley/Oats/Wheat	450-650
Bean	300-500
Cabbage	350-500
Citrus	900-1200
Cotton	700-1300
Maize	500-800
Melon	400-600
Onion	350-550
Groundnut	500-700

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Pea	350-500
Pepper	600-900
Potato	500-700
Rice (paddy)	450-700
Sorghum/Millet	450-650
Soybean	450-700
Sugarbeet	550-750
Sugarcane	1500-2500
Sunflower	600-1000
Tomato	400-800

(Source: http://www.fao.org/3/s2022e/s2022e02.htm**)**

9.11 Methods of determine crop water requirement

There are several methods are employed to estimate the crop water requirement. However, these methods depend on the availability of equipment and technical knowhow and desired level of accuracy. These methods are given below:

1. Direct methods,
2. Empirical methods and
3. Pan evaporimeter method.

The details about already discussed earlier (see section 8.4).

Suggested reading and references

Indian Society of Agronomy. 2009. Agronomy terminology. Division of Agronomy-IARI, New Delhi.
Majumdar, D.K. 2013. Irrigation Water Management Principles and Practices, PHI learning private limited. New Delhi.

Course Name	**Water Management including Micro Irrigation**
Lesson 10	**Methods Of Irrigation-Surface, Subsurface, Sprinkler And Drip; Their Types And Efficiencies; Constraints And Advantages Of Different Methods**
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Course Reviewer	**Prof. Ummed Singh**
University	**Agriculture University Jodhpur, Jodhpur**

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Objectives

1. To know about various methods of irrigation for application of water to irrigate fields
2. Which method of irrigation is suitable for most of crops

Terminology:

Basin Irrigation: A method of surface irrigation in which water is applied in small plots or nearly flat plot formed in the field by ridges.

Border strip irrigation: In this method of surface irrigation, the field is divided into strips separated by low parallel ridges called borders.

Bubbler irrigation: Bubbler typically applies water on per plant basis and is very similar to the point source external emitters in shape but differ in performance. Water from the bubbler head either runs down from the emission device or spread a few inches in an umbrella pattern. The flow rate in bubbler emitters is between 100-250 lph.

Cablegation: It is a semi-automated gated pipe system for achieving furrow inflow cutback that capitalizes on the natural reduction in infiltration rate as irrigation progresses to greatly reduce runoff. The operational advantage of this system is the ability to cut back furrow inflow while maintaining a constant delivery of water to the field along with inherent automation.

Check basin irrigation: Dividing the field into several relatively leveled plots called check surrounded by small bunds. Water is conveyed into check by system of supply channel.

Corrugation irrigation: It is modified furrow irrigation, adapted to rough slope of 10-15%. It consists of running water in shallow furrows called corrugations.

Drip (Trickle) irrigation: It can be defined as the process of slow application of water in discrete, continuous drops, tiny stream, or miniature sprays through mechanical devises called emitters which are

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located at selected points along water delivery lines. Agrochemicals can be effectively applied to individual or several plants using drip.

Micro spray: It is application of water on the soil surface by a small spray or mist which is distributed through air. Emitter discharge rates are < 100 lph. Spray system is like bubbler micro and it too needs minimal filtration and other maintenance but this system can be vulnerable to high wind and evaporation losses, particularly when the canopy is not well developed.

Micro-irrigation: The frequent application of required and measured quantity of water directly above or below the soil surface usually as continuous drops through emitters, as miniature spray along the water delivery line.

Spate irrigation: It may occur in hilly regions in dry zones where small rivers produce spate floods; ditches and bunds are built to guide the water to field for irrigation. No of fields irrigated are depended on the duration and intensity of irrigation.

Sprinkler irrigation: It is the application and distribution of water over the field in the form of spray created by expelling water under pressure from an orifice. In effect, it is a simulated series of rainfalls controllable frequency, duration, intensity and range of drop sizes.

Sub-surface irrigation: Irrigation is applied to crops by allowing water beneath the soil surface either by constructing trenches or installing underground perforated pipe lines.

Tidal irrigation: It is the sub-surface irrigation of levee soils in coastal plains with river water under tidal influence. It is applied in semiarid zones at the mouth of a large river estuary or delta where a considerable tidal range (2m) is present. The river discharge must be large enough to guarantee a sufficient flow of fresh water into the sea so that no salt water instruction occurs in river mouth.

Selection of suitable method of irrigation, the farmer must know which method suits the local conditions and their advantage and limitation. These methods are adopted to apply water to crops depending on the various factors i.e., natural conditions, type of crops, type of technology, previous experience with irrigation, required labour inputs, costs and benefits. Unfortunately, no single best solution: all methods have their advantages and disadvantages. In this chapter we discuss about important criteria in the selection of a suitable irrigation method to store water in the effective root zone and minimum water losses with optimum yield.

Methods of Irrigation

I. Surface

II. Sub-surface

III. Pressurized irrigation (Drip and sprinkler)

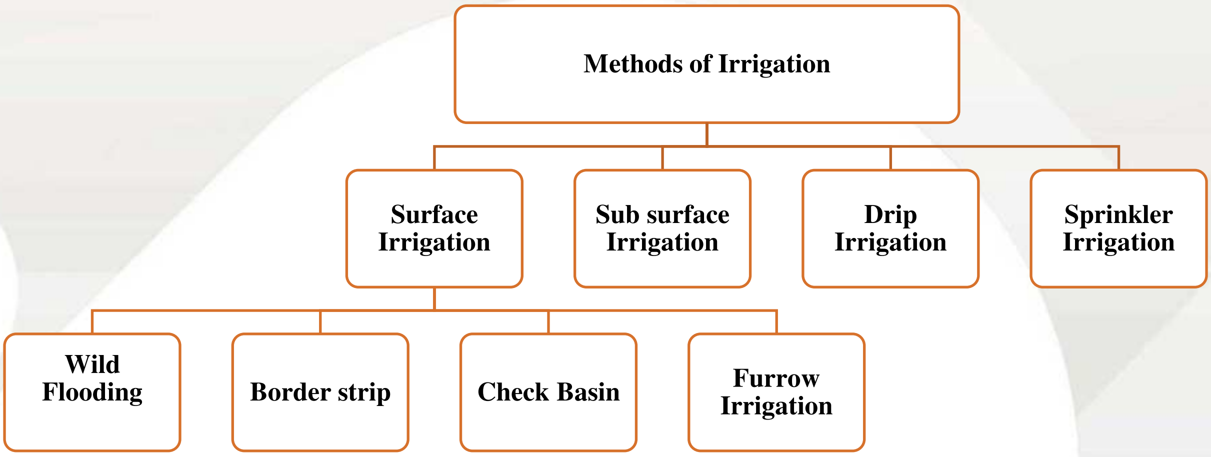

Fig 1 Classification of different method of irrigation

10.1 Surface irrigation

Surface irrigation is where water is applied and distributed over the soil surface by gravity. It is by far the most common form of irrigation throughout the world. Surface irrigation is grouped as border, check basin and furrow irrigations. Border is again classified in to two as straight and contour. Check basins may be of rectangular, contour or ring, whereas furrow irrigation is classified as deep furrow and corrugated furrows. These may be again straight or contour according to direction and leveled and graded as per their elevation.

10.1.1 Uncontrolled Flooding/Free Flooding

1. Refers to the irrigating fields that are relatively flat and level by allowing water from supply channels to flow overland along the natural slope
2. Size of stream, flow depth, land slope and water intake rate influence greatly the efficiency and uniformity of water application.

Suitability: Field should be relatively smooth and slope (~0.05%) gradually and uniformly towards natural drainage, deep soil not likely to crust badly, an area where land leveling could not be possible.

Crops: Grasses, fodder, close-growing grain crops, rice and pasture

Advantages

1. Don't require precise land leveling
2. application is easy and cheap
3. Don't require skilled labour

Disadvantages

1. Non-uniform wetting of land
2. accumulation of water in lower spots
3. Loss of water through percolation and runoff
4. Water application efficiency is very low
5. Poor crop performance due to uneven distribution of water

10.1.2 Border irrigation

1. The land is divided into several long parallel strips (3-15 m wide and 60-300 m long) called borders and these borders are separated by low ridges.
2. The strip has a uniform longitudinal gentle slope of 0.2-04 %.

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3. Border slope should be minimum 0.05% to provide drainage and maximum 2% to limit soil erosion problem
4. Each strip is irrigated independently by turning the water in the upper end.
5. The water spreads and flows down the strip in a sheet confined by the border ridges.

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

Border length: It varies from 60-300 m

Table 1 Recommended safe limit of slope and border length (for moderate slope & small to moderate flow) under different soil

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

Suitability: Soils having moderately low to moderately high infiltration rates. Not suitable in coarse sandy soils (very high infiltration rates) and heavy soilshaving (very low infiltration rate).

Crop: Close-growing crops like wheat, barley, fodder crops and legumes and upland rice, not suitable for rice.

Advantages of border irrigation

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

Disadvantages of border irrigation

1. High labour is required for leveling of the field.
2. Wastage of land.
3. High irrigation streams are required.
4. Repair of ridges and supervision during irrigation are needed.

10.1.3 Check basin irrigation

1. It is the most common method and widely practiced in India.
2. Here the field is divided into smaller unit areas so that each has a nearly level surface.
3. Bunds or ridges are constructed around the area forming basins within which the irrigation water can be controlled.
4. The water applied to a desired depth can be retained until it infiltrates into the soil.
5. The size of the basin varies from $10m^2$ to 25 m^2 depending upon soil type, topography, stream size and crop.

Suitability: Small gentle and uniform land slopes, soils having moderate to slow infiltration rates.

Crops: Both row and close growing crop, grain (wheat, maize etc.)and fodder crops in heavy soils.

Advantages

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

Limitations

1. The ridges interfere with the movement of implements.
2. More area occupied by ridges and field channels.
3. The method impedes surface drainage

4. Precise land grading and shaping are required
5. Labour requirement is higher.
6. Not suitable for crops which are sensitive to wet soil conditions around the stem.

10.1.4 Furrow irrigation

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

Suitability: Suitable to most soils except sandy soil

Crops: Wide spaced row crops including vegetables, Suitable for maize, sorghum, sugarcane, cotton, tobacco, groundnut, potatoes etc.

Fig 2. Furrow irrigation

(Source: https://www.usgs.gov/media/images/irrigation-methods-furrow-or-flood-irrigation)

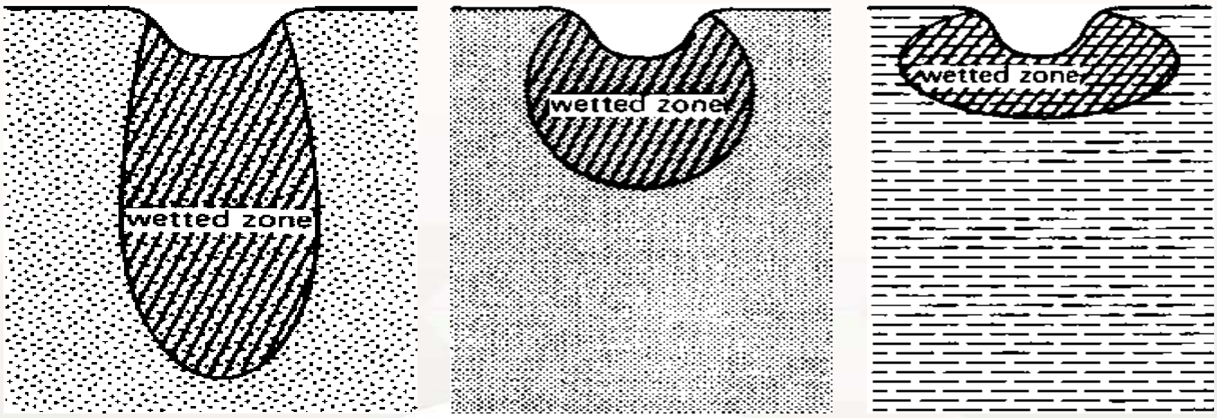
Advantages

1. Water in furrows contacts only one half to one fifth of the land surface.

2. Labour requirement for land preparation and irrigation is reduced.
3. Compared to check basins less wastage of land in field ditches.
4. Helpful in lands with high salt content as salts accumulate on the upper part.

Disadvantages

1. Land requires precise grading to a uniform slope
2. Labour requirement is high
3. This method is unsuitable for light irrigation



Sand **Loam** **Clay**

Fig 3. Wetting pattern in furrows in different soil type

(Source: http://www.fao.org/3/S8684E/s8684e04.htm)

Types of furrow irrigation

10.1.4.1 Based on alignment of furrows

1. Straight furrows
2. Contour furrows

10.1.4.2 Based on size and spacing

1. Deep furrows
2. Corrugations

10.1.4.3 Based on irrigation:

1. **All furrow irrigation:** Water is applied evenly in all the furrows and are called furrow system or uniform furrow system.
2. **Alternate furrow irrigation:** It is not an irrigation layout but a technique for water saving. Water is applied in alternate furrows for eg. During first

irrigation if the even numbers of furrows are irrigated, during next irrigation, the odd number of furrows will be irrigated.

3. **Skip furrow irrigation:** They are normally adopted during the period of water scarcity and to accommodate inter crops. In the skip furrow irrigation, a set of furrows are completely skipped out from irrigation permanently. The skipped furrow will be utilized for raising intercrop. The system ensures water saving of 30-35 per cent. By this method, the available water is economically used without much field reduction.
4. **Surge irrigation:** Surge irrigation is the application of water in to the furrows intermittently in a series of relatively short ON and OFF times of irrigation cycle. It has been found that intermittent application of water reduces the infiltration tare over surges thereby the water front advances quickly hence, reduced net irrigation water requirement. This also results in more uniform soil moisture distribution and storage in the crop root zone compared to continuous flow. The irrigation efficiency is in between 85 and 90%.

10.1.5 CORRUGATION

1. This is a partial surface flooding method of irrigation
2. These are miniature furrows adopted for irrigated close growing crops such as grain, forage and pasture crops.
3. This method is used for fine to moderately coarse soils, especially soils that bale and form crusts.
4. Corrugations are about 6-8 cm deep and 40-75cm apart depending on the physical properties soil and spacing of crops.
5. Crops: Wheat, Setaria, Groundnut.

10.2 Sub-surface irrigation

1. In subsurface irrigation, water is applied beneath the ground by creating and maintaining an artificial water table at some depth, usually 30-75 cm below the ground surface.
2. Moisture moves upwards towards the land surface through capillary action

3. Water is applied through underground field trenches laid 15-30 m apart.
4. Open ditches are preferred (relatively cheaper and suitable to all types of soil)
5. The irrigation water should be of good quality to prevent soil salinity.

Advantages

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

(Source: https://www.geo.fu-berlin.de/en/v/iwrm/Implementation/technical_measures/bilder/Bilder-irrigation/Sub-surface-irrigation.jpg?width=500)

Disadvantages

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

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10.3 DRIP IRRIGATION SYSTEM

1. Drip or trickle irrigation is one of the latest methods of irrigation.
2. Highest area under drip irrigation in Andhra pradesh (2018)
3. It is suitable for water scarcity and salt affected soils.
4. Water is applied in the root zone of the crop
5. Discharge rate: <12 lph.

Components

1. A drip irrigation system consists of a pump or overhead tank, main line, sub-mains, laterals and emitters.
2. The mainline delivers water to the sub-mains and the sub-mains into the laterals.
3. The emitters which are attached to the laterals distribute water for irrigation.
4. The mains, sub-mains and laterals are usually made of black PVC (poly vinyl chloride) tubing. The emitters are also made of PVC material
5. The other components include regulator, filters, valves, water meter, fertilizer application components, etc.

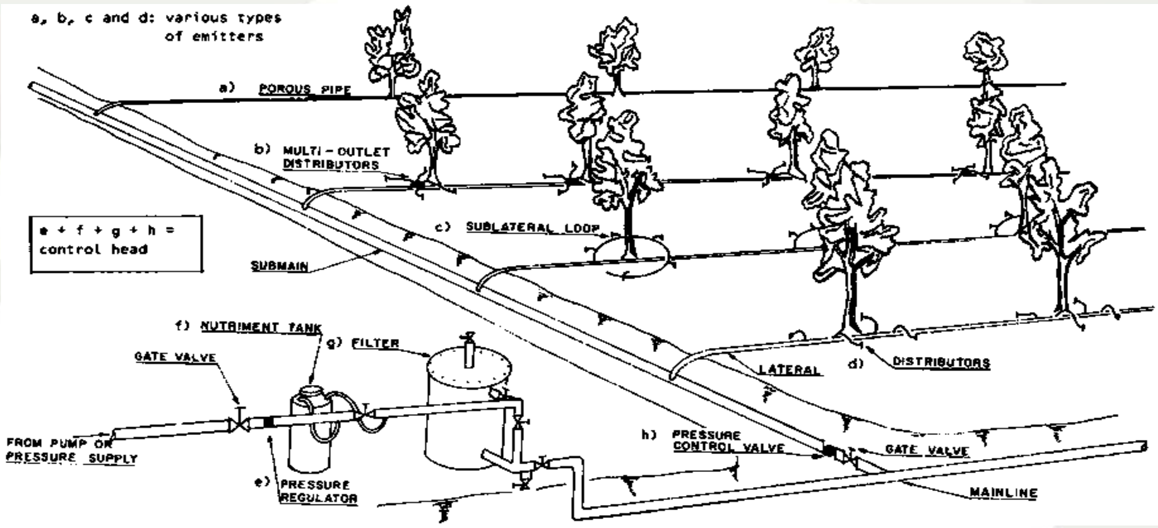

Fig.4 Layout of drip irrigation system

Source: http://www.fao.org/3/s8684e/s8684e1g.gif

Pump

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

Chemical tank

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

Filter

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

Emitters

Drip nozzles commonly called drippers or emitters are provided at regular intervals on the laterals. They allow water to emit at very low rates usually in trickles.

The amount of water dripping out of each emitter in a unit time will depend mainly up on the pressure and size of the opening. The discharge rate of emitters usually ranges from 2to 10 litres per hour.

Micro-tubes are also used in a drip lateral. They are used mainly in the following ways

(1) As emitters (2) as connectors, (3) as pressure regulators

Advantages of drip irrigation

1. Water saving- losses due to deep percolation, surface runoff and transmission area avoided.
2. Brackish water can be used more safely
3. Localized fertilizer application can be made with this system (fertigation)
4. Uniform water distribution
5. Application rates can be adjusted by using different size of drippers
6. Suitable for wide spaced row crops, particularly coconut and other horticultural tree crops

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7. Soil erosion is reduced
8. Better weed control
9. Land saving
10. Less labour cost.

Disadvantages

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

10.4 SPRINKLER IRRIGATION

1. It refers to the application of water to crop in form of spray from above the crop like rain.
2. Also called as overhead irrigation.
3. Highest area under sprinkler irrigation in Rajasthan.
4. Very low discharge rate as compared to surface irrigation.

Suitability:

1. Sandy soil or soil having high infiltration rate
2. Shallow soil that do not allow proper land leveling
3. Undulating, sloppy area
4. High priced crop
5. Water scarce area

Layout of sprinkler irrigation system

1. The sprinkler (overhead or pressure) irrigation system conveys water to the field through pipes (aluminum or PVC) under pressure with a system of nozzles.
2. This system is designed to distribute the required depth of water uniformly, which isnot possible in surface irrigation.

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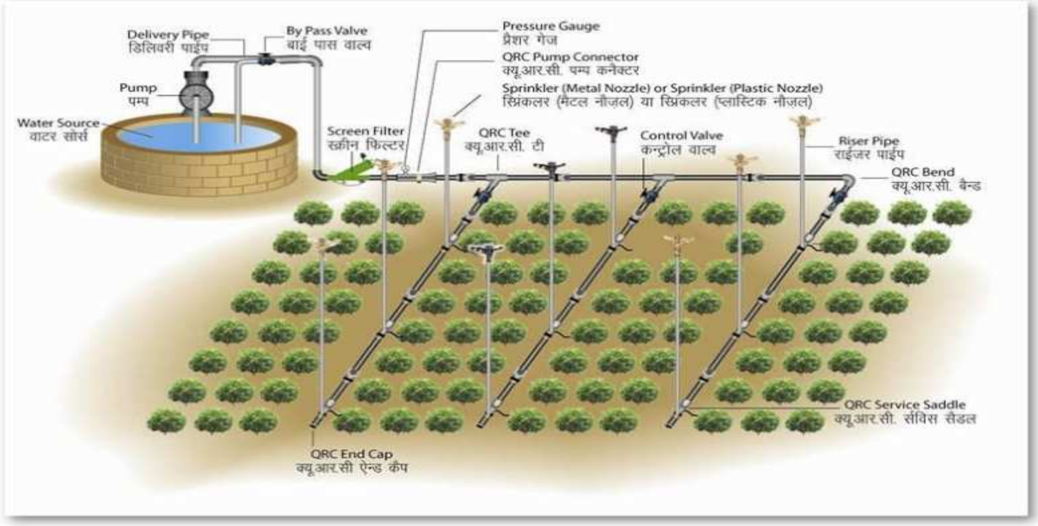
3. Water is applied at a rate less than the infiltration rate of the soil hence the runofffrom irrigation is avoided.



Layout of Sprinkler Irrigation System (छिड़काव सिंचाई प्रणाली का रेखाचित्र)

(Source: https://static.vikaspedia.in/media/images_en/agriculture/agri-inputs/farm-machinary/sprinkler-2test.jpg)

A sprinkler system usually consists of the following parts.

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

Pumping unit

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

Pipe lines

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

Couplers

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

Sprinklers

Sprinklers may rotate or remain fixed. The rotating sprinklers can be adapted fora wide range of application rates and spacing. They are effective with pressure of about10 to 70 m head at the sprinkler. Pressures ranging from 16-40 m head are considered the most practical for most farms. Fixed head sprinklers are commonly used to irrigate small lawns and gardens.

Other accessories / fittings

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

Types of sprinkler system

On the basis of arrangement for spraying irrigation water

1. Rotating head (or) revolving sprinkler system

2. Perforated pipe system

Based on the portability

1. **Portable system:** It has portable mainlines and laterals and a portable pumping unit
2. **Semi portable system: A** semi portable system is similar to a fully portable systemexcept that the location of the water source and pumping plant are fixed.
3. **Semi permanent system:** A semi permanent system has portable lateral lines,permanent main lines and sub mains and a stationery water source and pumping plant.The mainlines and sub-mains are usually buried, with risers for nozzles located at suitableintervals.
4. **Solid set system:** A solid set system has enough laterals to eliminate their movement.The laterals are placed in the field early in the crop season and remain for the season.
5. **Permanent system:** It consists of permanently laid mains, sub-mains and laterals anda stationary water source and pumping plant. Mains, sub-mains and laterals are usuallyburied below plough depth. Sprinklers are permanently located on each riser.

Advantages of sprinkler irrigation

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

Disadvantages of sprinkler irrigation

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

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

1. Irrigate at night
2. Increase the speed of the sprinkler rotation
3. Decrease the frequency of irrigation.

Table 2 Irrigation efficiency (%) under different irrigation methods

Irrigation Efficiency	Surface	Sprinkler	Drip
Conveyance efficiency	40-70	100	100
Application efficiency	60-70	70-80	90
Evaporation loss	30-40	30-40	20-25
Overall efficiency	30-35	50-60	80-90

(Source: Reddy and Reddy, 2016)

10.5 Other irrigation system

Modern irrigation systems do not fall in above mentioned categories but they may have combine characteristics of two or much such systems.

10.5.1 Low Energy Precision Applicators (LEPA)

The LEPA is modifications of centre pivot or linear move sprinkler systems. The sprinkler heads on such systems are replaced by closely spaced drops pipes releasing water at pressures of 7-35KPa few centimeters above the soil surface. Water can be applied at a rate to meet crop requirements as dikes are constructed in such a way that a few furrows row crops are accommodated in small basins. The irrigation efficiency is high as runoff is checked and irrigation requirement can be reduced as a result of improved use of water sprinkler.

10.5.2 Control Conduit gravity system

A buried corrugated plastic pipe distributes water between each two rows of trees. From this pipe a much smaller (< 10mm inside diameter) tube conveys water to each individual tree. The end of this tube is elevated several centimeters above the ground surface, but is left open without any emitter, etc. Since this system applies water at rates greater than the soil intake capacity, small dikes are formed around each tree to hold applied water until it infiltrates.

With the advancement of electronic technology, now-a-days chips ae used in computers which control the switching over the running of an irrigation system at the predetermined time interval so that the crop may not suffer from soil moisture stress particulraly at the critical crop physiological stages. This practice recently has been introduced in USA and in other advanced countries.

Suggested reading and references

Majumdar, D. K. 2018. Irrigation water management: Principle and practices. PHI Learning Private Limited, Delhi.

Michael, A. M. 2019. Irrigation- Theory and Practices. Vikas Publishing House, Delhi.

Reddy, S. R. and Reddy, G. K. 2016. Irrigation Agronomy, Kalyani Publishers, New Delhi, Punjab.

Course Name	**Water Management including Micro Irrigation**
Lesson 11	**Efficiency Of Irrigation; Methods To Measure Them**
Content Creator	**Dr. Hardev Ram**
University	**NDRI - National Dairy Research Institute**
Course Reviewer	**Prof. Ummed Singh**
University	**Agriculture University Jodhpur, Jodhpur**

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OBJECTIVE

1. **To learn about water losses during application**
2. **To measure irrigation efficiencies and how to improve it.**

TERMINOLOGY

Conjunctive use of water: It refers to the sum of surface water and groundwater used for providing soil moisture for optimum plant growth.

Consumptive use of water: It is the sum of total water transpired and used for carrying out metabolic activities and building up the plant body by vegetation and water evaporated from the unit area of vegetation.

Deep percolation: Water that percolates downwards through the soil beyond the crop root zone.

Field channel efficiency: It is the ratio between water received at the field inlet and that at the inlet of a block of field.

Irrigation frequency: It is the number of days between irrigations during period without rainfall.

Runoff: The portion of the precipitation which is not absorbed by the soil but finds its way into stream.

Seepage: The slow movement of the water through small cracks, pores, interstices, etc., in the surface of unsaturated material into or out of a body of surface or sub surface water.

Water-application efficiency: The percentage of water applied that can be accounted for as moisture increase in the crop-root zone of the soil.

Water-conveyance efficiency: It is the proportion of water delivered to the irrigated field from the total water diverted from the source.

Water-distribution efficiency: The extent to which water is uniformly distributed in a irrigation system.

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Water-expense efficiency: Grain yield per unit of net water use.

- Efficiency is a measure of output obtainable from a given input. Irrigation water is an expensive input and therefore has to be used very efficiently.
- The performance of an irrigation system is determined by the efficiency with water is diverted, conveyed and stored
- Irrigation efficiency is the ratio expressed in percentage of water stored in the root –zone depth of the water delivered in the field from the farm-supply source.
- The main losses during irrigation of field
- Conveyance (transportation of water)
- Storage losses
- Runoff losses
- Seepage (20 to 35%)
- Evaporation
- Deep percolation
- Field percolation losses estimated annually as 20 -30%
- Irrigation efficiency can be maximised by minimising the losses during conveyance, application, distribution and storage.
- In India, overall irrigation efficiency of major irrigation projects ranges between 35-40%.
- In order to meet the growing demands of water for food, environment, industry, and municipal use it is necessary to improve irrigation efficiency at all levels.

11.0 IRRIGATION EFFICIENCY (E_i)

•It is the ratio usually expressed as percent of the amount of water used to meet the **consumptive use** requirement of the crop (W_t) plus necessary to maintain salt balance in the crop root zone (W_S) to the total volume of water diverted, stored, pumped for irrigation(W_I).

$$E_i = W_t + W_S - R_e / W_I \times 100 \qquad (R_e = \text{effective rainfall})$$

11.1 Water Conveyance Efficiency (E_c)

•It is the ratio between water delivered to the irrigated plot and total delivered at the source.

•It indicates the losses of water that occur while water is conveyed from source to the point of utilisation.

$$E_c = (W_P)/(W_r) \times 100$$

Where;

$W_P = Water$ delivered to the plot.
W_r= Water delivered from the source.

11.2 Water application efficiency (E_a)

• It is ratio between the quantity of water stored in the root zone and the water delivered to the field.

•Irrigation water applied to the field is lost due to runoff and deep percolation.

$$E_a = W_s / W_p \times 100$$

Where;

W_s= water stored in the root zone.

$W_P = water$ delivered to the field.

Table 1 Indicative values of the field application efficiency

Irrigation methods	Field application efficiency
Surface irrigation (border, furrow, basin)	60%

Sprinkler irrigation	75%
Drip irrigation	90%

11.3 Water storage efficiency (E_s)

• This parameter estimates whether the amount of water necessary for the crop is stored in the root zone or not.

•It is the ratio of water stored in the root zone during irrigation to the water needed in the root zone prior to irrigation.

$$(E_s) = W_s/W_n \times 100$$

Where;

W_s= Water stored in the root zone.

$W_n = Water$ needed prior to irrigation in the root zone.

11.4 Water distribution efficiency (E_d)

• It is defined as the percentage of the difference from the unity of the ratio between the average numerical deviations from the average depth stored during the irrigation.

•It indicates uniformity in distribution of water over the entire root zone.

•It measure the efficiency of irrigation system over the other.

$$E_d = (1 - \frac{Y}{d}) \times 100$$

Where;

Y= average numerical deviation in depth of water stored from the average depth stored during irrigation.

d= average depth of water stored during irrigation.

11.5 Overall Project Efficiency

It is the ratio between the average depth of water stored in the root zone during irrigation and water diverted from the reservoir. When this is measured at the inlet to the field it is called as field irrigation efficiency. It is expressed as:

$$(E_s) = W_s/W \times 100$$

Where;

Eo = overall efficiency (%)

Ws= Water stored in the root zone (cm)

Wd= Water diverted from the reservoir (cm)

11.6 Operational efficiency

•It is the ratio of actual project efficiency, relative to the operational efficiency of an ideally designed and managed system.
•Low operational efficiency shows management or system design problems or both.

11.7 Economic irrigation efficiency

•It is the ratio of the total net or gross farm returns compared to total returns expected with ideally operated system under ideal conditions.
•It is a measure of overall efficiency of the project.

11.8 Factors influencing irrigation efficiencies

•**Soil texture:** finer soil texture has more surface runoff and hence less percolation losses.
•**Land surface:** irregular land surface reduce irrigation efficiency.
•**Size of streams:** too small or too large streams have low efficiency.
•**Application:** single and one go run application contribute to losses.

11.9. WATER USE EFFICIENCY

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

WUE=Y/ET

Y= Yield (kg/ha)

ET= Evapotranspiration (mm)

WUE = Water Use Efficiency (Kg/hamm)

- More yields is achieved with less water but with proper management.
- **Better management leads to better efficiency.**

It is of 3 types

11.8.1 Crop water use efficiency(CWUE)

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

CWUE=Y/ET

11.8.2 Field water use efficiency(FWUE)

It is the ratio of crop yield (Y) to the total amount of water used in the field (ET+Deep Percolation)

FWUE= Y (/ET+DP)

11.8.3 Physiological water use efficiency(PWUE)

It is the ratio of dry matter accumulation to the water lost in evaporation.

PWUE= DWA/ET

11.8.4 WAYS TO IMPROVING WUE

11.8.4.1 EFFICIENT WATER MANAGEMENT PRACTICES

1. Localised irrigation method
2. Irrigation scheduling
3. Deficit irrigation practices
4. Improving irrigation efficiencies
5. Conjunctive use of water

11.8.4.2 EFFICIENT CROMANAGEMENT(AGRONOMIC PRACTICES)

1. Selection of crop and cropping system
2. Tillage
3. Weed management
4. Mulching
5. Antitranspirant
6. Interaction with other inputs

Suggested reading and references:

FAO:http://www.fao.org/3/T7202E/t7202e08.htm#:~:text=Estimate%20the%20conveyance%20efficiency%2C%20using,48%25%20or%20approximately%2050%25

Majumdar, D. K. 2018. Irrigation water management: Principle and practices. PHI Learning Private Limited, Delhi.

Michael, A. M. 2019. Irrigation- Theory and Practices. Vikas Publishing House, Delhi.

Reddy, S. R. and Reddy, G. K. 2016. Irrigation Agronomy, Kalyani Publishers, New Delhi, Punjab

Course Name	**Water Management including Micro Irrigation**
Lesson 12	**Quantitative Estimation Of Irrigation Water-Direct And Indirect Methods; Expressions Of Flowing Water And Their Mutual Relations**
Content Creator	**Dr. Hardev Ram**
University	**NDRI - National Dairy Research Institute**
Course Reviewer	**Prof. Ummed Singh**
University	**Agriculture University Jodhpur, Jodhpur**

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
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Objective: To learn about the measurement water of flow

Terminology:

Hectare – centimetre: A volume necessary to cover an area of 1 hectare (10,000 sq. m) up to a depth of 1 centimetre (1 hectare – centimetre = 100 cu. m = 100,000 litres)

Hydrant / Vertical meter: used to measure flow in vertical pipes. It is portable. it is place in vertical end of any riser pipe

Hydrometry: Science and practice of water measurement called Hydrometry

Orifice: An orifice is an opening with closed perimeter usually circular or rectangular cross-section through which water flows

Parshall flume: Parshall flumes are devices for the measurement of flow of water in open channels, head drop is very small, adopting the venturi principle. It consists of three principal sections: (i) a converging upstream section, (ii) a throat which is a constricted section and (iii) a diverging downstream section

Submerged orifice: The downstream water level is above the top of the opening and flow discharges into water.

Venturi Meter: Venturi meter is a device in which pressure energy is converted into kinetic energy and it is used for measuring the rate of flow of liquid through pipes

Weirs: A weir is a notch of regular form built across the stream through which water flows

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12.0 Irrigation water measurement

Measurement of irrigation water is necessary to determine the amount of water is applied the crops. Accurate measurement also needed in field experiments on soil water relationships. In soil water conservations measurement of runoff helps to planning suitable soil and water conservation measures.

Presently, groundwater levels have been declining in most of the irrigated areas due to over pumping and faulty irrigation practices, causing concern over the long term water availability. Therefore, improved irrigation water management is needed, but without water measurements it is impossible to determine current usage and what management must accomplish.

12.1 Why water measurements required:

- To determine the amount of water to be applied to the crops.
- Measurement of runoff from particular area and measurement steam flow are required in planning suitable soil and water conservation measure.
- Determining irrigation efficiency;
- Improving water management;
- Estimate conveyance losses
- Monitoring and detecting problems in irrigation system and
- Estimation of annual water use

12.2 Units of water measurement:

Water may be measured in two condition viz. (i) at rest and (ii) in motion. At rest means volume of water is measured and different units used for volume measurement are litre, cubic metre, hectare-centimetre, hectare-metre etc. Water is measured in motion means rate of flow is measured and different units used for this are litre per second, cubic metre per second, etc.

1. Litre: The volume equal to one cubic decimetre or 1/1000 cubic metre.
2. Litre per second: A continuous flow amounting to 1 litre passing through a point each second.
3. Hectare – centimetre: A volume necessary to cover an area of 1 hectare (10,000 sq. m) up to a depth of 1 centimetre (1 hectare – centimetre = 100 cu. m = 100,000 litres)
4. Hectare –metre: A volume necessary to cover 1 hectare (10,000 sq. m) up to a depth of 1 metre (1 hectare –meter = 10,000 cu. m = 10 M litres)
5. Cubic metre: A volume equal to that of a cube 1 metre long, 1 metre wide and 1 metre deep.
6. Cubic metre per second: A flow of water equivalent to a stream 1 metre wide and 1 metre deep, flowing at a velocity of 1 metre per second. 1cumec = 35.314cusec
7. 1 cubic foot per second (c.f.s.) = 450 gallons per minute = 1 acre-inch per hour

12.3 Indirect methods of measurement of irrigation water in open channel

Indirect discharge measurement methods are used the flow measurement in open channels are as below:

a. Volumetric method

b. Velocity-area methods. I. Float method II. Current meter

c. Tracer method

d. Dilution technique

e. Radio isotope method

12.3.1 Volumetric method

This is the most simple and accurate method and can be used to measure small discharge flowing through a channel or a pipe. In this method, volume of water collected and time to fill a known volume of the container is noted with the help of a stop watch.

Discharge is obtained by dividing the volume of fill by the required time.

Discharge rate $= \frac{\text{Volume of container,litres}}{\text{Time,second}}$

12.3.2 Velocity-area method

The rate of flow passing a point in a pipe or channel is determined by multiplying the cross-sectional area of flow section at the right angles to the direction of flow by the average velocity of water.

Discharge = area × velocity

Area is determined by direct measurements. Velocity measured with float method or current meter

12.3.2.1 Float method

The float method of making rough estimate of the flow in a channel consists of noting the rate of movement of a floating body.

The surface velocity is always higher than the average stream velocity. Therefore, the surface velocity is multiplied by a factor of 0.85 to get the average velocity.

Vm=0.85 x Vs

The average velocity is multiplied by the average cross-sectional area gives the discharge

12.3.2.2 Current Meter Method

The velocity of water in a stream or river may be measured directly with a current meter and discharge estimated by multiplying the mean velocity of water by the area of cross-section of the stream.

Both the float and the current meter methods are used to measure flow of water, have very limited application in farm irrigation practice.

Types of current meters:

1. Cup type 2. Propeller type

These are used for measurement of velocity in irrigation channels, streams or rivers. The cup type current meter consists of a wheel having several cups and the propeller type consists of vanes or propeller attached to a rod.

12.3.3 Tracer method

The principle of this method is that a substance (referred as tracer) which dissolves in water but doesn't react with it is introduced into flow and its concentration is measured at two points.

12.3.4 Dilution method

In the dilution method of flow measurement, a relatively large quantity of chemical (common salt or sodium dichromate) or dye called as a tracer is dissolved in small quantity of water and placed in bottle so that tracer solution can be discharged at known rate into the water flowing in a channel or pipe

$Q= q_1 [C_2-C_1/C_0-C_2]$

Q= the rate of flow

q_1= rate at which solution added

C_1= initial concentration

C_0= concentration of solution being added

C_2= concentration measured downstream

12.3.5 Radio isotope method: The radio isotopes may be used in place of chemical or dye as a tracer and degree of dilution determined by counting the gamma ray emissions from diluted isotope

Q= FA/N

Q= rate of flow

F= counts per unit radioactivity per unit vol

A= total units of radioactivity introduced

N= total counts

12.3.6 Direct measurement of irrigation water

a. Weirs

b. Orifices

c. Parshall flume

12.3.6.1 Weirs: A weir is a notch of regular form built across the stream through which water flows. A notch may be a rectangular, trapezoidal or triangular. Rectangular and triangular are commonly used in farm.

Weirs may be divided into general classes: (i) sharp crested weirs (ii) broad crested the sharp crested weir is mostly used for measurement of irrigation water.

The weir is said to have free flow condition, if the surface of water downstream is below the crest level so that the nape is surrounded by air. If the downstream water level is higher than the weir crest level then it is a submerged flow condition.

12.3.6.1.1 Rectangular weir: The rectangular weir is used to measure large discharge. It has horizontal crest and vertical sides. In case, the crest length is same as that of the channel width, it is known as suppressed weir, otherwise contracted weir.

Suppressed weir $Q= 0.0184LH^{3/2}$

Q= litres/sec

L= Length of crest, cm

H= weight above the crest (cm)

Contracted weir $Q= 0.0184(L-0.2H)^{3/2}$

Q= litres/sec

L= Length of crest, cm

H= weight above the crest (cm)

12.3.6.1.2 Trapezoidal weir / Cipolletti Weir

The trapezoidal weir has a horizontal crest and the slides slope outward to give the weir a trapezoidal cross-section. Commonly a side slope of 1 horizontal to 4 verticals is used and it is named as Cipolletti weir. It is commonly used to measure medium discharges.

$Q= 0.0186L.H^{3/2}$

$L = L_1+L_2/2$

L_1= Crest bottom length (cm)

L_2 = crest top length (cm)

H= weight above the crest (cm)

12.3.6.1.3 Triangular or V- notch weir: The 90º V-notch weir is used to measure low discharges accurately (70 -112l/s). It is easy to install and portable at stationary.

$Q= 0.0318H^{5/2}$

Q= litres/sec

H= weight above the crest (cm)

Advantages of weirs:

- Easy to construct, portable and adjustable
- Accurately measuring a wide range of flows
- Can be used in combination with turnout and division structures

Disadvantages

- Relatively large head required, particularly for free flow conditions.
- Required continuous cleaning of sediment and kept free of weeds and trash, otherwise accuracy will be compromised

12.3.6.2 Orifices

An orifice is an opening with closed perimeter usually circular or rectangular cross-section through which water flows. Orifice act as weir when opening flow only partially for measurement of water. In case of free discharge, the flow from the orifice discharges entirely into air. In case of submerged orifice, the downstream water level is above the top of the opening and flow discharges into water.

$$Q = 0.16 \times 10^{-3}\, a\sqrt{2gH}$$

Q = discharge through orifice, litres/sec

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

g= acceleration due to gravity cm/sec^2

H = depth of water over centre of the orifice, cm

12.3.6.3 Parshall flume:

Parshall flumes are devices for the measurement of flow of water in open channels; head drop is very small, adopting the venturi principle. The loss of head for free flow limit is only 25% of that of weir. It is self-cleaning device. Parshall flume was designed by Ralph L. Parshall

It consists of three principal sections: (i) a converging upstream section, (ii) a throat which is a constricted section and (iii) a diverging downstream section

To determine discharge through the flume under free flow condition, head is measured at upstream section (Ha). However, downstream head (Hb) is also measured for submerged flow condition. Free flow condition prevails if the submergence ratio (Hb/Ha) remains within the following limits

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Width of throat	Free flow limit (Hb/Ha)
2.5 to 7.5 cm	0.5
1.5 to 22.5 cm	0.6
3.0 to 24.0 cm	0.7

Advantages of Parshall flume over the weirs:

a) The weirs and orifices require considerable head loss, get silted up easily therefore the accuracy of the measurement is affected.
b) Its operation is independent of approaching velocity.
c) Being a self-cleaning device, it is not affected by sand or silt deposition.

Disadvantages of Parshall flume

a) It is more expensive.
b) The construction is difficult.
c) Only the small size made of sheet metal is portable.
d) Correct selection of the size and proper setting for precise measurements require some expertise.

12.4 Water measurement structures for earthen channel

Earthen channels are shallower than concrete channel they are comparatively low velocities of flow. There are number of broad crest weir and long throated flumes are used to measure the discharge in canals.

a) Broad-crest weir
b) Triangular throated flumes
c) Truncated flumes

Course Name	Water Management including Micro Irrigation
Lesson 13	Concept Of Water Use Efficiency, Its Relevance And Factors Affecting It- Methods To Improve Wue
Content Creator	Dr. Hardev Ram
University	NDRI - National Dairy Research Institute
Course Reviewer	Prof. Ummed Singh
University	Agriculture University Jodhpur, Jodhpur

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
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Objective: To understand the concept of water use efficiency and how to improve it.

Terminology:

Consumptive use of water: It is the amount of water required by a crop for its vegetated growth to evapotranspiration and building of plant tissues plus evaporation from soils and intercepted precipitation. Consumptive use = Evapotranspiration = Evaporation + transpiration. It is expressed in terms of depth of water.

Efficiency: Efficiency is defined as dimension ratio of out over input. Efficiency= (Output from process/Input to process) x 100

Transpiration coefficient: It is the quantity of water required to produce one kg of dry matter.

Transpiration ratio: The amount of water transpired to produce unit quantity of dry matter. C_3 plants have higher transpiration ratio than C_4 plants.

Water productivity: water productivity is the ratio of net benefit from crops, forestry, fishery, and mixed agricultural systems to the amount of water used to produce those benefits.

Water use efficiency: The amount of dry matter that can be produced from a given quantity of water**.**

Water expense efficiency: Grain yield per unit of net water use. Expressed in per cent.

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13. Water Use Efficiency (WUE)

In India, agriculture sector consumes over 85 percent of the available water. Therefore, it's important that whether the water is used efficiently in different crops or not and how we can increase the productivity from available water. The efficiency concept in any system implies a measure of output obtained from a given unit of input. In agriculture sufficient use of water reflects how bets the irrigation water is used in crop production. The concept of WUE is introduced by Briggs and Shantz (1913), as a measure of the amount of biomass produced per unit of water used by a plant.

13.1 Water used by crop is evaluated in terms of water use efficiency (WUE). It is 3 types.

1. Crop water use efficiency (CWUE)
2. Field water use efficiency (FWUE)
3. Physiological water use efficiency (PWUE)

13.1.1 Crop water use efficiency (CWUE): It is the ratio of crop yield (Y) to the amount of water used by the crop in evapotranspiration (ET).

CWUE= Y/ET

13.1.2 Field water use efficiency (FWUE): It is the ratio of crop yield to the amount of water used by the crop in field, which includes ET and deep percolation (DP).

FWUE= Y/(ET+DP)

13.1.3 Physiological water use efficiency (PWUE): It is the ratio of dry weight accumulation to the water lost in evapotranspiration.

PWUE= Dry wt. accumulation/ET

13.1.4 Consumptive water use efficiency (CU WUE): It is the ratio of consumptive use of water (CU) to the amount of water depleted from the crop root zone (WDR).

CU WUE= CU/WDR

Table 1 Water use efficiency of important crops

Crop	Productivity of grain (or) WUE (kg/ha-mm)
Rice	3.7
Sorghum	9.0
Bajra	8.0
Maize	8.0
Groundnut	9.2
Wheat	12.6
Fingermillet	13.4

Table 2 water use efficiency of C3 and C4 species

Classes	WUE (mg dry wt/ g of water)	
	C3	C4
Dicotyledonous	1.59	3.44
Monocotyledon	1.49	3.14

(Source: Panda, 2009)

13.2 Factors influencing water use efficiency

13.2.1 Climatic Factors

- Climatic parameters influence both crop yield and crop water use. Temperature, day length, precipitation, RH etc influences the photosynthesis and finally yield. WUE has an almost inverse relationship with RH.
- On the other hand sunlight and temperature that influence both ET and photosynthesis will either increase or decrease water use efficiency depending on the predominance of one of the two processes in a

particular condition. However, weather conditions are cannot be altered by management.

13.2.2 Genetic factor*s*

- Yield is the result of interaction between plan genetic constitution and environmental factors in which they grow. Plant species therefore differ widely in their productive and water use. WUE of C_4 plants is higher than that of C_3 plants.
- Within the plant species greater variation occurs in yield due to differences in their genetic matter that affect various physiological processes.
- Traditional varieties with week stem and less vegetative growth have lower water use efficiency compared with the present day high yielding varieties in many crops.

13.2.3 Crop management practices

- Time and depth of sowing, plant population and row direction affect water use efficiency. Timely sowing is to harness the incidental radiation to the more extent for higher yields.
- Deep sowing delays the seed emergence, low plant population leads to loss of soil moisture more through evaporation than through evapotranspiration. In other hand, higher population causes competition for limited moisture that resulted in decrease of water use efficiency.
- N-S sowing improves water use efficiency. More growth and yield are obtained when crops do not experience water stress during their growth period and soil moisture is maintained at higher level (near FC)
- Water use efficiency under field condition increases, except in cases where the crop is harvested for vegetative fresh parts. Use of antitranspirants, growth retardants, mulches, shelterbelts and weed control increases water use efficiency by reducing ET.
- The WUE of crops invariably increases with the application of fertilizers on deficit soils under adequate soil moisture conditions. This happens

because adequate supply of nutrients increases crop yields without much increase in the crop water needs.

- WUE can be improved by growing high yielding varieties well adapted to the region with timely agronomic practices like timely sowing, optimum plant stand, adequate and timely irrigation, fertilizer application, weed control etc. and need based plant protection.
- Pests and disease reduce crop yield and hence WUE varies depending on the degrees of infestation because water requirement of crops, do not change to a significant level except increase where premature death of plants occur.
- Any management practice that increases yield without correspond increase in crop water requirement will increase WUE.

13.3 Methods to improve water use efficiency

Strategies for efficient management of water for agricultural use involve enhancing water use efficiency by crops. The WUE may increase by reduced ET and/ or increasing yield, if both are independent. Management practices for improving water use efficiency can be broadly grouped into two:

13.3.1 Efficient water management practices

- Localized irrigation methods
- Irrigation scheduling
- Deficit irrigation practices.
- Improving the irrigation efficiency
- Conjunctive use of water resources
- Irrigation water pricing

13.3.2 Efficient crop management (agronomic) practices

- Selection of crop and cropping system
- Tillage
- Fertilizer use
- Weed management
- Plant density and pattern

- Mulching
- Anti-transparent
- Amelioration of problem soils
- Interaction with other inputs

13.4 Water productivity

The crop physiologists defined water use efficiency as the amount of biomass or marketable yield per unit of transpiration or evapo-transpiration. Irrigation scientists and engineers used the term water use efficiency as "the ratio of irrigation water transpired by the crops to the water delivered from a source. The concept of water use efficiency does not indicate the total benefits produced, nor does it specify that water lost by irrigation. The term water productivity includes the benefits and costs of water used for agriculture and defined as "the ratio of net benefit from crops, forestry, fishery, and mixed agricultural systems to the amount of water used to produce those benefits". Further it can use as per the use of water.

13.4.1 Physical water productivity (Kg/m^3): It is the ratio of agricultural output to the amount of water consumed from all available sources including irrigation, rainfall etc.

13.4.2 Irrigation water productivity (Kg/m^3): It is the ratio of crop output to the irrigation water applied by the farmer/irrigation system either through surface canals, tank, pond or the well and tubewell during the crop growth.

13.4.3 Economic water productivity (Rs/m^3): It is the ratio of value of crop output to the amount of water consumed or to the amount of irrigation water applied by the farmer.

13.4.5 Key principle to increase water productivity

1. Increase the marketable yield of a crop for each unit of water transpired
2. Reduce all outflow (drainage, seepage, percolation, evaporation, excluding stomatal transpiration)
3. Increase effective use of rainfall, stored water and marginal quality water

13.4.6 Water productivity depends on many factors like-

1. Cropping patterns
2. Irrigation technology
3. Climate patterns
4. Land and infrastructure
5. Geohydrology
6. Water footprint and virtual water
7. Climate change
8. Economic and policy issues.

Table 3 Enhancing Water productivity

At plant level	At field level	At basin level
1. Improve seedling vigour 2. Increasing rooting depth 3. Increase harvest index 4. Enhance photosynthetic efficiency	1. Selection of crops 2. Panting methods 3. Minimum/Conservation tillage 4. Irrigation at most sensitive stage 5. Nutrient management 6. Micro Irrigation and drainage 7. Timely plant protection	1.Basin land use planning 2.Better use of medium term weather forecasting 3.Improved irrigation scheduling to account for rainfall variability 4.Conjunctive use of water

Course Name	**Water Management including Micro Irrigation**
Lesson 14	**Assessment Of Irrigation Requirement. Scheduling Of Irrigation-Approaches And Methods To Schedule Irrigation**
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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Objectives:

1. To assessed the irrigation requirement of crops
2. To find out suitable approach of irrigation scheduling

Terminology:

Irrigation: artificial application of water to soil to help crop growth and production especially can be during stress periods.
Irrigation Scheduling: amount and time of application of irrigation according to crop need and water availability.
IW/CPE ratio: based on the climatological approach scheduling of irrigation water is done and the depth of irrigation water is fixed for different crops.
IW : CPE = Irrigation water (mm or cm) / Cumulative pan evaporation (mm or cm).
Lysimeter: A device for measuring percolation and leaching losses from a column of soil under controlled conditions.
Moisture regimes: The different levels of the available soil moisture (ASM as %), a testing factor or unit inputs used in conducting irrigation experiments, such as ASM at 100, 80, 60, 40% etc.
Open pan evaporation: It is the value of evaporation from an open pan (standard USWB class 'A' pan) evaporimeter. Water needs of crops can be well predicted from the values of open pan evaporation in a given area and in a specified period.
Tensiometer: A device for measuring the negative pressure (or tension) of water in soil in situ, consisting a porous permeable ceramic cup connected through a tube to a manometer or vacuum gauge. It is used in irrigation scheduling

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14.1 IRRIGATION REQUIREMENT

The major objective of irrigation is supply of optimum water to obtain optimum yields and quality. The timing and amount of applied water is determined by the existing climatic conditions, crops and its growth stages and soil properties. Thus, it is important to study the irrigation requirements which can be estimated by following equations.

➢ **Irrigation requirement (IR):** It is part of total water requirement of crop, exclusive of effective rainfall and soil moisture stored in the root zone or that contributed from the shallow ground water table.
Irrigation requirement of crop refers to the water requirement of crops, exclusive of effective rainfall and contribution from soil profile.

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

Where IR is Irrigation requirement

ER is effective rainfall and S is the soil moisture stored in the root zone.

➢ **Net irrigation requirement (NIR):** The depth of irrigation water required to bring the soil water level to field capacity in the effective root zone depth. The net irrigation requirement excludes precipitation, carry-over soil moisture or groundwater contribution or other gains in soil moisture.
➢ **Gross irrigation requirement:** The total amount of water applied through irrigation to meet the soil water depletion from field capacity, including the losses that may occur during conveyance, distribution and application of water.

Gross irrigation requirement = Net irrigation requirement / Irrigation frequency

14.1.1 Importance of estimating irrigation requirements (IR)

➢ IR is essential for planning, design and operation of irrigation and water resources systems

➢ It is assessing the adequacy of water resources, for evaluating the need of storage reservoirs and for the determining the capacity of irrigation systems.
➢ It is also essential for formulation the policy for optimal allocation of water resources as well as in decision-making in the day-to-day operation and management of irrigation systems.

14.2 SCHEDULING OF IRRIGATION

Scientific irrigation scheduling is a technique providing knowledge on when and how much water to apply to a field to optimize crop yields with maximum water use efficiency and at the same time ensuring minimum damage to the soil properties.

14.2.1 Advantages of Irrigation Scheduling

Irrigation scheduling offers several advantages:

A) It enables the farmer to schedule water rotation among the various fields to minimize crop water stress and maximize yields.

B) It reduces the farmer's cost of water and labor through less irrigation, thereby making maximum use of soil moisture storage.

C) It lowers fertilizer costs by holding surface runoff and deep percolation (leaching) to a minimum.

D) It increases net returns by increasing crop yields and crop quality.

E) It minimizes water-logging problems by reducing the drainage requirements.

F) It assists in controlling root zone salinity problems through controlled leaching.

G) It results in additional returns by using the "saved" water to irrigate non-cash crops that otherwise would not be irrigated during water-short periods.

14.2.3 Practical considerations in irrigation scheduling

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

1. Crop factors

a) Sensitiveness to water shortage

b) Critical stages of the crop

c) Rooting depth

d) Economic value of the crop

2. Water delivery system

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

b) Well irrigation (individual decision is final)

3. Types of soil

a) Sandy – needs short frequency of irrigation and less quantity of water

b) Clay – needs long frequency of irrigation and more quantity of water

4. Salinity hazard

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

5. Irrigation methods

a) Basin method allows more infiltration through more wetting surface which in turn needs more water and long interval in irrigation frequency

b) Furrow method allows less infiltration due to less wetting surface which needs less water and short interval in irrigation frequency.

c) Sprinkler method needs less water and more frequency

d) Drip method needs less water and more frequency

6. Irrigation interval

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

7. Minimum spreadable depth

We cannot reduce the depth based on the water requirement of the crop alone.

14.3 Criteria for scheduling irrigation

With the advancement of knowledge in the field of soil-plant-atmospheric system several criteria for scheduling irrigations are now available and are being used by investigators and farmers. All the available criteria can be broadly classified into the following three categories:

CRITERIA OF IRRIGATION SCHEDULING

Soil water regime

1. Feel and appearance
2. Depletion of available soil moisture
3. Soil moisture tension

limatological pproach

1. Cumulative pan evaporation
. IW/CPE ration

Plant indices

. Visual systems
. Soil cum sand mini-plot
. Plant population
. Growth rate
. Relative water content
. Relative water potential
. Canopy temperature
. Indicator plants
. Critical growth stages

However, criteria most suitable for scheduling irrigation's would vary with soils, plants, climatic and management factors.

14.3.1 Soil water regime approach

In this approach the available soil water held between field capacity and permanent wilting point in the effective crop root zone depth described in several ways is taken as an index or guide for determining practical irrigation schedules. Alternatively soil moisture tension, the force with which the water is held around the soil particles is also sometimes used as a guide for timing irrigations. Different methods of scheduling irrigation following soil moisture regime approach are as follows:

14.3.1 Feel and appearance of soil

This is one of the oldest and simple methods of determining the soil moisture content. It is done by visual observation and feel of the soil by hand. The accuracy of judgment improves with experience. Based on several years of experience guidelines have been developed, which help the farmers to judge the soil moisture present in the soil samples drawn from the crop root zone depth and based on depletion of available soil moisture (DASM) irrigations are scheduled. Though it is a crude method it can be used satisfactorily for some purpose if experience is backed by other local information. Further this method is subjective.

14.3.2 Depletion of the available soil moisture (DASM)

In this method the permissible depletion level of available soil moisture in the effective crop root zone depth is commonly taken as an index or guide for scheduling irrigations to field crops. In general, for many crops scheduling irrigation's at 20 – 25% DASM in the soil profile was found to be optimum at moisture sensitive stages. While at other stages irrigations scheduled at 50% DASM were found optimum. Some of the examples are given in Table 14.1.

Table 1 Optimum DASM levels for various crops

Crop	Optimum soil moisture depletion level
Maize	5–50%DASM in Hyderabad, Andhra Pradesh
Sugarcane	25 – 65% DASM in Lucknow, Uttar Pradesh
Groundnut	5 – 40% DASM in Tirupathi, Andhra Pradesh
Cotton	65% DASM in Coimbatore, Tamilnadu
Sesame	50% DASM in Parbhani, Maharashtra
Tobacco	35% DASM in Rajahmundry

Wheat	50% DASM in Delhi & Jobner, Rajasthan

Disadvantages

A. Soil moisture alone is taken into account.

B. Hence it cannot be taken for all type of soil in particular region.

C. It varies from soil to soil.

14.3.3 Soil moisture tension

Soil moisture tension a physical property of film water in soil, as monitored by tensiometer at a specified depth in the crop root zone could also be used as an index for scheduling irrigations to field crops.

Tensiometers are installed in pairs, one in the maximum rooting depth and the other below this zone. Whenever critical soil moisture tension is reached say for example 0.4 or 0.6 or 0.75 bars etc in the upper tensiometer the irrigation is commenced. While the lower one (tensiometer) is used to terminate the irrigations based on the suction readings in the below soil profile zone. It is generally used for irrigating orchards and vegetables in coarse textured soils because most of the available soil moisture is held at lower tensions.

Table 2 Critical soil moisture tension (Cent bars)

S.No.	Crop	Critical soil moisture tension (Cent bars)	Depth of maximum rooting density (cm)
1	Sugarcane	30 – 65	30
2	Maize	25– 50	30
3	Cotton	40 – 50	30
4	Sorghum	50 – 65	60
5	Tobacco	30 – 40	30
6	Soybean	50 – 60	30
7	Wheat	40 – 50	30
8	Potato	25 – 50	30

Merits

A. Same location and depth is observed with time, giving consistency.
B. Good for irrigation scheduling of sensitive crops which require frequent irrigations.
C. Good for irrigation scheduling in coarse textured soils where majority of ASM is between 0 and -80 kPa.

Demerits

A. Maximum pressure potential which can be measured is about -0.8 bars.
B. Maximum depth of insertion about 5m.
C. Water in tensiometer must be maintained at a constant height.

14.3.4 Depth interval and yield approach

In this method, different depths of irrigation water at different time intervals fixed arbitrarily are tried without considering the soil and weather characters. The irrigation treatment which gives the maximum yield with minimum depth and extended interval is chosen as the best irrigation schedule. Earlier workers have adopted this practice to work out the duty of water for different crops in many irrigation projects. It is the rough irrigation schedule. Hence may irrigation projects which have adopted this practice have failed to achieve the full efficiency?

Disadvantages

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

14.4 Climatological Approach

The potential rate of water loss from a crop is primarily a function of evaporative demand of the atmosphere under adequate soil water conditions. Thus in this method the water loss expressed in terms of either potential evapotranspiration (PET) or cumulative pan evaporation (CPE) over short periods of time are taken as an index for scheduling irrigation's. Different climatological approaches are described below:

14.4.1 Potential evapotranspiration (PET)

Penmen (1948) introduced the concept of PET and he defined it as "the amount of water transpired in a unit time by short green crop of uniform height, completely covering the ground and never short of water". He further stated that PET cannot exceed pan evaporation under the same weather conditions and is some fraction of pan evaporation. PET can be estimated by several techniques viz., lysimetric methods, energy balance, aerodynamic approach, combination of energy balance and empirical formulae etc., and irrigation's can be scheduled conveniently based on the knowledge of PET or water use rates of crops over short time intervals of crop growth.

Lysimeter

By isolating the crop root zone from its environment and controlling the processes that are difficult to measure, the different terms in the soil water balance equation can be determined with greater accuracy. This is done in lysimeters where the crop grows in isolated tanks filled with either disturbed or undisturbed soil. Lysimeter is a large tank filled with soil and supported on a weighing mechanism. Rectangular units of 4 m^2 seem practical and satisfactory for most of crops. Total depth should be 100 cm for shallow rooted crops and 150 cm for deep rooted crops. In general, 50% available soil moisture depletion in root zone should not be exceeded. Some plants as in the surrounding area are grown in the lysimeter.

Advantage

Lysimeter provide a standard against which other method can be tested and calibrated.

Disadvantages

A. As lysimeters are difficult and expensive to construct and as their operation and maintenance require special care.
B. Their use is limited to specific research purposes.

14.4.2 Cumulative pan evaporation

Earlier investigations have shown that transpiration of a crop is closely related to free water evaporation from an open pan evaporimeter (Fig. 8.4). Thus, the open pan evaporimeter being simple and as they incorporate the effects of all climatic parameters into a single entity i.e., pan evaporation could be used as a guide for scheduling irrigation's to crops.

Based on the same analogy, an alternative, simple can evaporimeter was devised by Jain (1975). The evaporation from it was shown to be closely related to pan evaporation as well as soil moisture depletion; hence it could also be satisfactorily employed in place of evaporimeter for scheduling irrigation to crops.

14.4.3 IW: CPE ratio

Prihar *et al*. (1974) advocated irrigation scheduling on the basis of ratio between the depth of irrigation water (IW) and cumulative evaporation from U.S.W.B. class A pan evaporimeter minus the precipitation since the previous irrigation (CPE).

An IW/CPE ratio of 1.0 indicates irrigating the crop with water equal to that lost in evaporation from the evaporimeter. If 5cm water is applied when the cumulative pan evaporation is 10 cm, the IW/CPE ratio will be 0.5. The ration usually fixed anywhere between 0.5 and 1.0. Smaller ratio indicates irrigation is longer intervals and larger ratio indicates frequent irrigations.

Table 3 Crop and IW/CPE ratio

S.No.	Crop	IW/CPE ratio	Critical stages
1.	Rice	1.2	Flowering, panicle initiation
2.	Wheat	0.9	CRI, flowering
3.	Maize	0.9	Tasselling, silking
4.	Cotton	0.75	Flowering, boll formation
5.	Sugarcane	0.8	Shoot elongation, tillering
6.	Sorghum	0.8	Flowering, premordia elongation

7.	Pearlmillet	0.6	Flowering, tillering
8.	Barley	0.6	Tillering, heading
9.	Rapeseed-mustard	0.7	Flower initiation, pod formation
10.	Groundnut	0.6	Peg formation, pod filling
11.	Sesamum	0.6	Flowering, seed setting
12.	Gram	0.6	Flower initiation, pod formation
13.	Pigeon pea	0.6	Flower initiation
14.	Potato	1.2	Stolonization, tuber formation
15.	Tobacco	0.4-0.5	Vegetative phase
16.	Lentil	0.6	Pre-flowering, pod formation
17.	Peas	0.6	Flower initiation, pod formation
18.	Sunflower	0.9	Flower bud initiation, seed setting
19.	Safflower	0.4	Flower initiation
20.	Soybean	0.6	Flower initiation, pod filling
21.	Berseem	1.0	Flowering, seed setting
22.	Green gram/black gram/cowpea	0.6	Flowering
23.	Sugar beet	0.6	Root initiation and development
24.	Linseed	0.6	Flower initiation, seed setting
25.	Finger millet		Heading

Advantages

A. Gives best correlation compared to other formulae where climatic parameters and

B. Soil parameters (depth) are considered.

Disadvantages

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

14.5 Plant Indices Approach

The plant in one form or the other expresses water deficits in the soil, since it is the one, which is affected by the water, stress. Any plant character, related directly or indirectly to water deficits and which responds readily to the integrated influences of soil water, plant and environmental parameters may serve as a criterion for timing irrigation to crops. Some of the plant indices commonly used is discussed below:

14.5.1 Visual plant symptoms

In this method the visual signs of plants are used as an index for scheduling irritations. For instance, plant wilting, drooping, curling and rolling of leaves in maize is used as indicators for scheduling irrigation. Change in foliage colour and leaf angle is used to time irrigations in beans.

14.5.2 Soil-cum-sand mini-plot technique

This method is also referred to profile modification technique. The principle involved in this technique is to reduce artificially the available water holding capacity of soil profile (i.e., effective root zone depth) in the mini-plot by mixing sand with it. Plants are growing on sand mixed plot showed wilting symptoms earlier than in the rest of the area. Usually, an area of 1.0 m^2 is selected in the field and a pit of 1.0m depth is excavated. About 5% of sand by volume is added to the dug up soil and mixed well. The pit is then filled back with the mixture and while filling up every 15 cm layer is well compacted, so that the soil in the pit retains the original bulk density as that of surrounding soil. Crop is sown normally and is allowed to grow as usual with the rest of the field. As and when the plants in the mini-plot show wilting symptoms it is taken as a warning of impending water need and cropped field is irrigated.

14.5.3 Increased Plant population

An area of about 1.0m^2**,** preferably in a high spot, is sown with the same crop to maintain about 4 times the plant population compared with that in the surrounding area. Crop with high stand established wilts earlier than the crop in the rest of the field indicating timing of irrigation.

14.5.4 Relative water content

This concept was proposed by Weatherly (1950). It is the actual water content of the leaf or plant when sampled relative to water at saturation or turgid. It is expressed as relative water content (RWC) and is calculated as follows:

RWC= Fresh weight – Dry weight / Turgid weight – Dry weight

14.5.5 Plant water potential

This method measures the energy status of plant water analogous to the tension of film water in the soil, and serves as a better index of physiological and bio-chemical phenomena occurring in the plant. Plant or leaf water potential can be precisely measured either by a pressure bomb or pressure chamber apparatus in situ or by the dye method in the laboratory.

The critical plant water potential values for cotton below which yield reductions are expected were 1.2 to 1.25 MPa throughout the crop life. While for sunflower they were 1.0, 1.2 and 1.4 MPa at vegetative, pollination and seed formation, respectively.

14.5.6 Canopy temperature

Several studies have shown that plant temperature or canopy temperature adequately reflects the internal water balance of the plant, and can be used as a potential indicator for scheduling irrigation to crops. It can be measured by several instruments, which are commercially available viz., porometer, infrared thermometer etc.

14.5.7 Indicator plants

Some workers have suggested the use of indicator plants as a guide for scheduling irrigations. In wheat, scheduling irrigations on the basis of wilting symptoms in maize and sunflower gave the highest grain yields.

14.5.8 Critical growth stages

The crop plants in their life cycle pass through various phases of growth, some of which are critical for water supply. The most critical stage of crop growth is the one at which a high degree of water stress would cause maximum loss in yield. Further, studies on irrigation at growth stages may give an indication as to whether scarce water can be used more efficiently by scheduling irrigation's at critical stages. The critical growth stages of various crops for moisture supply are presented in Table 14.3.

References and suggested reading

Allen, R.G., Pereira, L.S., Raes, D., and Smith M. (1998). "Crop evapotranspiration: Guidelines for computing crop water requirements." Irrigation and Drainage Paper No. 56. Rome: FAO.

https://ecourses.icar.gov.in/e-Leaarningdownload3_new.aspx?Degree_Id=01

Indian Society of Agronomy 1987. Agronomy terminology. New Delhi.

Indian Society of Agronomy 1998. Fifty years of agronomic research in India, New Dehli.

Majumdar, D.K. 2013. Irrigation Water Management Principles and Practices, PHI learning private limited. New Delhi.

Michael, A.M. (2008). Irrigation Theory and Practice. Vikas Publishing House Pvt. Ltd. New Delhi.

Reddy S.R., 1999 Principles of agronomy. Kalyani publications, Ludhiana, New Delhi.

Yelamanda Reddy, T., and Shankara Reddi G.H. 2017. Efficient use of Irrigation water. Kalyani publishers, Ludhiana.

Yelamanda Reddy, T., and Shankara Reddy G.H. 1992. Principles of Agronomy. Kalyani publications, New Delhi.

Course Name	**Water Management including Micro Irrigation**
Lesson 15	**Development Of Irrigation Plans For Individual Farms And Micro And Macro Commands**
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Course Reviewer	**Prof. Ummed Singh**
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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
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Objective: To learn about irrigation planning for better water management

Terminology:

Command area (CA): The command area of a water source is the extent of area which can be reliably irrigated from that source. Reliable irrigation means that the availability of water is always larger than or equal to the irrigation need of a scheme.

Cultivable area: It consists of net area sown, current fallow, fallow lands, other lands, current fallow, culturable waste and land under miscellaneous tree crops.

Cultivable Command Area (CCA): The area which can be irrigated from a scheme and is fit for cultivation.

Irrigation Plans: An irrigation plan is a detailed systematic record of information often supported by sketch of irrigated area, to plan and estimate all the aspects of irrigation in a given area.

Irrigation Potential Created: The total gross area proposed to be irrigated under different crops during a year by a scheme. The area proposed to be irrigated under more than one crop during the same year is counted as many times as the number of crops grown and irrigated.

Irrigation Potential Utilised: The gross area actually irrigated during reference year out of the gross proposed area to be irrigated by the scheme during the year.

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15.0 Command Area Development Programme

The National Commission on Agriculture, 1976 recommended the need for development of command area of projects and suggested the following:

1. Consolidation of farmers scattered plots
2. Land grading and shaping
3. Construction of field channels
4. Provision of field drainage
5. Construction of farm roads

15.1 Reasons for gap in utilization irrigation potential

Besides the lack of field channels, there are several other reasons for gap in utilization of irrigation potential:

1. Long gap between declaration of creation of irrigation potential and construction of carrier systems
2. Farmers reluctance to develop land in anticipation of receiving water
3. Deficiencies in design, construction, operation and maintenance of carrier systems. Unrealistic assumption of duties for crops and heavy seepage and operational losses in the system
4. Differences in cropping pattern assumed at the time of designing of the project and that adopted by the farmers year after year depending on returns on investment for crop production
5. Provision of dual commands (both rice and light irrigation crops under the same pipe outlet) resulting in farmers raising rice in areas localised for light irrigated crops
6. Unauthorised irrigation of lands not localised especially in the upper reaches
7. Over irrigation by farers in the upper reaches due to uncertainty in availability of water for the next irrigation

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8. Lack of political will to stop unauthorised irrigation in non-localised area and wilful damages to structures caused by farmers to draw water unauthorizedly.

15.2 Objectives of Command Area Development Programme

The following objectives suggested by Government of India for developing the command area.

1. Modernisation, maintenance and efficient operation of irrigation system down to the outlet of one cusec capacity
2. Development and maintenance of main and intermediate drainage systems
3. Development of field channels and field drains within the command of each outlet
4. Land levelling on the basis of an outlet command for the type of irrigated crop to be grown
5. Consolidation of holdings and redrawing of field boundaries on an outlet command basis
6. Enforcement of a proper system of rotational irrigation (Warabandi) and equitable distribution of water to individual fields
7. Development of ground water for conjunctive use
8. Introduction of a suitable cropping pattern
9. Supply of input and services including credit
10. Developing of marketing and processing facilities and communication system
11. Preparing individual programmes for action for small farers and agricultural labourers as part of a master plan
12. Diversification of agriculture and development activities like animal husbandry, farm forestry and poultry
13. Soil conservation and afforestation
14. Town planning

15.3 Irrigation Plans

An irrigation plan is a detailed systematic record of information often supported by sketch of irrigated area, to plan and estimate all the aspects of irrigation in a given area. Like any other plant, it deals with estimations on all aspects of irrigation and therefore, helps making realistic expectations of yield/ income from a farm. The preparation of an irrigation plan is extremely useful because:

- It can help in efficient utilization of available irrigation (source, flow and method) to cover more area and thereby, increase the yield and income of a farm
- It helps in estimating the expected cost to be incurred on various aspects of irrigation, (e.g. purchase of pump, digging canals, purchase of paper, etc.)
- It helps in identifying the time and quantity of irrigation needed for each crop at each stage, so that comprehensive details could be worked for entire farm to efficiently distribute the given flow during the cropping period
- It is ale to estimate the various losses of water during conveyance, application and distribution and calculate efficiencies for various crops involved. This helps in more efficient use of irrigation water
- It helps to often plan the crops ad cropping pattern based on availability of a flow. Hence, seasonal variation in flow rate can be synchronised to suitable changes in crops and cropping patterns.

15.3.1 Preliminary considerations for irrigation planning

The irrigation system to function as planned both irrigator and planner must know and agree on some things before they spend much time in planning.

15.3.1.1What the irrigator should know:

Conservation irrigation, like other farm operations, must be undertaken only if it can be done successfully and at a profit. In other words, the benefits from irrigation must increase farm income enough to cover all costs of purchasing, installing, operating, and maintaining the irrigation system and provide a reasonable return from the owner's investment.

Conservation irrigation is the use of irrigated soils and irrigation water in a way that insures high production without wasting either water or soil. To an irrigator, conservation irrigation can mean saving water, controlling erosion, better crop yields, lower production costs and continued productivity of his irrigated land.

15.3.1.2What the planner should know:

It is impossible to design an effective conservation irrigation system without complete understanding by both irrigator and planner. The planner should know the adequacy of water supply; consider the farmer's preferences and entire farm.

15.3.2 Planning Procedure: After a preliminary plan has been made, studied and discussed with the farmer, detailed plans for command area prepared. First, select a method of water application for each field and prepare a layout. Then design the delivery, application, and disposal facilities as well as the necessary access roads.

15.3.3 Types of Irrigation Plans

The irrigation plans could be broadly classified into two categories:

15.3.3.1

Irrigation plans for large area (micro and macro command area)

- A micro command area of a reservoir/ tank/ distributory/ lift irrigation project. Such plans are necessary to be drawn up mainly to distribute the given flow rate of water to the entire command/ micro command area equitably depending upon the cropping pattern and soil type.
- The main feature of such plans includes the scheme to use the continuous flow of water efficiently through out the period of water availability duly considering the irrigation frequency.
- Such plans are useful to compute the flow to be allowed in a main canal or to plan the time schedule when and how long water has to be let in or to utilize the limited sources of collected water efficiently.

Assumptions:

- All the farmers get water from distributory by check gates on volumetric basis and the check gates are operated by a supervisor.
- Ignoring the crop stage, the total irrigation is divided equally in to required number of irrigations.
- Cropping systems
- Calculate the season wise irrigation requirement
- Calculate the gross and net irrigation requirement

15.3.3.2 Irrigation plans for farm

Irrespective of source of irrigation, such plans are necessary to be developed for each irrigated farm so that available flow is utilized more efficiently. The cropping plan evolved for each irrigation will have to be readjusted according to flow available for irrigation.

As compared to general area plan, the farm plan will have to consider the soil type and its water holding capacity for each of the plot in a farm. If the source of water is at the command of the farmer, the period of flow could be suitably altered to increase the total water available for distribution to cover either more area or to increase the depth of irrigation.

Assumptions

1. B.D. is assumed to be uniformly throughout ERZ.
2. Calculate the irrigation requirement is for entire crop period
3. FC/ PWP are assumed to be uniform throughout the plot.
4. Ignoring the stage of crop, entire irrigation requirement is distributed uniformly throughout the crop period.
5. Cropping systems
6. Calculate the gross and net irrigation requirement

15.3.4 Features of Irrigation Plans

- Irrigation plans are prepared based on water resources available at command area.
- They aim at minimising water losses and maximise the utility of irrigation water.
- They consider the crops locally adaptable to the region for which the plan is prepared.
- The distribution of water is done based on the need of the crop at different growth stages as well as capabilities of soils to hold the water.
- They invariably consider the efficiencies of irrigation to compute the requirement.
- Irrigation plan will include the control structures; distribution structures and methods of conveyance.
- An irrigation plan will have to consider the cost of the project as well as net returns based on annulated cost of the whole project.
- An irrigation plan will have to consider the conjunctive the rain water to reduce the irrigation requirement.
- The plan will aim at full utilization of continuous flow on all the days during which irrigation is available.
- An irrigation plan is usually supported by layout map of entire farm or large area showing all the ground details.
- Irrigation plan should be prepared in close agreement with cropping plan of a farm or large area.
- Measurement devices at various places of the far/ area are necessary to be part of scheme.
- Contingent plant and mid-season correction strategies will have be a part of irrigation plan.

15.3.4 Factors affecting the irrigation planning

- Soil: It includes the intake rate, water holding capacity, water depth, drainage, erosion, saline and alkaline conditions, etc.
- Topography: Due to different slope of land, the different irrigation method is used. It includes sprinkler, drip, surface, subsurface, conservation irrigation, supply lines, etc.

- Water supply: It comprises the water right, quantity, quality, type and location of supply.
- Climate: It includes precipitation, temperature, etc.
- Farm enterprises: It includes the crops and labours.
- Field arrangement
- Availability of farm equipment
- Available power
- Existing facilities at farm or command area
- Field road system
- Finances
- Physical features, etc.

Suggested reading and references:

Joshi, M. And Setty, T.K.P. 2006. A text book of irrigation and water management, Kalyani Publication, New Delhi

Majumdar, D.K. (2006) Irrigation water management: principles and practice, Prentice-hall of India private limited, New Delhi.

Course Name	**Water Management including Micro Irrigation**
Lesson 16	**Suitability Of Irrigation Water For Irrigation-Quality Of Water & Its Impact On Growth, Development And Yield Of Crops**
Content Creator	**Dr. Hardev Ram**
University	**NDRI - National Dairy Research Institute**
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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Objectives

1. To understanding the effect of water quality on soil and crops

2. To assessed the suitable alternatives to cope with potential water quality related problems

Terminology:

Conjunctive use of water: It refers to the use of saline water of wells in combination with canal water.

Leaching requirement: It is the fraction of water entering the soil that must pass through the root zone in order to prevent soil salinity from exceeding a specified value.

Osmotic effect: The force a plant must exert to extract water from the soil. The presence of salt in the soil water increase the force the plant must exert.

Salt balance: The relation between the quantities of dissolved salts carried to an area in irrigation water and the quantity of dissolved salts removed by drainage water

Saturation index: An estimate of carbonate precipitation from irrigation water as function of the degree of calcium carbonate saturation of the soil solution.

Sodium adsorption rate (SAR): A ratio for soil extracts and irrigation waters used to express the relative activity of sodium ions in exchange reactions with soil:

SAR = Na+ x [(Ca2^{+} + Mg^{2+})/2] $^{-0.5}$ expressed in meq/litre.

16. Quality of irrigation water

Water quality refers to the characteristics of a water supply that will influence its suitability for a specific use. Good quality of irrigation water is essential for optimum crop yield and soil health. Poor qualities of irrigation water damage the soils by making it saline or alkaline through salt accumulation, which injures to crops and ultimately reduce yield and quality of produce.

Whatever the source of irrigation water viz., river, canal, tank, open well or tube well, some soluble salts are always dissolved in it. The quality and quantity of salts in the irrigation water depends on sources of water and soils. The main soluble constituents in water are cations include Na+, K+, Ca_2+ and Mg_2+ and anions include $CO_3{}^{2}$−, HCO_3−, Cl− and $SO_4{}^{2}$−. However ions of other elements such as lithium, silicon, bromine, iodine, copper, cobalt, fluorine, boron, titanium, vanadium, barium, arsenic, antimony, beryllium, chromium, manganese, lead, selenium phosphate and organic matter are also present.

Among the soluble constituents, calcium, sodium, sulphate, bicarbonate and boron are important in determining the quality of irrigation water and its suitability for irrigation purposes. However other factors such as soil texture, permeability, drainage, type of crop etc., are equally important in determining the suitability of irrigation water.

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16.1 The following are the most common problems for using poor quality water.

16.1.1 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.

16.1.2 Permeability

Some specific salts reduce the rate of infiltration in to the soil profile like high Na and low Ca.

16.1.3 Toxicity

When certain ions (Na, Cl and B) form soil or water is taken up by plans which accumulates in large quantities and results in plant toxicity and reduces yield.

16.1.4 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.

16.2 Impact of poor quality water on growth, development and yield of crops

1. If higher concentrations of soluble salts are present in irrigation water, which accumulated in crop root zone, crops face difficulty in extracting

water (physiological drought) even plenty of water is present.

2. Suppressed root growth due to the presence of impermeable soil layer caused by $CaCO_3$ and high exch Na.

3. Soil permeability is reduced due to the deflocculating of sodium resulted into infiltration of water is reduced.

4. Toxicity of B, Cl, Na, in plants were observed.

5. Due to increase of osmotic pressure of the soil solution vegetative growth decrease.

6. Thick cuticle, waxy bloom and deep blue-green color of leaves.

7. Higher salinity reduces cell division, cell enlargement and protein synthesis.

8. Structure and integrity of plant membranes and chloroplast swell.

9. Ions imbalance; like higher sulphate reduces the uptake of Ca and increase the uptake of Na.

10. Higher Ca concentration reduces the uptake of K and high Mg induces Ca deficiency.

11. Leaf burning due to using poor quality irrigation water in sprinkler irrigation.

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16.3 Classification and suitability of irrigation water

The concentration and composition of soluble salts in water will determine its quality for various purposes. The following criteria are used for classification and suitability of irrigation water for use to crops are based on

1. Total salt concentration (salinity hazards)

2. Relative proportion of sodium to other cations

3. Carbonates and bicarbonates

4. Boron concentration and other toxic elements

16.3.1 Total salt concentration (salinity hazards)

Higher salt increases the osmotic pressure of the soil solution, result in a physiological drought. Thus, even though the soils have sufficient moisture, the plants cannot meet the transpiration demands and will wilt. Under such conditions plant roots are unable to take up water due to its high osmotic potential.

Table 1 Salinity hazard of irrigation water

Hazards	Dissolved salt content	
	ppm	EC ($\mu S\ cm^{-1}$)
None – Water for which no detrimental effects will usually be noticed.	500	750

Hazards	Dissolved salt content	
	ppm	EC (µS cm^{-1})
Some – Water that may have detrimental effects on sensitive crops.	500–1000	750–1500
Moderate – Water that may have adverse effects on many crops, thus requiring careful management practices.	1000–2000	1500–3000
Severe – Water that can be used for salt tolerant plants on permeable soils with careful management practices.	2000–5000	3000–7500

Source: https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#Sec2

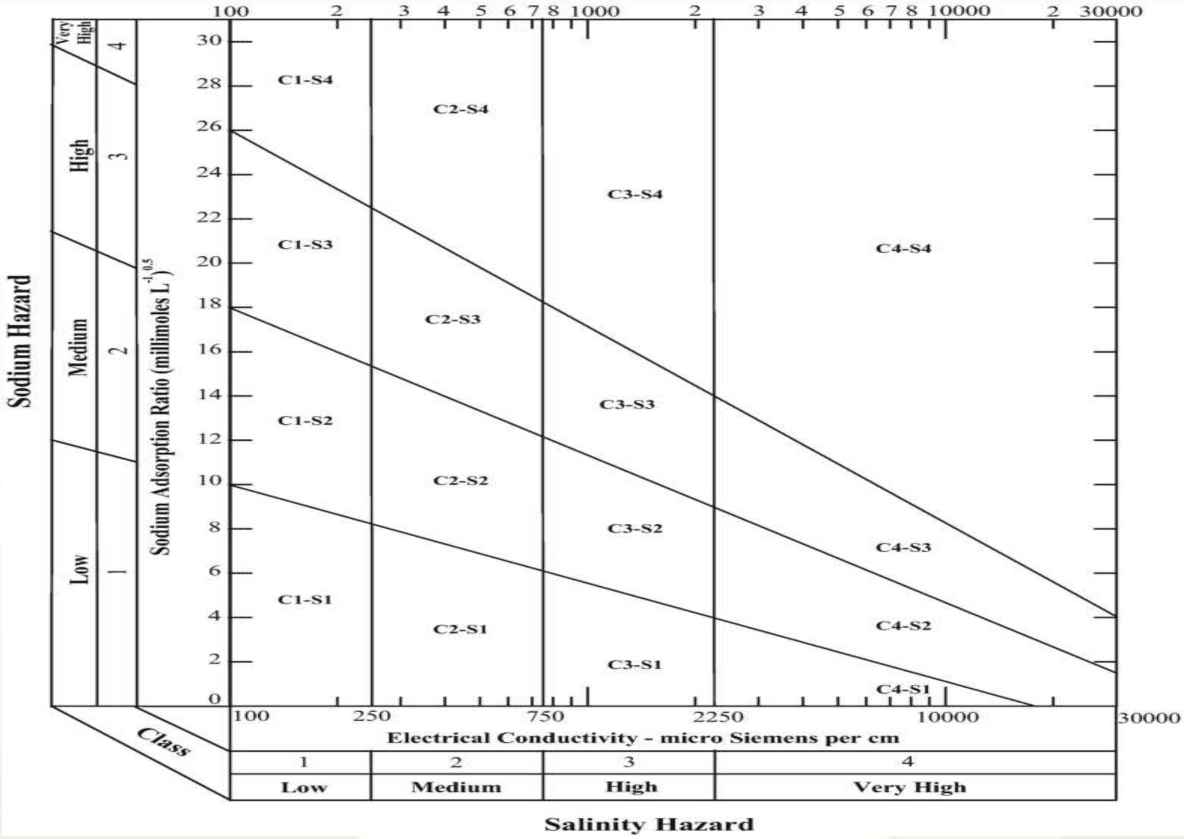

Fig 1. Classification of irrigation waters based on salinity hazards

Source: https://media.springernature.com/lw785/springer-static/image/chp%3A10.1007%2F978-3-319-96190-3_5/MediaObjects/466735_1_En_5_Fig1_HTML.png

16.3.2 Relative proportion of sodium to other cations

The sodium hazard of irrigation water is expressed as the sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP) and sodium percentage. The main problem with a high sodium concentration is its effect on the physical properties of soil i.e. soil structure degradation. In fine texture like high clay soil, dispersion of soil particles and that causes the soil to become hard and compact when dry, and impervious to water penetration when wet.

Table 2 Classification of irrigation water based on salinity and sodium hazards

Salinity	Classes	C (mmhos/cm) at 25 ^{0}C
Low	C1	0-250
Medium	C2	250-750
Medium to high	C3	750-2250
High	C4	2250-5000
Very high	C5	5000-6000

Sodium hazards	Classes	SAR	Remarks
Low	S1	0-10	Can be used for all soils with little danger of harmful Na
Moderate	S2	10-18	Can be used soils with good permeability; Sodium hazard likely in fine textured and low OM content soil
High	S3	18-26	Harmful exchangeable Na accumulation in most of soils except gypsiferous soils. Requires drainage, high leaching and addition of organic matter and gypsum
Very High	S4	>26	Unsatisfactory for irrigation except at low and perhaps nedium salinity of irrigation water, special management like leaching is required

16.3.3 Carbonates and Bicarbonates Concentration

Waters contents high carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) will precipitate in calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$), in soil solution resulted into increased the Na % and other Na hazards of water.

Table 3 Suitability of irrigation water based on RSC

RSC (me/l)	Classes
<1.25	Safe
1.25-2.5	Marginal
>2.5	Unsafe

16.3.4 Boron concentration and other toxic elements

Besides of salinity and sodium hazards, certain crops may be sensitive to the specific ions in the irrigation waters. Many trace elements are toxic to plants at a very low concentration e.g. boron, chloride, and sodium.

Table 4 Classification of irrigation water based on exchangeable sodium percentage (ESP)

Classes	ESP	Crops
Sensitive	<15	Most of legumes and Maize,
Semi-tolerant	15-40	Carrot, Berseem, Oat, Sorghum, Tomato,
Tolerant	>40	Alfalfa, Barley, Beet, Rhoades grass and Karnal grass

Table 5 Effects of boron (B) concentration in irrigation water on crops

Boron concentration (ppm)	Effect on crops
< 0.5	Satisfactory for all crops
0.5–1.0	Satisfactory for most crops
1.0–2.0	Satisfactory for semi-tolerant crops
2.0–4.0	Satisfactory for tolerant crops only

Source: https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#Sec2

Table 6 Effect of chloride (Cl−) levels of irrigation waters and their effects on crops

Cl− concentration (ppm)	Effect on crops
< 70	Generally safe for all plants
70–140	Sensitive plants usually show slight to moderate injury
141–350	Moderately tolerant plants usually show slight to substantial injury
> 350	Can cause severe problems

Source: https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#Sec2

16.4 Guidelines for using poor quality irrigation water

1. Leaving the field and use of gypsum when saline water (SAR>20; Mg/Ca ratio >3 and high silica).
2. Application of phosphorous if, Cl/SO_4 ratio is greater than 20.
3. Conjunctive use of saline water as presowing irrigation and at early stages of crop growth canal water may used.
4. Use of higher seed rate (>20%) and quick irrigation (within 2-3 days) will ensure better germination.
5. If, $EC_{iw} < EC_e$ may apply saline water before onset of monsoon.
6. Use of organic matter such as FYM, compost etc., to the soil to improve permeability and structure.
7. Mixing of good quality water with poor water in proper proportions so that both the sources of water are effectively used to maximum advantage.
8. Periodical application of organic matter and raising as well as incorporation of green manure crops in the soil.
9. Irrigating the land with small quantities of water at frequent intervals instead of large quantity at a time.
10. 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
11. Drainage facilities must be improved
12. Growing salt tolerant crops such as cotton, barley, ragi, sugar beet, paddy,

sorghum, onion, tomato, amaranths and Lucerne.

Suggested reading and references:

Majumdar D.K. 2013. Irrigation Water Management Principles and Practices, PHI learning Private Limited. New Delhi.

Michael A.M. 1978. Irrigation theory and practice, Vishal Publishing House Private Limited. New Delhi.

Zaman M., Shahid S.A., Heng L. 2018. Irrigation Water Quality. In: Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques. Springer, Cham. https://doi.org/10.1007/978-3-319-96190-3_5.

Course Name	**Water Management including Micro Irrigation**
Lesson 17	**Irrigation Control And Water Conveyance Methods-Their Advantages & Disadvantages**
Content Creator	**Dr. Hardev Ram**
University	**NDRI - National Dairy Research Institute**
Course Reviewer	**Prof. Ummed Singh**
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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Objective

To learn about various water control and conveyance methods for achieving higher conveyance efficiency.

Chute spillways: Chute spillways carry the flow down steep slopes through a lined channel rather than by dropping the water in a free overfall.

Open channel flow: The water flows with a free water surface i.e. a surface on which pressure is equal to local atmospheric pressure.

Check dam: A check dam is a small, sometimes temporary, constructed across a swale, drainage ditch, or waterway to counteract erosion by reducing water flow velocity

Seepage: Seepage is the infiltration (vertically) downward and lateral movements of water into soil or substrata from a source of supply such as a reservoir or irrigation canal.

Siphon tube: These are bent pipes which convey the water over a channel bank into field or furrow

Uniform flow: The flow is said to be uniform, if the velocity and depth of flow are constant throughout the length of the channel considered.

17.0 Water conveyance methods

A method or system should be designed to convey the water from source to point with minimum loss and without soil erosion. The conveyance and distribution systems consist of open channel and pipes transporting the water through the whole irrigation system. The main aims of study of various conveyance methods to reduce losses and achieve higher conveyance efficiency. There are two method of water conveyance as follows:

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17.1 Open channel flow

17.2 Pipe flow

17.1 Open channel flow: The most common type of water conveyance system is the open channel. In the open channel, water flows with a free water surface i.e. a surface on which pressure is equal to local atmospheric pressure.

17.1.1 Open Channel Flow Characteristics

- Open channel flow is not completely enclosed by solid boundaries.
- Free surface is subject to atmospheric pressure.
- Flow is caused by the gravity along the slope of the channel. e.g.: All irrigation channels, drainage channels, natural streams, partially full pipe flows.

17.1.2 Based on their existence, an open channel can be natural or artificial:

- **Natural channels**: Natural channels are streams, rivers, valleys, etc. These are generally irregular in shape, alignment and roughness of the surface.

- **Artificial channels**: Built for some specific purpose, such as irrigation, water supply, wastewater, water power development, and rain collection channels. These are regular in shape and alignment with uniform roughness of the boundary surface.

17.1.3 Based on their shape, an open channel can be prismatic or non-prismatic:

- Prismatic channels: The cross section is uniform and the bed slop is constant.
- Non-prismatic channels: When either the cross section or the slope (or both) change, the channel is referred to as non-prismatic.

17.1.4 Open channel flow is divided into:

(i) Uniform flow
(ii) Varied flow
(iii) Steady flow
(iv) Unsteady flow

- Uniform flow: The flow is said to be uniform if the velocity and depth of flow are constant throughout the length of the channel considered.
- Non uniform flow: When mean velocity changes from cross section to cross section, the flow is uniform.
- Varied flow: When the velocity or depth changes along the channel length it is known as varied flow or non-uniform flow.
- Steady flow: If the velocity and depth of flow remain constant at a cross-section with time, the flow is said to be steady.
- Unsteady flow: If the velocity and depth of flow change with time at a cross-section, the flow is called unsteady.

17.1.5 Channels can be either

(i) Unlined channel or
(ii) Lined channel.

17.1.5.1 Unlined channels

Channels without artificial lining of bed or sides are called earth channels.

Advantages of earth channels

- Commonly used by the farmers
- Can be built and maintained by unskilled persons
- Require no special equipment or materials
- Easy to construct and cheaper

Disadvantages of earth channels

- Excessive seepage losses
- Low velocities due to retardance of flow by rough surfaces due to growth of weeds
- Susceptibility to erosion and therefore, relatively large cross-sectional areas are required
- Danger of breaks due to erosion and burrowing animals
- Growth of aquatic weeds which reduce velocity
- High labour requirements for maintenance

The major disadvantage of earth channel is excessive seepage losses, is often a problem in irrigated areas. Therefore, it is highly essential to provide lining to the irrigation channels to serve the following purposes:

- Reduces or eliminates water loss due to seepage up to 95%.
- Prevents weed growth and increases the carrying capacity of water
- Provides safety against breaks
- Prevents scouring of the channel
- Reduces labour requirement for maintenance of the channel

17.1.5.2 Lined channel

By lining the channel or canal, the earthen surface of the channel is lined with a stable (in erodible) lining materials, such as concrete, tiles, asphalt, etc. Depending upon the type of lining adopted the seepage losses can be reduced to 2-5% of their original values by lining the canals.

Advantage of lining channels

- Water conservation through seepage control
- Reduce water logging
- Reduced canal dimensions and
- Low maintenance cost

Disadvantage of lining channels

- Initially high investment
- Shifting from one place to another not possible
- Require continuous maintenance

17.2 Pipe flow (buried pipes)

An underground pipeline water distribution system consists of buried pipes for conveying water to different points on the farm and allied structures required for the efficient functioning of the system. A properly designed pipeline system saves water, energy consumption and land used for field channels.

Type of pipes:

- Reinforced concrete pipes
- Asbestos cement pipes
- Steel & aluminium pipes
- PVC pipes

Component of pipeline system

- Pump stand: Inlet structure connected to underground pipeline
- Gate stand: It is provided to control the flow into laterals when the pipeline branches off in different directions. It is provided with slide gates or valves to control the flow into laterals.
- Air vents: Provided to release the entrapped air in the pipe line and prevent vacuum.
- End plug: It is provided at all closing points of pipe line. The end of the plug should be supported sufficiently to with stand the operating pressure developed.
- Float valve: This is an open stand structure used in semi closed system which permits reduction in the pipe head or pressure, while connecting hydraulically upstream and downstream sections.
- Outlets: these are needed to deliver the water from pipeline system to field.

Advantages

- Cultivation can be done above the pipeline saves land area. The pipelines do not interfere with farming operations
- Long life and low maintenance costs
- Water conveyance losses through seepage, evaporation and breaches in the channels are avoided
- Operate under pressure and can be laid uphill or downhill, thus permitting the delivery of irrigation water to areas not accessible by open channels
- Water pumped from wells may be delivered directly into the pipeline system
- Maintenance cost of the water distribution system is very low

Disadvantages

- Underground pipeline irrigation distribution systems have a higher initial cost
- Needs higher operating pressure and additional power to distributed water as compared to open channel
- Difficult to locate leakages and repair is costly
- Needs technical man power for installation
- Must screen out debris and prevent sedimentation.
- Not feasible for large flows

17.2 Water conveyance structures

17.2.1 Drop structures: Drop structures are used to discharge water in a channel from higher level to lower one in order to avoid high velocity of the flow and risk of erosion.

17.2.2 Chute spillways: Chute spillways carry the flow down steep slopes through a lined channel rather than by dropping the water in a free overfall. Chutes are used where there are big differences in the elevation of the canal. Chutes may be made to control flow for elevation changes up to 6m.

17.2.3 Channel crossing: It aids channels in cross roads, depressions, high spots, drainage channel. Inverted siphon, culvert and flume are some channel crossing structures.

17.4 Water control and diversion structure

Water control and diversion structures are necessary to give easy and effective control of irrigation water on the farm. Good control of irrigation water reduces the labour required to irrigate and check erosion and water loss. The structure includes check gates, portable check dams, diversion boxes, turnout boxes, siphons and turnouts.

- Check gates: Check gates are raised the upstream water level so that water can be easily diverted to field.

- Portable dam: Canvas, plastic and sheet metal dams are suitable to check water and raise or control the water surface elevations.
- Turnouts: Is used to convey the irrigation from lateral channel to field distribution channel or from a channel into field. It may be portable or built in.
- Spiles: Spiles are made of bamboo, concrete, or backed clay pipes to convey water from field to furrow.
- Siphon tubes: To convey the water over a channel bank into field or furrow

Suggested reading and references

http://ecoursesonline.iasri.res.in/pluginfile.php/2186/mod_page/content/2/fig-28.3.jpg

http://www.fao.org/3/r4082e/r4082e06.htm

Michael, A. M. 2010. Irrigation Theory and Practice, Second Edition Vikas Publishing House Pvt. Ltd, Noida, U.P. India: 311-348.

Murthy, V.V.N. 1985. Land and Water Management Engineering, Kalyani Publishers, Ludhiana, India: 261-289.

Course Name	Water Management including Micro Irrigation
Lesson 18	Concept Of Drainage-Surface And Subsurface Methods Of Drainage
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Objective: To study important of drainage for crops and soil health.

Terminology:

Drain: A buried pipe or other conduit (closed drain) or ditch (open drain) for carrying off surplus surface or sub-surface ground water.

Drainage: The removal of excess surface or ground water from land by means of surface or sub-surface drains.

Drainage basin: An area from which surface run-off is carried away by a single drainage system. Also called catchment area, watershed and drainage area.

Drainage coefficient: The rate expressed as depth (in cm) of water drained off from a given area in 24hrs is known as drainage coefficient.

Drainage water: The water that the soil is unable to hold against the force of gravity. Also called gravitational, free and excess water.

Vertical drainage: The control of an existing or potential high water table or artesian groundwater through a group of adequately spaced wells.

Horizontal drainage: A method of groundwater drainage in which low water tables are maintained by pipe drains or open ditches.

18.0 CONCEPT OF DRAINAGE

For optimum growth and yield of field crops, proper balance between soil air (50%) and soil moisture (50%) is quite essential. Except rice, most of the cultivated plants cannot withstand excess water in the soil. When the soil contains excess water than that can be accommodated in the pore spaces it is said the field is water logged.

Drainage is one of the most important factors to maintain or improve agricultural productivity. Drainage is a reverse process of irrigation. It is broadly defined as the removal of excess surface or ground water from land by means of surface or sub-surface drains. The terms 'drainage', 'land drainage', 'agricultural drainage' and 'field drainage' are used as synonyms. Since drainage is necessary not only for the removal of excess surface or ground water but also for removing salts from the soil, As per International Commission on Irrigation and Drainage (ICID, 1979) land drainage is defined as “Land drainage is the removal of excess surface and subsurface water from the land to enhance crop growth, including the removal of soluble salts from the soil”.

18.1 Classification of waterlogged areas in India and other South Asian countries (Bhattacharya and Michael, 2003):

1. Waterlogged Area: Water table is within 2 m from soil surface during pre-monsoon (April/May) or water table is within 1 m from soil surface during post-monsoon (October/November).
2. Critical Area for Waterlogging: When the water table is between 2-3 m from the soil surface during pre-monsoon and/or between 1-2 m during post-monsoon, it is considered as critical.
3. Potential Area for Waterlogging: In monsoon season, irrigated areas with water table between 3-5 m during pre-monsoon may be considered as potential areas for waterlogging.

18.2 Effect of poor drainage on soil and plants health

Excess water in the crop root zone soil is injurious to plant growth and development. Crop yields are significantly reduced on poorly drained soils. In cases of prolonged waterlogging, plants eventually die due to a lack of oxygen in the root zone. Waterlogging in irrigated regions may result in excess soil salinity, i.e., the accumulation of salts in the plant root zone. The following effects are observed due to water logging or poor drainage on soil and plant as follow:

1. Poor root growth due to low oxygen availability.

2. Reduction of soil strength.

3. Plant susceptible to diseases (Club Root in brassicas, Foot Rot of leguminous)

4. Oxygen diffusion is 10,000 times lesser than running water.

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5. High redox potential is – 400 mV.
6. Toxicity of nutrients (Mn, Fe)
7. Change in the pH and natural stabilization.
8. Reduced nutrient uptake (In order of K>N>Ca>Mg>P >B and Mo).
9. Accumulation of toxicants (CO_2, H_2S, CH_4, HCO_3^-, CO_3^{-2}).
10. Poor crop growth/nutritional disorders and yield reduction.
11. Loss of soil fertility and soil erosion.
12. Reduce the activity of beneficial soil micro-organism.

18.3 NEEDS FOR DRAINAGE

Drainage is required under the following condition

1. High water table
2. Water ponding for longer periods in irrigation water and canal seepage in the irrigated lands
3. Excessive soil moisture content above field capacity, not draining easily as in clay soil
4. Areas of salinity and alkalinity where annual evaporation exceeds rainfall and capillary rise of ground water occurs
5. Humid region with continuous of intermittent heavy rainfall
6. Flat land with fine texture soil
7. Low lying flat areas surrounded by hills

18.4 BENEFICIAL EFFECT OF DRAINAGE:

1. Drainage improve soil aeration thus promotes beneficial soil bacteria activity and improves soil tilth.
2. Reduce surface runoff and soil erosion.

3. Improve root growth, nutrient uptake and reduce harmful effect of various gases like CO_2, CH_4.

4. Reduce the toxicity of micronutrients like Mn, Zn, and Co

5. Improved field machine trafficability reduces soil structural damage.

6. Drainage also allows for timely field operations.

7. In general, land value and productivity are increased.

8. Drainage maintains favorable salt balance in the crop root zone.

9. Prevent some plant disease like club root in brassica, foot rot of leguminous, stem rot and damping off seedlings.

18.5 CHARACTERISTICS OF GOOD DRAINAGE SYSTEM

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

18.6 METHODS OF DRAINAGE

18.6.1 Surface drainage
18.6.2 Sub-surface drainage

18.6.1 Surface drainage

This is designed primarily to remove excess water from the surface of soil profile. This is most economical, simplest and most common method in India. This can be done by developing slope in the land so that excess water drains by gravity. Irrigation channel also serve as drainage channel. Surface drainage problems occur in flat or nearly flat areas, in the areas having uneven land surfaces with depressions or ridges preventing natural runoff, and in the areas where there is no outlet.

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It is suitable for

1. Slowly permeable clay and shallow soil
2. Regions of high intensity rainfall
3. To fields where adequate out lets are not available
4. The land with less than 1.5% slope

The surface drainage can be classified as

a. Bedding

Bedding is the oldest surface drainage method in which the land surface is formed into beds. These beds are separated by parallel shallow, open field drains, oriented in the direction of the greatest land slope (gravity flow). The water drains from the beds into the field drains, which discharge into a collector drain constructed at the lower end of the field and at right angles to the field drains. Bedding system was good for poorly drained soils on flat lands with slope upto 1.5%.

b. Random system

It is suitable where there are a number of large but shallow depressions in a field, but where a complete land-forming operation is not necessary. The random system connects the depressions by means of lateral field drain and evacuates the water into a collector drain. The system is suitable in pasture land or where mechanization is done with small equipment.

c. Parallel or field ditch System

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It is most suitable surface drainage system for irrigated and rainfed areas. In this system fields are separately graded such a way that discharge into laterals and main drains. The laterals and main drain should be deeper then field ditched to provide free outfall. This method is adopted in nurseries, seed beds and rainfed crops. This is an effective and efficient method but requires smoothening of surface and construction of ditches. This involves cost and wastage of crop lands. Shifting of soil, restriction for the movement of farm machineries reconstruction and renovation of ditches during the crop duration and harvesting of crops and the problems in this method. In flat land, bed or parallel field ditches may be constructed.

d. Terrace system

This system is suitable for sloppy land and hilly areas. Drains are constructed along the contour and they interconnected to flow of drain water down the slope.

Other surface drainage system are

a. Lift drainage

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

b. Gravity drainage

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

18.6.2 SUB SURFACE DRAINAGE SYSTEM

Sub surface drains are underground artificial channels through which excess water may flow to a suitable outlet beyond the root zone of the crops. Subsurface drainage problems occur in the areas having shallow

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water table (canal commands), which occurs due to substantial groundwater recharge and sluggish subsurface outflow.

The movement of water into sub surface drains is influenced by

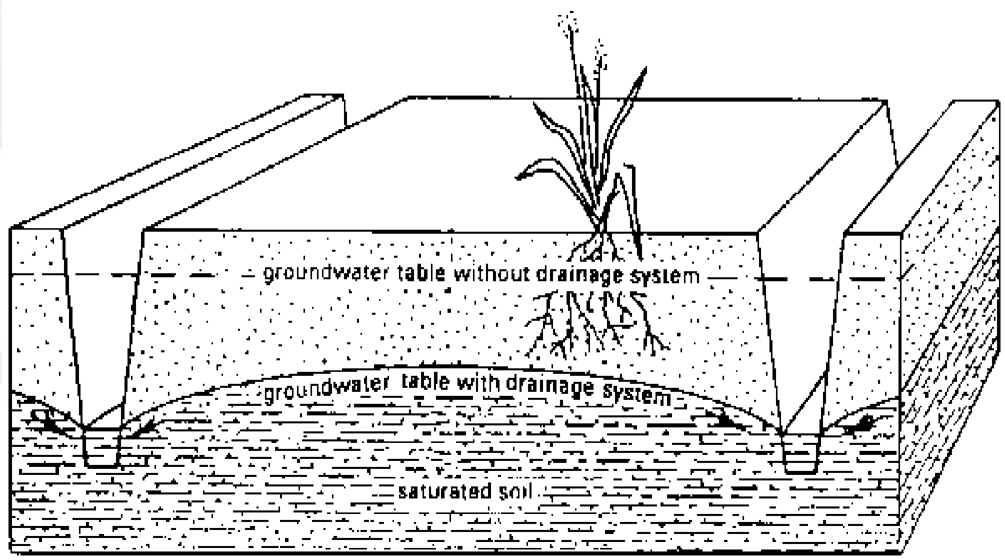
1. The hydraulic conductivity of soil
2. Depth of drain below ground surface
3. The horizontal distance between individual drains

Underground drainage is mostly needed to the
Medium textured soil
High value crop
High soil productivity

Types of sub surface drainage

a) **Open drains:**

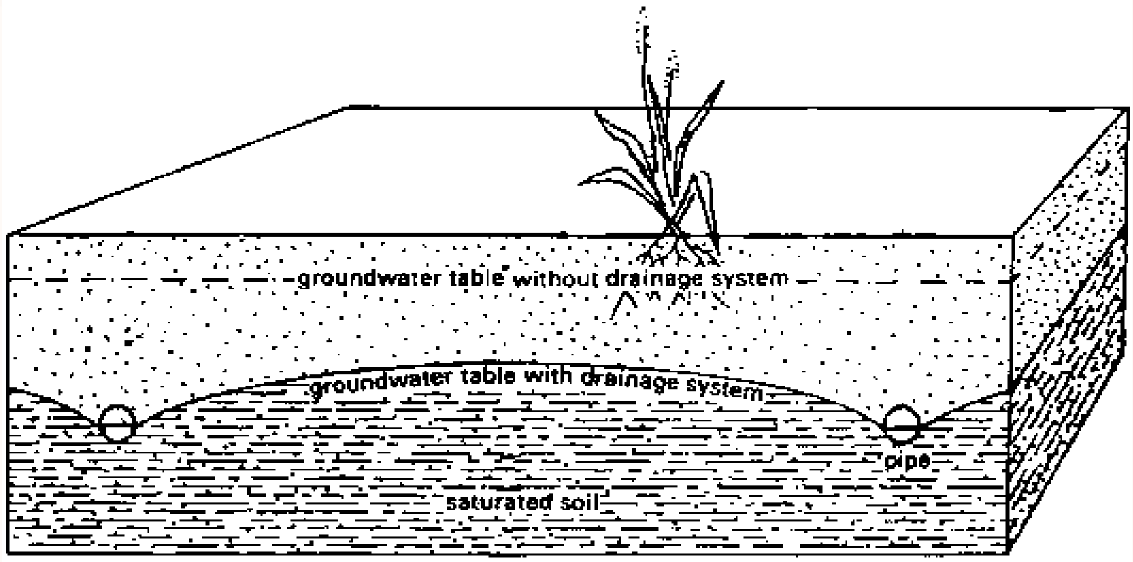
The removal of excess water from the root zone flows into the open drains. The main disadvantage of this type of drainage is wastage of land and uses of machinery are difficult.



Source: http://www.fao.org/3/r4082e/r4082e3y.gif

b) **Pipe drains:**

Pipe drainage is most widely used subsurface drainage method worldwide. Pipe drains are buried pipes with openings through which the soil water can enter. The PVC pipes laid at specified spacing, depth and grade. In general pipes are placed at 60-70 cm below the soil surface.



Source: http://www.fao.org/3/r4082e/r4082e3z.gif

c) Tile drains

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. Tile drains are made with clay and concrete.

d) **Mole drains**

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

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

5. Removal of toxic substances, such as salts
6. Improvement of soil water conditions in relation to the operation of tillage, planting and harvesting
7. Ensuring that crops may be planted and harvested at optimum times

Disadvantage of sub surface Drainage

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

Other types of sub-surface drainage:

a. Vertical or well drainage

Vertical drainage is the disposal of drainage water through well into porous layers of earth, have been used as outlets for both surface and subsurface drains. The wells are used for the drainage of agricultural lands especially in irrigated areas.

b. Bio-drainage

Bio-drainage is the removal of ground-water by plants through evapotranspiration. The transpiration capacity of a plant depends on its species, root depth and spread, leaf area and leaf structure. The medium to deep rooted plants in shallow water table areas may act as small capacity tube wells, regularly pumping groundwater to maintain their transpiration rates like eucalyptus tree.

18.7 Systems of drainage

a. Random

b. Herringbone

c. Grid iron

d. Interceptor

a. Random

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

b. Herring bone

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

c. Gridiron

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

d. Interceptor

Ditches of different dimension are constructed at distance to drain the excess water accumulated on the surface and inside the soil up to 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.

Course Name	Water Management including Micro Irrigation
Lesson 19	Irrigation Practices Of Important Field And Horticultural Crops
Content Creator	Dr. Hardev Ram
University	NDRI - National Dairy Research Institute
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Objective: To learn about the suitable irrigation practices of different crops.

Terminology:

Irrigation requirements: It refers to the water requirement of crops, exclusive of effective rainfall and contribution from soil profile. IR = WR – (ER + S), where IR is Irrigation requirement, ER is effective rainfall and S is the soil moisture stored in the root zone.

Irrigation Scheduling: Amount and time of application of irrigation according to crop need and water availability.

Irrigation: Artificial application of water to soil to help crop growth and production especially can be during stress periods.

IW/CPE ratio: Based on the climatological approach scheduling of irrigation water is done and the depth of irrigation water is fixed for different crops. IW/CPE = Irrigation water (mm or cm) / Cumulative pan evaporation (mm or cm).

Water requirement of crops: It is the quantity of water regardless of its source, required by a crop in a given period of time for its maturity. It includes the losses due to ET + other unavoidable losses during application and field operations.

19.1 IRRIGATION PRACTICES OF FIELD CROPS

19.1.1 Rice

- Rice is a semi aquatic plant and usually grown under water logged condition.
- The critical stage of water requirement are tiller initiation, primordial initiation and flowering stages
- The water requirement is vary from 750 to 2250 mm, depends on duration of crop, climatic condition and soil texture.
- Usually 9-15 irrigation are required for rice and it is depends on season, climate, duration, variety and soil condition.

- A higher amount about 50-60% of water lost through deep percolation.
- In the heavy soil and water table is close to the soil surface, percolation losses are low, about 1-2 mm/day. On the other hand, where the light soil and the water table is deep, percolation losses may be high, about 8-15 mm/day, or more.

The percolation losses can be reduced by adopting following agronomic practices:

- Growing rice on clayey soils
- Scrupulous land leveling
- Thorough puddling
- Shallow depth of submergence
- Sub-soil compaction

The most of medium to long duration varieties are grown under submerged condition throughout the crop-growing period, though not always essential. However, soil saturation is sufficient for kharif rice, while submergence not exceeding 5 cm seems to be essential and adequate for rabi rice.

Advantages of continuous submergence

- Less weed problem
- Reduce water losses due to deep percolation
- Nitrogen fixation by Blue green algae
- Increased availability of nutrients such as P, Fe, Mn, Zn and silicon
- Regulation of soil temperature
- Reduction in labour cost

Disadvantages of continuous submergence

- Higher losses of irrigation water
- Leaching of nutrients particularly nitrogen
- Sulphide injury
- Iron toxicity

Table 1 Optimum depth of submergence

Crop growth stage	Depth of submergence
At transplanting	2 cm
After transplanting for 3 days	5 cm
days after transplanting to maximum tillering	2cm
At maximum tillering (midseason drainage)	Drain water for 3 days
Maximum tillering to panicle initiation	2 cm
Panicle initiation to 21 days after flowering	5 cm
After 21 days after flowering	Drain out water gradually

- The intermittent soil submergence after establishment of crop saves a considerable amount of water.
- The best method of irrigation in rice is check basin method.

19.1.2 Wheat

- The seasonal crop water requirement varies between 350 to 500mm depending upon the agro-climatic zone.
- First irrigation should be given at 20-25 DAS, at crown root initiation stages of wheat, which is most critical stage for moisture stress because the tiller formation will initiate after this stage.
- The second and third important stages requiring irrigation were found to be flowering (80-85 DAS) and dough formation (95-100 DAS). Crown root initiation and heading stages are the most critical to moisture stress. Four to six irrigations are enough for wheat crop.

Table 2 Number of irrigation based on availability of water

No. of irrigation available	Critical stages
One	CRI
Two	CRI + LJ
Three	CRI + B + M
Four	CRI + LT+ F+M
Five	CRI + LT+LJ+ F+M
Six	CRI + LT+LJ+ F+M+D

CRI- Crown root initiation (21 DAS); LT-Late tillering (42 DAS); LJ-Late jointing (60-65 DAS); F-Flowering (80 DAS); M-Milk (95 DAS); D-Dough (115 DAS).

- Based on soil water regime approach 40 – 50% DASM under north Indian conditions was found to be optimum.
- Irrigations at 0.75 to 0.9 IW/CPE ratio based on climatological approach was found to be optimum for most of climate condition. An IW/CPE ratio of 1.0 was optimum at CRI stage.
- The recommended method of irrigation is check basin and border strip method of irrigation.

19.1.3 Maize

- The maize is highly sensitive to water logging and moisture stresses.
- The effective root zone depth of the maize crop varies from 0.9 to 1.5 m.
- Water requirement for maize vary from 400 to 600 mm of water depending upon the soil, plant and climatic factors.
- In general 2-3 irrigation are applied in pre-monsoon crop, while 5-6 irrigation will applied to the rabi crop. Irrigation should be applied at 50% DASM.
- If irrigation will applied based on IW/CPE ratio at 0.7 to 0.9.
- Based on growth stages and irrigation water availability the irrigation scheduling can be follows as:

✓ If five irrigation available should given at, 4 leaf stage, knee-high, tasselling, 50% silking, and dough stages,

✓ If four irrigation available should given at, 4 leaf, knee-high, 50% silking, and dough stages, and

- ✓ If three irrigation available should given at, knee-high, tasselling and 50% silking stages.
- ➢ The furrow method of irrigation is commonly practiced; the irrigation should be applied in furrow in two-third height of the ridges/beds.

19.1.4 Sugarcane

Sugarcane being a long duration crop having high water requirement. The crop duration varies from 12 months in north India, 15-18 months in South India. Sugarcane is deep and fibrous root system and roots depth up to 240 cm.

Physiological factors to be considered for efficient water management in sugarcane

- ✓ A liberal water supply reduces the cane yield and/or sugar yield, while mild water stress enhances the yield.
- ✓ Excessive watering at tillering should be avoided since it coincides with active root development and hinders nutrient uptake due to poor O_2 diffusion.
- ✓ Since there is no secondary thickening of the stem in sugarcane the length of the cane determines the sink available for sugar storage.
- ✓ A 'drying off' or 'cut out' period of 4 – 6 weeks prior to harvest ensures an optimum sugar yield.
- ✓ Restricted water application during the 'ripeness to flower' stage helps to control tassels or arrows.
- ✓ Sugarcane has an intrinsic ability to circumvent water shortages and can more than make up for the potential yield loss.
- ➢ Water requirements of Sugarcane vary from 1,400 to 2500 mm depending on location and environment condition.
- ➢ Annual precipitation is the major contributor to the total water-requirement of the crop, as the highest water-require during grand growth or elongation phase.

- In sub-tropical north, irrigation at critical stages of sugarcane has been worked out and tillering phase of sugarcane that coincides with dry pre-monsoon period has been found most critical.
- In tropical India, usually one or two irrigations are given at an interval of 3 to 4 days after planting to help setts germinate and seedling to establish well. Thereafter, in the absence of rains, cane is irrigated every 10-12 days during its growing period.
- The depth of irrigation varies from 7.5 to 8.89 cm.
- The optimum IW/CPE ratio varies from 0.6 to 0.8 in different sugarcane-growing regions.
- Water application based on the available soil moisture in effective root zone has been found effective in water conservation and irrigation field at 50% and 75% depletion of soil moisture during tillering and maturity phases and it recorded higher cane yield under tropical conditions.
- Sugarcane is irrigated by the furrow method.

19.1.5 Groundnut

- The water and irrigation requirement of groundnut differ because it cultivated in all the three agricultural seasons viz., Kharif (June to September), Rabi (October to January) and summer (January to May) seasons in various part of India.
- It does not require supplement irrigation during rainy season if rainfall is adequate and well distributed. However supplemental or protective irrigations during rainy season in the event of drought significantly improve the pod yield.
- The effective root zone depth of the crops varies between 0.5 to 0.9 m depending upon the range of environment, variety and crop duration.
- The seasonal water requirements vary from 400 to 650 mm.
- The critical stage for irrigation is flowering, pegging, pod initiation & pod development
- First irrigation (after germination) should be given 25 – 30 days after sowing.

- Scheduling of irrigations between 25% to 50% DASM or 0.75 to 1.0 IW/CPE ratio at different growth stages was found to be optimum for producing higher pod yields.
- Irrigate using tensiometer installed at 30 – 60 cm soil depth to maintain 40 centibars at germination, 60 centibars at early vegetative growth, 40 centibars at pod development and 60 centibars at maturity to maximize pod yields.

19.1.6 Rapeseed and Mustard

- Rapeseed and mustard are grown generally with the conserved soil water of the preceding monsoon rains and the winter rains received during the growing period.
- Indian mustard was given significantly higher yield when pre-sowing 50 mm irrigation and subsequent post sowing 50 mm irrigation are given to crop.
- The seasonal water requirements vary from 300 to 400 mm.
- The critical sensitive physiological stages for irrigation are branching, flowering and pod development.
- Scheduling of irrigation between 25 to 50% DASM or 0.6 to 0.9 IW/CPE ratios at different growth stages was found to be optimum for higher yield and productivity.
- Rapeseed and mustard crops are irrigated by Check basin or border strip method.

19.1.7 Sesame

- Sesame is grown mainly in kharif season depending on rainfall.
- 2-3 Irrigations were needed by sesame to get established and producing higher crop yield.
- The seasonal crop water requirement varies between 400 to 550mm depending upon soil and growing areas.
- Scheduling of irrigation at IW/CPE ratio is 0.6 found to be optimum for higher yield.

- The most sensitive critical stages for irrigation in sesame are 4-5 leaf stage, flowering and capsule formation stage.
- The common method of irrigation in sesame is border strip.

19.1.8 Chickpea (Gram)

- Chickpea is sensitive to water stagnation even for a short period and a provision for good drainage is essential.
- Gram is usually grown using the conserved soil water from the preceding monsoon season.
- Seasonal water requirement of gram is 400-550 mm.
- Scheduling of irrigation at 25-50% DASM or 0.4 to 0.6 IW/CPE ratios.
- Critical stage of water need are branching, flowering & pod formation stages
- Multi Location studies revealed that two irrigations at branching & pod formation stages increased the grain yield by 25-32 percent.
- Check basin is the most commonly used method of irrigation in chickpea.

19.1.9 Lentil (Masur)

- The critical stages of water are branching, flowering & pod development stages.
- Two irrigations at flowering & pod development stages gave the best yield.
- Yield of lentil can be increased considerably if at least one irrigation is applied either at pre Flowering or post flowering stage.
- Lentil is irrigated by check basin method.

19.1.10 Pigeon pea (Arhar)

- Due deep tap root system Pigeonpea withstand with drought.
- Crops give more yields if irrigation is provided particularly during drought periods.
- Scheduling of irrigation at 25-50% DASM or 0.6 IW/CPE ratios.
- Two irrigation increases the yield.
- One light irrigation just before flowering is necessary, if rain fails.
- Furrow method of irrigation is most suitable for the pigeon pea.

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19.1.11 Green gram, Black gram and Cow-pea

- These crops are kharif season crop does not require any irrigation. But effective water management in rainfall deficient areas.
- These are also sensitive to higher water stagnation and drought conditions.
- Moisture deficient sensitive stages for these crops are branching, flowering and pod formation stage. Lack of adequate soil moisture at these stages reduces the yield greatly.
- Irrigation is scheduled for these crops at 50-75% of DASM or 0.6-1.0 IW/CPE ratio.
- Border strip and check basin are most commonly method of irrigation.

19.2 Water Management Practices in Horticulture crops

19.2.1 Mango

- Most of the areas cultivated with mango are located in regions of short periods of rain, where water deficit takes place most of the year in the soil water balance.
- Irrigation scheduling from flowering to fruit ripening stage considering the following factors contributes to higher yield and improved fruit quality.

- Climatic conditions
- Crop age – Young and non-bearing orchards differ from the bearing orchards
- Root penetration and proliferation
- Fruit-bud differentiation takes place in terminal mature (8 to 10 months) shoots
- During fruit-bud differentiation and vegetative phase, requirements are antagonistic.
- Fruit quality depends upon moisture content in soil during fruit development and maturity.

- Most of the feeding roots are found at distances from the plant of 0.9 m to 2.6 m and at depths from soil surface to 0.90 m though root penetration was noticed up to 2 m soil depth.
- Critical stages for water supply are flowering, pollination and fruit development.
- Greatest decrease in fruit yield is caused by water deficits during the flowering and fruit development period, due mainly to a reduction in number of flowers, fruit number and fruit size.
- The annual water requirement for a mature orchard of 8 – 10 years old was found to be 1100 – 1300 mm/year.
- The basin and drip method of irrigation are commonly practiced in India.

19.2.2 Banana

- Banana is a tropical herbaceous evergreen plant which has no natural dormant phase and hence has a high water demand throughout the year, especially during high temperatures.
- With respect to water management the important characteristics of the banana plant are:

a. A high transpiration potential due to the large broad leaves and high LAI
b. A shallow root system compared with most tree fruit crops
c. A poor quality to withdraw water from soil beneath field capacity
d. A rapid physiological response to soil water deficit

- The establishment period and the early phase of the vegetative period determine the potential for growth and fruiting and adequate water and sufficient nutrient supply is essential during this period.
- The critical growth stages for irrigation in banana are vegetative growth, flowering and fruit development.
- The banana plant has a sparse, shallow root system. Most feeding roots are spread laterally near the surface. Rooting depth will generally not exceed 0.9 m.
- Daily water requirements vary in the range of 3 – 7 mm/day depending on the combination of LAI, temperature, humidity, radiation & wind.

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- The annual water requirements vary between 1200 to 1500 mm depending on climatic conditions and crop duration. \
- The drip irrigation method is most suitable for higher yield.

19.2.3 Tomato

- Tomato is the second most important vegetable crop next to potato in India. It is rapidly growing crop with a growing period of 120 – 150 days.
- The crop has a fairly deep root system and in uniform deep soils roots penetrate up to 1.2m. Over 80% of the total water uptake occurs in the first 50 cm.
- The crop is most sensitive to water deficit during and immediately after transplanting and during, flowering and fruit development stages.
- Water deficit during the flowering period causes flower drop. Moderate water deficit during the vegetative period enhances root growth.
- Seasonal water requirements after transplanting, of a tomato crop grown in an open field for a 150 day crop are 400 – 600mm depending on the climate.
- Scheduling of irrigations between 25% to 50% DASM or 0.75 to 1.0 IW/CPE ratio at different growth stages was found to be optimum for producing higher fruit yields.
- The crop usually irrigated by the furrow method but drip irrigation is most suitable for higher yield.

19.2.4 Onion

- Onion is a shallow rooted crop and meets 90% of water demands from top 30 cm soil layer, therefore needs frequent irrigation.
- The seasonal consumptive use was varies with 63 to 104 cm, which depends on location and climate condition.
- The pre-bulb development (20 to 60 DAT) and bulb development stage (60 to 110 DAT) significantly reduced onion yield found to be more sensitive to moisture stress.
- The no of irrigation was depends on planting seasons i.e. October planted crop required 12-15 irrigation, while summer planted crop required 15-20

irrigation and June planted crop required 5-6 irrigations, with a interval of 7-10 days.

- Based on IW/CPE ratio, 1.2 is optimum for higher yield of onion.
- The common method of irrigation in onion is check basin or border strip.

19.2.5 Cauliflower and cabbage

- Cauliflower and cabbage are shallow rooted vegetable crops and meets most of water requirement from top 30 cm of soil layer.
- The crops should be irrigated throughout the growth stages at 50% DASM with irrigation of 5 cm depth each.
- These cops mostly irrigated by the furrow methods.

19.2.6 Radish, turnip and beet root

- These crops are shallow rooted crops and draw most of water from upper 30 cm depth of soil layer.
- The water requirement is 227, 243 and 330 cm for radish, turnip and beet root, respectively.
- The optimum water regime for these crops are filed capacity to 0.2 - 0.6 atm.
- These crops are irrigated through furrow method.

Suggested reading and references

Majumdar, D.K. 2013. Irrigation Water Management Principles and Practices, PHI learning private limited. New Delhi.

Michael, A.M. 2008. Irrigation theory and practices. Vikas Publishing House Pvt. Ltd. New Delhi.

Prasad, R. 2011. Text book of Field crops Production Vol. 1st and 2nd. ICAR, New Delhi.

Reddy, Y.T. and Reddy, S.G.H. 2017. Efficient use of Irrigation water. Kalyani publishers, Ludhiana.