Evapotranspiration

Evaporation (E) of water is a diffusive process by which liquid water in the form of vapour is lost to the atmosphere. Two essential requirements for evaporation are: (i) A source of heat to transform liquid water into water vapour. Solar radiation is the principal source of energy (590 cal g^{-1} of water at 20^0C).

(ii) Concentration gradient between evaporating surface and surrounding air.

The climatological parameters for assessing evaporation are- solar radiation, air temperature, air humidity and wind speed.

Datton's law of evaporation

Evaporation (E) = (es - ea) f (u)

Where es = Saturation vapour pressure of water

Ea = Actual vapour pressure of air above

f (u) = function of wind velocity

Evaporation measurements are usually made by piche evaporimeter, atmometer and pan evaporimeter. The standard US Weather Bureau (USWB) class A Pan is the most widely used evaporation pan. It is 122 cm in dia and 25 cm in depth, made up of 22 gauge galvanized iron. Painted white and installed on a wooden frame. Water is filled to a depth of 20 cm, water level is daily measured with a hook gauge in a stilling well . Evaporation is computed as the differences between observed levels, adjusted for any precipitation measured in a rain gauge. Water is added daily to bring the level to a fixed point in the stilling well. The pans have higher rate of evaporation than a large free water surface. Thus a factor of 0.7 is, usually used for converting the observed evaporation to those of large water surface area. This factor is called Pan Coefficient.

Evaporation from land surface is affected by degree of soil saturation, temperature of soil and air, humidity and wind velocity.

Transpiration (T) : Loss of water in the form of vapour from the plant canopy to the atmosphere is termed as transpiration.

Evapotranspiration : The total loss of water from soil surface through evaporation and that as water vapour from plant surface through transpiration, in together refers to evapotranspiration. It has direct correlation with crop yield. Evaporation rate is normally expressed in millimeters (mm) per unit time.

As one hectare = 10000 m^2

One mm = 0.001 m

Loss of 1 mm of water = 10 m^3 water ha^{-1}

Thus 1 mm ET/day = 10 m^3 $ha^{-1}day^{-1}$

Energy or heat required to vapourise free water, known as latent heat of vapouri sation (λ), Is a function of the water temperature. At 20^0C, λ is about 2.45 MJ kg-[1]; means 2.45 MJ are needed to vapourise 1 kg or 0.001 m^3 of water. Hence, an energy input of 2.45 MJ per m^2 is able to vapourise 0.001 m or 1 mm of water. Therefore, 1 mm water = 2.45 MJ $m^{-2.}$ Evapotranspiration rate expressed in units of MJ m^{-2} day^{-1} is represented by λ ET, the latent heat flux.

Conversion factors for ET

Expression	Depth mm day^{-1}	Volume per unit area		Energy per unit area MJ m^{-2} day^{-1}
		m^3 ha^{-1} day^{-1}	l $s^{-1}ha^{-1}$	
1 mm day^{-1}	1	10	0.116	2.45
1 m^3 ha^{-1} day	0.1	1	0.012	0.245
1 l s^{-1} ha^{-1}	8.640	86.40	1	21.17
1 MJ m^{-2} day^{-1}	0.408	4.082	0.047	1

Factors affecting evapotranspiration

A. weather/climatic parameters

1. Air temperature
2. Solar radiation
3. Relative humidity
4. Wind velocity
5. Precipitation

B. Crop characteristics

1. Stomata number and size
2. Stomatal opening and closing
3. Canopy cover
4. Adaptive mechanism
5. Rooting characterstics
6. Length of crop growing season

C. Management and environment factors

1. Tillage
2. Irrigation schedule
3. Fertilizers
4. Plant protection
5. Weed management
6. Wind breaks
7. Salinity
8. Antitranspirants
9. Ground water level.

Evapotranspiration and crop yield relationship

Water use-yield relationship – Under adequate water supply the ET is expected to be maximum for realizing potential crop yield, provided other management practices are optimal. Relative yield is the proportion of actual yield (Ya) to the maximum yield (Ym), can be expressed as percentage or as a function by subtracting by one. (1- Ya/Ym). Similarly, relative ET can be expressed as 1- Eta/ ETm. Thus, the relationship equation can be as-

$$= \quad 1 - \frac{ETa}{ETm} \quad = \quad K_y \quad 1 - \frac{Ya}{Ym}$$

Where ky is a constant which is the yield response factor and can be estimated if the ET and yield data are available.

<u>Evapotranspiration and consumptive use</u>:

Evapotranspiration (ET) = Evaporation from crop field (E) + Transpiration (T) + intercepted precipitation by crop and lost as evaporation (IP)

Consumptive use (CU) = E.T. + water used by crop plants for metabolic activities (Ww). It is nearly 1%

<u>Evapotranspiration concepts</u>

<u>Potential Evapotranspiration (PET)</u> is the highest rate of evapotranspiration by a short and actively growing crop with abundant foliages completely shading the ground surface with abundant soil water supply under a given climate. This refers to the maximum water loss from the crop field.

<u>Reference crop evapotranspiration</u> (ET_0)- Evapotransiration rate from a reference surface, not short of water is called the reference crop evapo-transpiration. Reference surface is a hypothetical grass reference crop with specific characteristics. The redefined (FAO Penman-Monteith) crop evapotranspiration (Allen et al. 1998) is: ‘Evapotranspiration from a hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 sm^{-1} and the albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered.

Actual crop evapotranspiration (ET crop) refers to the rate of evapotranspiration by a particular crop in a given period under prevailing soil water and atmospheric conditions. Crop evapotranspiration under standard condition is the evapotranspiration from a well maintained crop, grown in large fields, under optimum soil moisture condition and able to give maximum production under given climatic condition.

To find the ET crop the following relationship is used

ETc = ETo x Kc

Kc = Crop coefficient

$$Kc = \frac{ETc}{ETo}$$

Crop evaporation under non-standard condition (ETc adj) is the evapotranspiration from crops grown under management and environmental condition that differ from standard condition.

ETc adj is calculated by using a water stress coefficient Ks and /or by adjusting crop coefficient Kc for other stresses and environmental constraints .

The effects of soil water stress are described by multiplying the basal crop coefficient Kcb by the water stress coefficient Ks:

ETc adj = (Ks Kcb+Kc) ETo

Measurement of Evapotranspiration

1. Energy balance and microclimatological methods.
2. Soil water balance
3. Lysimeters
4. Empirical methods (from meteorological data).

1. Energy balance and microclimatological methods

Evaparation of water requires energy in the form of sensible heat or radiant energy. Therefore, the evapotranspiration process is governed by energy exchange at the vegetation surface and is limited by the amount of energy available.

$$Rn - G - \lambda Et - H = O$$

Where Rn = net radiation, H = Sensible heat

G = Soil heat flux, ƛ ET = Latent heat flux,

Latent heat flux (ƛET) representing the evapotranspiration fraction can be derived from the 'energy balance equation' if all other components are known.'Rn' and 'G' can be estimated from climatic parameters. Measurement of 'H' is complex and requires accurate temperature gradients above the surface.

2. Soil water balance : It is an account of all quantities of water added, removed or stored in soil during a given period of time.

Change in soil water = Inputs of water – Losses of water

Water Inputs = P + I + C

Where, P = Precipitation, I = irrigation

C = Contribution from ground water.

Losses of water = ET+D +RO

Where ET = Evapotranspiration, D = Deep drainage RO = Surface runoff.

Thus, **Change in soil water** = (P + I + C) - (ET + D + RO) . Suppose, the amount of water in root zone at the beginning is M_1 and at the end of period is M_2 . Then , $M_1 - M_2 = P + I + C – ET - D – RO$

Or $M_1 + P + I + C = ET + D + RO + M_2$

Using this equation any unknown parameter can be computed, if all others are known. This is useful for selecting appropriate water management strategies.

3. Lysimeters : Lysimeters provide the direct measurement of water flux from vegetative surface. Lysimeter is a large tank filled with soil. Rectanular units of 4.0

m^2 are satisfactory for most crops. Total depth ranges between 100-150 cm as per root depth of crops. In general, 50% available soil moisture depletion in root zone should not be exceeded. The crop grown in lysimeter is the same as in surrounding area.

There are two types of lysimeters, weighing and drainage type. In the drainage type, the inflows and drainage are measured, but changes in storage within soil are not measured. In weighing type lysimeters each element i.e. rainfall, irrigation, runoff and ET can be determined by using water balance equation.

ET = Weight change + water added - percolation

4. <u>Empirical methods</u>: Empirical methods to predict the water requirements are primarily based on climetological data and crop factors. There are four methods of predicting ET under different climatic conditions, recommended by FAO group of Scientists (Doorenbos and Pruitt, 1975)

1. Blaney - Criddle method
2. Radiation method
3. Modified penman method
4. Pan evaporation method

Three major steps involved in estimation of ET by empirical methods are

1. Estimation of reference evapotranspiration (ETo)
2. Determination of crop coefficients (Kc)
3. Making adjustments to location specific environments

Modified Penman and radiation methods offer best results for periods as short as 10 days followed by pan evaporation method. Blaney-criddle method is ideal for periods of one month or more in many climates.

Blaney-criddle Formula: Blaney- Criddle (1950) formula is based on mean monthly temperature, daylight hours and locally developed crop coefficients

$$U\ (CU) = \Sigma u = KF = \Sigma kf = \Sigma \frac{ktp}{100}$$

Where,

U or CU = Seasonal consumptive use

u = monthly consumptive use

t = Mean monthly temperature (^{0}F)

p = Monthly daylight hours expressed as percentage of daylight hours of the year.

f = t x P/100, monthly consumptive use factor

k = empirical consumptive use crop coefficient, for the month (= u/f)

Doorenbos and Pruitt (1975) recommended following relationships for 'f' in this formula

f = p (0.46 t +8.13) , using t in ^{0}C

Or

f = 25.4 (p x t) /100, using t in ^{0}F

Thus, finally it become

$$ET_0 = C\ [p\ (0.46\ t + 8.13]$$

Where, ET_0 = reference ET (mm day^{-1}) for the month

C = adjustment factor depending on RHmin, daytime wind velocity and ratio of actual sunshine h to maximum possible sunshine hour.

T = mean daily temperature for the month.

P = mean daily percentage of total annual daytime.

Radiation method : This method requires direct measurement of bright sunshine hours, general levels of humidity and wind velocity.

$ET_0 = C (W \times Rs)$

Where, **Rs** = Measured mean incoming shortwave radiation (mm day^{-1}) – (by pyrenometer) or obtained from Rs = (0.25+0.50x n/N) Ra. Where = Ra is extraterrestrial radiation (mm day^{-1}), N = maximum possible sunshine duration (h day^{-1}), n = measured mean actual sunshine duration (h day^{-1}), **W** = Temperature and altitude dependent weighing factor

C = Adjustment factor made graphically on w. Rs using estimated values of R H mean and U daytime.

Pan evaporation method : Evaporation from pans provides measurement of integrated effect of radiation, wind, temperature and humidity on evaporation from open water surface. To relate pan evaporation to ET_0, empirically derived Pan coefficients are suggested to account for climate, type of Pan and Pan environments

ETo = K pan x E pan

Where, E pan = evaporation (mm day) from class A Pan

K pan = Pan coefficient.

Modified Penman method : It gives fairly satisfactory results for predicting the effect of climate on ET_0 as it utilises almost all the meteorological Parameters associated with ET.

$ET_0 = C [W \times Rn + (1- W) \times f (u) \times (ea - ed)]$

Rn = Net radiation (mm day^{-1})

or Rn = 7.5 Rs – Rnl

Rs = Short wave radiation (given earlier)

Rn1 = net long wave radiation (mm day^{-1}) a function of temperature f (T), of actual vapour pressure f (ed) and sunshine duration f (n/N) or Rnl= f (T) x f (ed).

ea - ed = Vapour pressure deficit, the difference between saturation vapour pressure (ea) at T mean (mb) and actual vapour pressure (ed)

f (U) = wind function or f (U) = 0.27 (1- U/100) with U in Km day^{-1} at 2 m ht.

W = Tempreature and altitude dependent weighting factor.

C = Adjustment factor for the ratio U day/U night for RH max and for Rs.

Crop coefficients for estimating ET crop

The conditions that affect crop water loss (ET_C) will also affect evaporation from free water surface in a similar manner. It is then necessary to obtain a crop coefficient (Kc) to estimate ETc.

$$ETc = ETo \times Kc$$

Actual crop water requirements, in addition to climate, include the effect of crop characteristics and management practices. Crop coefficient is used to account for all these variations. The climatic data required for selection of crop coefficients are wind speed and humidity. The FAO kc curve is constructed by dividing crop growing period into four growing periods and placing straight line segments through initial and mid season periods being horizontal. The four growth periods are initial period, crop development, mid season and late season. However, FAO coefficients (kc) for major crops (Doorenbas and kassam, 1979) are available for use.

CROPWAT : FAO IDP 46 and 49

CROPWAT is a water balance based computer programme to calculate crop water requirements and irrigation water requirements from climatic and crop data. The programme also allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying cropping patterns. Water balance procedures also allow an assessment of effective rainfall and an evaluation of rainfed production through calculated yield decreases through water balance procedures. This also allows yield reduction predictions to be made and taken into account in making irrigation management decisions to optimize crop water productivity and return to investment.

Soil Plant and Meteorological factors determining Water needs of crops

Water requirement (WR): Water requirement of crop is the quantity of water, required by a crop or diversified pattern in a given period of time for their normal growth under field conditions. It includes ET and other economically unavoidable losses.

Consumptive use (CU): It is the sum of the volumes of water used by crop over a given area in producing plant tissue, in transpiration (T), and that evaporated (E) form adjacent soil or plant foliage. Since the volume used in producing plant tissue is negligible (<1%), CU can be approximately equal to ET.

WR= CU = ET

Since water requirement also include the unavoidable application losses eg. Percolation, seepage, runoff etc. (AL) and water used for special operations (WSO) like land preparation, presowing irrigation etc, it is expressed as - WR = ET + AL + WSO

In terms of source of water it is expressed as - WR = IR + EP + S

Where, IR = Irrigation requirement

EP = Effective precipitation

S = Soil profile moisture contribution

Irrigation requirement (IR) : The total amount of water required to supplement precipitation (EP) and soil moisture contribution (S) to meet crop water needs for optimum growth and yield.

IR = WR - (EP + S)

Net irrigation requirement: It is the depth of irrigation water exclusive of precipitation and ground water contribution or other gains in soil moisture, that is required for plant growth; the amount of irrigation water required to bring the soil moisture level in the effective root zone to the field capacity.

NIR = (CU – EP) + AL

Gross Irrigation requirement : It is the net irrigation requirement and losses in conveyance, distribution and application of water in operating system.

$$GIR = \frac{NIR}{Irri:Efficiency}$$

Optimum water requirement (OWR) : It is the amount of water required during the growing season to produce highest crop yield.

Irrigation frequency : It refers to the number of days between two successive irrigation during the periods without precipitation.

Determination of crop water requirements

A . Direct measurements

1. Transpiration ratio method 2. Depth- interval – yield approach 3. Lysimeter experiments 4. Soil moisture depletion studies 5. Field experimentation

6. Water balance method

B – <u>From climatic data</u>

1. Pan evaporation data 2. Estimation by climatic parameters.

<u>Factors affecting irrigation water needs</u>

1. Climate and crop growing season 2. Crop characteristics 3. Soil factors

4. Crop management practices

1. <u>Climate</u> : Principal climatic factors influencing crop water requirement are precipitation, solar radiation, temperature, wind velocity and relative humidity.

- Well distributed rainfall during the crop season minimises the irrigation need of crops.
- Crop in sunny and hot climate need more water per day than that under cloudy and cool climate.
- Crop water needs are higher under dry weather than the humid.
- High wind velocity increase crop water requirement

2. <u>Crop characteristics</u> : Crop water requirements vary according to growth habit, canopy development, leaf area, sensitivity to drought and duration of crops.

- Tall crops and varieties intercept more solar radiation and have more daily water requirement than shorter crops & varieties.
- Crops with deep root system, have higher water requirement than shallow rooted crops.
- High leaf area increases crop water needs.
- Longer the duration, higher crop water need.
- Crop with higher water sensitivity suffer greater reduction in yield.

General sensitivity of crops to drought

Group I- Low sensitive : Safflower, ground nut, pearlmillet.

Group II- Moderate Low: Sorghum, fingermillet cotton, sunflower, castor sugarcane

Group III – Moderate high : Wheat, Pulses, upland rice

Group IV – Highly Sensitive : Lowland rice, Maize

3. Soil factors: Coarse textured and well aggregated soil retain less water and have low hydraulic conductivity; hence they support less E.T.

- Rideges and furrows minimize evaporation loss.
- Dark coloured soils absorb more heat which lead to higher E.T.

4. Crop management Practices

- Frequent irrigations increases crop water requirements.
- Water requirements with border and check basin irrigation are higher.
- Harrowing or hoeing minimizes water loss.
- Weed management reduce water loss.
- Fertilizer application increases water needs.
- Plant population and row spacing influence E.T.

SCHEDULING IRRIGATION

Irrigation Scheduling : Supply of water in optimum quantity at right time with appropriate application method is called irrigation scheduling.

It enable irrigator to apply exact amount of water ; increases irrigation efficiency. There is accurate measurement of the volume of water applied or depth of application.

Advantages

1. It enables the farmers to schedule water rotation among different fields to minimise water stress and maximise yields.
2. It reduces cost of water and labour through fewer irrigations, thereby making maximum use of soil moisture.
3. Save fertilizer costs by reducing run off and leaching losses.
4. Increases net returns by increasing yield and crop quality.
5. It minimises water logging problems.
6. It assist in controlling root zone salinity problems through controlled leaching.
7. Additional returns by using saved water.

Factors influencing irrigation schedules

1. Soil   2. Plant   3. Climate   4. Managements

When to irrigate

1. Maintanance of soil moisture around field capacity is ideal for many crops.
2. As the soil moisture tension increases crops can’t extract needed moisture for optimum growth.
3. Crop starts wilting leading to retard growth and permanent wilting.

4. Crop should not experience moisture stress between two irrigations.

5. By knowing ASM in crop root zone and ET demand, irrigation need can be determined.

Approaches for scheduling irrigation

1. Soil moisture monitoring

(i) Measurement of soil water potential by tensiometer or gypsum blocks etc.

(ii) Soil moisture content by direct methods (gravimetric)

(iii) Feel and appearance method.

2. Atmospheric measurements and water balance technique

(i) Measurement of crop evapotranspiration (ETc)

(ii) IW/CPE approach

(iii) Lysimeter studies

(iv) Field water balance

3. Plant based monitoring

(i) Contact methods

a. Measuring plant-water status by pressure chamber , Dew point hygrometer, osmometer, tissue water content.

b. Measurement of plant response by sap flow sensors, stomatal conductance (porometers) and plant growth rate.

(ii) Non contact method

a. Site specific crop management and irrigation

b. Plant spectral responses

c. Radiometric sensors

- Multispectral sensors
- Hyperspectral sensors
- Thermal sensing

Plant Indices

1. Visual symptoms
2. Soil cum sand miniplot
3. Plant population
4. Growth rate
5. Indicator plants
6. Critical growth stages .

Delta is the total depth of irrigation to a crop in centimeters. It can be calculated by dividing the volume of irrigation water by the area irrigated.

Duty is the ratio between irrigated area and quantity of water used. It is expressed in litres per second per ha and indicates the flow requirement per hectare of cropped area.

Water Resources

World: Ocean cover 3/4th of earth surface. UN estimated total amount of water 1400 million cubic kilometer on earth.

Fresh Water: Only 2.7% of total water on earth, of which 68.7% lies frozen in polar region &30.1% as ground water and rest in lakes, rivers, atmosphere, moisture, soil and vegetation.

India: India occupies only 3.29 M km2 geographical area which is 2.4% of the world's land area and 17% population.

India supports about 1/6th of world population, 1/50th worlds land and 1/25th of water resources (Institution of Engineers 2003).

The total utilizable water flows of India are estimated as 668 BCM by Garg and Hassan (2007) as against 1110 BCM by CWC (1988), 1209-1255 BCM by NCIWRDP (1999) and 1122 BCM by national water Policy of India.

It is estimated that 1.952 x 1011 m3of water is available out of total precipitation of 4 x 1011 m3. The CWC estimate that ultimate irrigation Potential that can be created through major, medium and minor projects would be around 75.9 M ha. Irrigation Potential with ground water has been assessed as 64 M ha. Thus, the total irrigation potential would be about 139.9 M ha (MOWR 2006).
Water budget in its elementary form can be represented by the equation-

Total rainfall input = Surface water flows+Ground water recharge + evapotraspiration.

Principal annual components of India's water budget:

Component	**Volume(Km^3)**	**Precipitation%**
Precipitation	3838	100
Potetial flows in river	1869	48.7
Natural recharge	432	11.3
Available water	1869+432=2301	60.0
Evapotranspiration	3838-(1869+432) =1537	100-(48.7+11.3)=40

Where Indias Av. Annual Raifall-1187.6 mm (2016-17)
Land area 3.29m Km^2
Total Rainfall input 3838 Km^3

Water resoruces scenario in India

S.No	Resource	Quantity(BCM)
1	Annual Precipitation including Snow fall	4000 (3000 during monsoon)
2	Evaporation+ground water	2131
3	Av. Annual Potential flow in rivers	1869
4	Utilisable surface water resources	1122
a	Conventional means	690
b	Replenishable ground water	432
5	Present Utilization	605
6	Future demand by 2025 AD	1093
	2050 AD	1447
7	Possible additional water Utilization through inter –basin water transfer	170-200

$1Km^3 = 10^9 m^3$ = 1 Billion cubic meter (BCM)=0.10 million ha-m

Ground water resources: Annual Potential G.W. recharge from rainfall in India is about 342.43 Km^3 which is 8.56% of total annual rainfall.

Ground water Resources of India (CGWB, 2002)

S .No	Particular	Quantity Km^3 yr^{-1}
1	Total replenishable ground water resource	432
2	Provision for domestic industrial & other uses	71
3	Available G.W. resources for irrigation	361
4	Utilizable G.W. resource for irri.(90% of S.3)	325
5	Total Utilizable GW resources (2+4)	396

<u>Problems of water reources</u>

1.Spatial & Temporal distribution-Rainfall

- Mousinram,, cherrapunji, Meghalaya-11690 mm
-Jaisalmer, Rajasthan - 150mm

2.Conflicting objectives of water Resource Development

Major & Medium irrigation Projects are multipurpose with hydropower generation, flood control and irrigation. The operational aspects of multipurpose Projects need to be optimized.

3.Increasing Sectorial competition:-

With increasing Population, change in food habits, life style changes, increasing emphasis on travel/tourism the demand scenario is expected to change.

4.Pollution of surface & G.W. resources:-

- Effluents form municipal and industries into rivers.
- Indiscriminate use of fertilizers, insecticides,& fungicides
- Disposal of domestic & industrial sewage
- G.W. Pollution is more serious.

5. Rising & Falling water table:-

-60-65% water lost in conveyance in field leading to rise in water table and ultimately water logging & soil salinity.

-Over exploitation of ground water causing decline in water table.

Irrigation Development in India:

At the time of Independence 19.4 Mha

Net irrigated Area

During 2014-15 (Area M ha):

Net Irrigated area- 68.38, Gross Irrigated Area - 96.46.

Net sown area- 140.13., Gross sown Area – 198.36

Cropping Intensity 141.6

State	**Net irrigated area (000ha)**
Uttar Pradesh	14389
Madhya Pradesh	9584
Rajasthan	7882

Crop-wise gross irrigated area (mha) in India

	Rice	Wheat	Total food grains	Total pulses	Fruits & Veg.	Total oilseeds	Sugar-cane	Total
Irrigated area	26.58	30.21	65.53	4.31	6.55	7.78	5.02	96.46
%of total area under the crop	60.1	94.2	53.1	19.9	65.6	27.4	90.2	48.6

Agri.Res. Data Book 2019.ICAR.

Important Irrigation Projects (44)				
S.No	**Name**	**Distt &River**	**Capacity at Full Res. Level (M m³)**	**Remarks**
1	**Andra Pradesh**			
I	Nagarjun Sagar	Nalgonda -Krishna	11561	Biggest in Asia
II	Sriram Sagar (Telangana)	Nizamabad- Godavari	3454	Multipurpose
III	Sri Sailam (Telangana)	Kurnaol-AP-Krishna mehboobnagar	8722	
2	**Gujrat**			
I	Sardar Sarovar	Bharuch-Narmada	($9.5km^3$)	2nd largest dam in world
II	Ukai	Tapi- Tapi	8511	
III	Sabarmati(Dharoi) dam	Mehsana-Sabarmati	908	
IV	Kadana	Mahi sagar-Mahi	1542	
3	**Karnataka**			
I	Krishnaraja Sagar(KRS)	Mandya –Kaveri	1400	India's first irri-dam vrindavan garden
II	Linganamakki	Lingammakki,Sagara-Sharavathi	4497	Multipurpoe
III	Tungbhadra	Chikmanglur-Tunghadra	3429	
IV	Ghataprabha	Belgaum & Bijapur-Ghatprabha	1440	
V	Malprabha	Belgaum-Malprabha	1068	
VI	Kabini	Mysore-Kabini	553	
VII	Bhadra	Chickmanglur-Bhadra	26	

Important Irrigation Projects (44)				
S.No	**Name**	**Distt &River**	**Capacity at Full Res. Level (M m^3)**	**Remarks**
4	**Kerala**			
I	Idukki	Idukki-Periyar	997	Arch dam, Hydroelectric
5	**Madhya Pradesh**			
I	Ban Sagar	Shahdol -Son		
II	Bargi	Jabalpur -Narmada		
III	Indira Sagar	Khandwa –Narmada	Largest resovior	
IV	Gandhi Sagar	Mandsour-Chambal	7413	
V	Tawa	Hoshangabad-Tawa	2312	
VI	IndiraSagar Medikheda dam	Shivpuri-Sindh		
6	**Maharashtra**	Aurangabad		
I	Jayakwadi	Godavari	2909	
II	Khadakvasla	Pune-Mutha	86	
III	Koyna	Sangli-Koyna	2797	

Important Irrigation Projects (44)				
S.No	**Name**	**Distt &River**	**Capacity at**	**Remarks**
7	**Orissa**			
I	Hira Kund	Sambalpur-Mahanadi	8146	
II	Mach Kund	Koraput-Machkund	971	
III	Balimela	Malkangiri-Sileru	3610	
IV	Salandi/Hadagarh	Kendujhar-Salandi	566	
8	**H.P**			
I	Gobind Sagar	Bilaspur-Sutlej	9351	Beas- Sutlej link
II	Pongdam/Maharana Pratap Sagar	Kangra-Beas	8579	
9	**Rajasthan**			
I	Ranapratap Sagar	Rawatabhata-chambal	2905	
10	**Tamil Nadu**			
I	Lower Bhavani/Bhavani sagar	Erode-Bhavani	929	
II	Mettur	Salem-Cauvery	2647	
III	Vaigai	Theni- Vaigai	193	
IV	Parambikulam	Palakkad-Parambikulam	505	
V	Adiyar	Chennai-Adyar	109	

Important Irrigation Projects (44)				
S.No	**Name**	**Distt &River**	**Capacity at**	**Remarks**
11	**Uttar Pradesh**			
I	Matatila	Lalitpur-Betwa	883	Multipurpose
II	Ramganga/Kewlagarh(U.Khand)	Garhwal-Ramganga	2448	
III	Rihand/Gobind Ballabh Pant Sagar	Sonbhadra-Rihand	10607	
12	**West Bengal**			
I	Mayurakshi (Jharkhand)	Deoghr-Mayurakshi	617	
II	Kangsabati Kumari	Bankura-Kangswnti Kumari	52	Irrigation, flood control
13	DVC			
I	Maithon-Jharkhand	Dhanbad	1275	
II	Panchethill dam- Jharkhand	Dhanbad- Damodar	1475	
III	Konar –Jharkhand	Hazaribagh	336	
IV	Tilaiya-Jharkhand	Koderna	394	

Soil water movement in soil and plants

Soil: The soil is a dynamic natural body developed as a result of pedogenic process during and after weathering of rocks, consisting of mineral and organic constituents, possessing definite chemical, physical, mineralogical and biological properties, having a variable depth over the earth surface and provide a medium for plant growth.

Soil is heterogeneous mixture of silicate particles, humus and a variety of insoluble salt and oxides of metals called solid phase, a liquid phase and a gaseous phase. Inside of the soil particles, the empty space constitutes the pore spaces that may be filled by air and water.

Soil texture: Soil texture refers to the relative proportion of the primary particles (sand, silt and clay) in the soil. According to the International soil science society (ISSS) the particles are classified as under

Clay	Silt	Fine Sand	Coarse Sand
<0.002 mm	0.002-0.02mm	0.02-0.2mm	0.2-2.0mm

Classification according to united states Department of Agriculture (USDA)

Clay	Silt	Sand				
		Very fine	fine	Med	Coarse	Very Coarse
0.002mm	0.05mm	0.1mm	0.25mm	0.5mm	1.0mm	2.0mm

Particles larger than 2.0-75mm in diameter termed as gravel, are ignored while considering texture. **Sand and gravels** are non sticky, have no plasticity, and possess low water holding capacity because of large pore space. Sandy soils are well drained.

Silt particles are intermediary in size and have properties between sand and clay. Silt cause soil surface compact and crusty.

Clay particles vary in shape from plate like to round. When it is wet, tends to be sticky and plastic. Water and air movement is restricted. Water holding capacity is high. It becomes hard and cloddy when dry. Clay fraction controls most of the important properties of the soils. They are chiefly composed of secondary minerals-crystalline alumino silicate.

There are six types of clay minerals.

1. **Kaolinite -** 1:1type, in which one silica tetrahedral layer is joined with one aluminum octahedral layer. $Si_4\ Al_4\ O_{10}$ (OH)8, CEC 3 to 15 me/100g soil. Total surface area = 37- 45m^2/g.
2. **Smectite -** One Central layer of aluminium octahedron is attached with two layer of silica tetrahedral, one at top and another at bottom. Montmorillonite- $Si_8\ (Al_3Mg)\ O_{20}(OH)_4\ nH_2O$. In montmorillonite the major replacement is MG++ for Al+++ in octahedral layer. There is considerable interlayer space between the units. CEC ranges between 80-150 me/100g. Total surface area is 580-750 m^2/g.
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4. **Vermiculite -** It consists of two silica tetrahedral layer and one octahedral layer, joined together. Some silicon Ions are isomorphously substituted by Al ions and therefore magnesium ions occur between the sheets of vermiculite to balance the structure electrically. Magnesium ions hold the units together, therefore the expansion is somewhat limited. CEC-100 to150 m.e./100g. Total surface area 780 to 900 sqm/g

   $Mg_2\ (Si_6\ Al_2)\ (Mg_2\ Fe_2)\ O_{20}(OH)_4\ nH_2O$.

5. **Chlorite -** It consist of one unit of a vermiculite layer and one unit of a magnesium octahedral layer called Brucite. Chlorite is also called 2:2 type clay. CEC is 15 to 40 m.e./100g and total surface area is 130 -180 sqm/g.
6. **Allophanes -** Allophanes are amorphous hydrated aluminosilicates which are random asymmetrical arrangement of silica tetrahedral and aluminiom octahedral.

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Particle density : The Particle density (ps) also called density of soil solids, is the ratio of mass of soil solids (Ms) to the volume of soil solids (Vs) and is expressed in g cm^{-3} or Mg m^{-3}. In most mineral soils the mean density of Particles varies from 2.6 to 2.7 g cm^{-3}.

$$Ps = \frac{\mathrm{Ms}}{\mathrm{Mv}}$$

Dry bulk density : Dry bulk density or bulk density(Pb) is the ratio of mass of oven dry soil solid particles(Ms) to the total volume of the soil (Vt). This volume includes the volume of soil solids (Vs), Soil water (Vw) and soil air (Va). It is expressed as gcm^{-3}.

$$\mathrm{Pb} = \frac{Ms}{Vt} = \frac{\mathrm{Ms}}{Vs} + \mathrm{Vw} + Va$$

Soil in which pores constitute half of the volume bulk density is half of Particles density i.e. 1.3 to 1.5 g cm^{-3}. In sandy soils bulk density can be as high as 1.6g cm^{-3}. Ideal bulk density for optimum crop growth varies from 1.2 g cm^{-3} for a clay soil to about 1.4 g cm^{-3} for a sandy soil.

Total or wet bulk density - It is the ratio of total mass of soil (Mt) to the total volume of soil (Vt). The bulk density depends more on the moisture content of the soil.

$$\text{pt} = \frac{Mt}{Vt} = \text{Ms} + \frac{\text{MW}}{Vs} + Vw + Va$$

Porosity : Porosity (f) is the ratio of total volume of pore spaces (vf) to the total volume of the soil (Vt) and is expressed as a fraction or percentage.

$$\text{Porosity (f)} = \frac{Vf}{Vt} = \frac{\text{VW}}{Va} + Vs + Vw + Va$$

It is related to the bulk density as under -

$$\text{Porosity(f)} = 100 - \frac{Bulk\ density}{Particle\ density} x100$$

Or f=(ps–pb)/ps or 1-(pb/ps) or pb =(1-f) ps

Porosity is an index of relative pore volume in the soil. Its value, generally lies between 0.3 to 0.6 (or 30 to 60%).

Pore Space - The pores larger than 0.06 mm in dia are considered as macropores and those smaller than this are micropores.

Void ratio (e) - It is an index of fractional volume of soil pores to the volume of solids.

$$e = \frac{Vol.of\ Pore\ space}{Vol.of\ Soil\ Solids} \quad \text{or (Va+Vw)/Vs}$$

Generally **e** varies between 0.3 to 2.0.

Gravimetric water content or mass wetness (**w**):It is the mass (weight) of water (Mw) relative to mass of oven dry soil particles (Ms) and expressedas a fraction or percentage.

W = Mw / Ms.

Volumetric water content or volume wetness (vwc):It is the ratio of

total volume of water occupied in the pore spaces at aspecific time to the total volumeof soil and is expressed as a fraction or percentage. **Vwc** = Vw / Vt = Vw /(Vs+Vf). It can be computed from gravimetric water content by multiplying with bulk density .
Vwc = w x pb.
Degree of saturation(DoS): It is the ratio of volume of water present in the soil at a particular time to the volume of pores.
DoS =Vw / Vf.

How soil holds water:

Soil holds water in two ways (1) as a thin film on individual soil Particle i.e. by adsorption. (2) Water stored in the pores of the soil, said to be in capillary storage.

Cohesion and adhesion - The attraction of like molecules (water) is known as cohesion, and the attraction of unlike-molecules (soil &water) is known as adhesion.

Soil water retention : When water is added to a dry soil it is distributed around soil particles, displaces air and fills the pores. When all the pores are filled with water, the soil is said to be saturated and it is at its maximum retentive capacity. This water is classified in three forms.

1. **Gravitational water -** Water in the macro-pores that moves downward freely under the influence of gravity beyond the root zone; held in soil at $1/3^{rd}$ or less atm is termed as gravitational water. It is not available for plants .
2. **Capillary water -** Water retained by soil in the micro-pores (capillary), against gravity by the forces of surface tension, as a continuous film around soil particles is called capillary water. It is held between tensions of $1/3^{rd}$ to 31 atm.
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Soil moisture costants

1. **Maximum water holding capacity :** The amount of moisture in a soil when total pore space is filled with water is called maximum water holding capacity or saturation percentage or maixmum retentive capacity.

$$\text{MWHC (\%)} = \frac{Max. amount\ of\ water\ absorbed\ by\ soil}{\text{Oven dry weight of soil}} x100$$

Saturation Percentage is approximately 4 times of wilting point and two times of field capacity. MWHC can be determined with Keen's box.

2. Field capacity : In the saturated soils, water continues to drain from large pores for a day or two and become negligible thereafter. The macro-pores are again filled with air. The micro-pores are still filled with water. When all the micro-pores are filled with water the soil is said to be at field capacity. The field capacity is considered as upper limit of water availability to plants. The soil water potential at FC ranges from - 0.1 to - 0.3 bars. Soil water content at FC always move in the direction of increasing tension.

3. Moisture equivalent : The amount of water retained by initially saturated soil after being centrifuged for 1000 times that of gravitational force for about half an hour is called moisture equivalent. Moisture remaining in the soil after this process is determined gravimetrically. This moisture content when expressed as percentage moisture on oven dry basis give the value of moisture equivalent. The values of FC and ME are nearly equal in medium textured soil. In sandy soils FC exceeds Me. In very clayey soils FC is generally lower.

4. Permanent wilting point : Also known as the wilting coefficent, is the moisture content of the soil at which plant can no longer obtai enough moisture to meet the transpiration requiements and remain wilted unless the water is added to the soil. The plant is not dead but remain in wilted condition. Soil moisture tension at PWP ranges between 7-32 atm. Commonly used average value is 15 atm. Soil water potential at this point is -15 bars or -1.5 MPa.

At soil water potential of - 30 bars water can move only in vapour phase. Moisture content of soil at this point is termed hygroscopic coefficient. At - 60 bars plants can not absorb moisture and die eventually. Soil moisture content at which plants die is called **ultimate wilting point.**

Available soil moisture : Moisture available for plant growth is the capillary water between FC and PWP , Hence, ASM =FC - PWP. Sandy soils has the lower amount of ASM and clay soils the highest. Soil texture, Soil structure,organic matter and concentrations of $CaCo_3$ and iron oxide (Fe_2O_3) affects moisture holding capacityof soil.

Moisture content of different soils

Soil texture	**FC%**	**PWP%**	**BDg cm^{-3}**	**Available water (mm) m^{-1} soil depth=FC-PWP/100 x BD x Soil depth.**
Sandy	5-10	2-6	1.5-1.8	50-100
Sandy loam	10-18	4-10	1.4-1.6	90-160
Loam	18-25	8-14	1.3-1.5	140-220
Clay loam	25-32	11-16	1.3-1.4	170-250
Clay	32-40	15-22	1.2-1.4	200-280

Concept of soil water availability :-

1. Equal availability from FC to PWP: water availability and consequently the crop growth is equal and uniform over the entire range from field capacity to permanent wilting point. This hold good for orchard & tree crops.

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Principal and Practices of Water Management

Water : Water is a bipolar liquid. It has a symmetrical structure in which hydrogen (H^+) atoms are attached to the oxygen in sort of 'V' arrangement. The H^+ atoms side holds a net positive charge and oxygen atom side holds a net negative charge.

Properties of water: The Properties of water arise from the hydrogen bonding and tetrahedral arrangement of electron pairs around the oxygen (4 faces) atom. The size of water molecule is2.75 A^0 ($1A^0=10^{-10}$m).

Polarity : Water molecules are dipolar in nature for which they cling to each other through H^+ bonding rather than acting individually.

Hydrogen bounding: The Phenomenon by which hydrogen atoms act as connecting linkages between water molecules.

Surface tension : Phenomenon occurring typically at the interface of liquid and gas and results from the greater attraction of water molecules for each other the for the gas above.

$$\text{Surface Tension(T)} = \frac{F(Force-Dynes)}{L(Length-cm)}$$

$$\text{S.T. of water } = 72\ dynes/\text{cm at 25 degree C}$$

Capillary rise : The rise of water in a capillary tube to a level higher than that in the container is called capillary rise. This rise is due to combined action of cohesion, adhesion and surface tension.

$$H = \frac{2T}{Pgr}$$

Where ,T= Surface tension(dynes/cm)

P= Density of water (gm/cm^3)

g = acceleration due to gravity (981cm/sec^2

r = radius of capillry tube (cm)

Viscosity : When a fluid is moved in shear, the force required is proportional to the velocity of the shear. The Proportionality factor is called viscosity. For water viscosity decreases about 3% Per 1^oC rise in temperature.

Role of water: Water is essential for human, animal & Plant life. Water plays a key role in photosynthesis. It is a medium for transport of nutrient and photosynthesis. Crop production depends on availability of water .Importance of water is classified as ecological and physiological values.

Ecological : The distribution of vegetation over the each surface is controlled more by the availability of water than any other factor. Temperature is correlated in this process.

Physiological :

1.Water is structural constituent of plants cells and maintains turger pressure/Turgidity. In young plants 85-90% and in matured plants 20-50% is water, by weight.

2. Source of oxygen and hydrogen required for synthesis of carbohydrate during photosyntesis.

3. Serves as a solvent of substances and a medium in plants allowing metabolic reactions to occur.

4.Acts as a solvent of plant nutrients and help in uptake of nutrients from soil. Plants also absorb nutrients through leaves from nutrient sprayes.

5. Carrier of photosynthates to be distributed to different plant parts.

6. Transpiration occurs at a potential rate as long as water is available in adequate amount. It otherwise seriously affect plant growth & yield.

7. Regulates opening & closing of stomata by maintaining turgor pressure of guard cells.

8. Cells and tissues are formed and plant growth occurs when an adequate amount of soil water is available.

9. Water acts as a buffer against high or low temperature injury as it has high heat of vaporiazation and high specific heat.

As a whole, water encourages good growth, development and yield of plants and quality of produce when available in sufficient quantities. plants cannot survive without water.

Categorization of water and their role in agriculture			
S.No	**Category**	**Sources**	**Potential use in agriculture**
1	Blue Water	Sea, lakes, river canal etc	Extensively used in irrigation, Availability decrease with increasing competition form other sources.
2	Green Water	Soil moisture and water in plants	Mostly used by plants /crops, Particularly forest, grass lands, & dry land agriculture.
3	Fossil Water	Ground water	Mostly agricultural and domestic use, availability decreases with increasing competition from other sources.
4	Grey Water	Waste water form bathrooms , kitchens and wash basins	Potential for use in crop production Irrigation in kitchen garden & lawns
5	Black Water	Domestic sewage/ industrial waste	Potential for use in crop production, provided the technology to avoid heavy metal and Pathogen is available.
6	Virtual Water	Water used in Producting grains/ animals products	Export import of food grains/animal products indirectly results in export-import of water. will be important in future.

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It can be determined by the following formulae

$$\text{Porocity} = 100 - \frac{Bulk\ density}{Particle\ density} x100$$

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<u>Factors affecting available soil moisture</u>

1.Soil texture 2.Soil structure 3.Conc. of $CaCo_3$ &Fe_2O_3

Water Intake : The movement of water from the soil surface into and through the soil is called water intake. It includes infiltration and Percolation.

Infiltration : Infiltration is the Process of water entry into the soil. The water flux into the soil is called infiltration rate (mm/h) or the rate at which water is passing through the surface to the soil.

It is grouped in four categories-

1 Very slow < 0.25cm h^{-1} –very clay soil
2 Slow 0.25 to 1.25 cm h^{-1} –high clay
3 Moderate 1.25 to 2.50 cm h^{-1} –sandy loam/ silt loam
4 Rapid > 2.50cm h^{-1} –deep /sandy silt loam

Typical values of final infiltration rate (FIR)

Soil type	F I R mm h^{-1}
Sands	>20
Sandy& Silty soils	10-20
Loams	5-10
Clayey soils	1-5
Sodicclay soils	<1

Factors affecting infiltration rate;

1. Compactness of soil surface **2.** Impact of raindrop **3.** Soil cover
4. Soil wetness **5.** Soil temperature **6.** Soil texture
7. Soil depth

Measurement- by cylinder infiltrometer.

Permeability: Qualitatively it is the characteristic of a porous medium relating to the readiness with which it transmits fluids.

Quantitatively, it is the specific property governing the rate of readiness with which a porous medium transmits fluids under standard conditions .

Factors

1. Macro & Micropores
2. Depth of soil
3. Soil texture
4. Soil moisture status
5. Salt concentration
6. Organic matter content

Slow- < 2.5 cm h^{-1}

Moderate-around 5.0 cm h^{-1}

Percolation: Percolation is the downward movement of water through saturated or nearly saturated soil in response to the force of gravity. It occurs when tension is smaller than 1/2 atm. It depends on soil and climate.

Inter flow : Interflow is the lateral flow of water in a relatively pervious soil above a less pervious layer.

Seepage : Seepage is the downward and lateral movement of water in the soil.

Measurement of soil moisture:

The soil moisture is determined by direct and indirect methods .

Direct measurement (Gravimetric methods) : Involve removing water from a soil sample by evaporation, leaching or chemical reaction. Soil moisture content is calculated from the mass of water removed and the mass of dry soil. They are simple and inexpensive, hence widely used.

7. Oven Drying : This is a standard method to which all other methods are referred. Soil samples are collected from the desired depth with a auger. They are placed in aluminium boxes and weighed. These samples are dried in oven at 105-110 ^{O}C atleast for 24 hrs. Then weight of dried samples is taken. The moisture content is calculated as under –

$$\text{Moisture content (\%)} = \frac{\text{Wt. of wet soil}(W_1)\text{-wt. of dry soil }(W_2)}{\text{Wt. of dry soil }(W_2)} \times 100$$

$$\text{Volumetric water content (\%)} = \frac{W_1-W_2}{W_2} \times 100 \times \text{Bulk density}$$

Depth of water per unit Soil depth (cm) = Vol. water content x Soil depth

8. Alcohol Burning method : Soil moisture from the sample is evaporated by adding alcohol and igniting. 1.0 ml of alcohol per g of soil at FC and 0.5 ml at PWP is adequate for evaporating soil moisture. This method is not recommended for soil with high organic matter.

9. Hot air drying : Hot air around 110^{O}C is passed on a screen with weighed samples of moist soil. Samples must be pulverized.

10. Gypsum sorption plugs : Gypsum plugs placed in soil comes into equilibrium with surrounding soil moisture. They are removed and weighed to determine soil moisture content. It is necessary to calibrate the wt. of porous cup with soil moisture content for different soils.

11. Infrared balance : It gives fairly reliable moisture estimate in about 5 minutes. It consists of a 250 watt infrared lamp, sensitive torsion and autotransformers, all housed in an aluminium cabinet. The radiation emitted by infrared lamp quickly vaporize the soil moisture. The instrument is directly calibrated in % moisture.

12. Feel and appearance method : A rough guide for scheduling irrigation. Soil moistures are judged by manipulating soil with hand and fingers. The soil samples from root zone are observed for colour, plasticity and cohesiveness.

Indirect methods : Usually measures the volumetric soil moisture content . Relatively quick and accurate.

8. Tensiometric method : Tensiometer is also called irrometer, used in irrigation scheduling. It provide a direct measure of tenacity (tension) with which water is held by soil. It estimate the soil -water matric potential which includes adsorption and capillary effects.

The working Principle of tensiometer is that when a sealed water-filled tube is placed in contact with the soil through a permeable and saturated porous material, the water (inside the tube) comes into equilibrium with the soil solution. Hence, the soil water matric potential is equivalent to the vaccume or suction created inside the tube.

Tensiometer consists of a sealed water filled plastic tube with a ceramic cup at one end and a negative pressure gauge at the other. Typically measurement range is 0 to 0.80 bars. The vaccume gauge is graduated to indicate tension values upto one atm and is divided into 50 divisions each of 0.2 atm. It is calibrated in centibars or 1/100 of one bar. (Bar is an international unit of pressure in metric system= 14.5 Psi or 0.987 atm.). One centibar is equal to 1 kilopaskal (kPa).

Tensiometer is installed at a depth of 30 cm and 60 cm below the ground surface with the help of a probe or screw auger. Depth of hole should be ¼ to 1 inch less than actual depth for the porous tip. Pour ¼ cup of water into the hole. Insert the tensiometer and gently push it down to the desired depth. Instrument is ready to use 24 hrs after installation. Readings should be taken early in the morning.

A reading of zero corresponds to a completely saturated condition. A reading of 85 indicates a very dry condition.

Meaning of tensiometer reading

i	0-5 cb	-	Saturated soil
ii	10 cb	-	Field capacity
iii	10-25 cb	-	Ideal soil water and aeration
iv	25-85 cb	-	Decreased soil water availability

Irrigation scheduling for different soils

i	Clay & Clay loam textured	-	50 cb
ii	Fine sand textured and sandy duplex	-	30-40 cb
iii	Corse sand textured	-	20-30 cb

Pressure plate technique : This is a laboratory method. The Pressure plate and Pressure membrane apparatus measures the uptake and release from soil samples over a wide range of suction values.

9. Electrical Resistance method : It works on the Principal based on the linear relationship between the electrical resistance and moisture content of soil. Electrical resistance increases with decrease in moisture content.

The resistance blocks are made of gypsum. The electrodes in the blocks are connected to a conductance-meter for measuring the electrical resistance or conductance.

The blocks are buried at an appropriate depth at a certain distance. After sometime equilibrium is reached. As the soil moisture increases or decreases, the water content of block also increases or decreases. Higher the water content, higher is the conductivity.

Resistance blocks read low resistance (400 to 600 ohms) at FC and high resistance (50,000 to75,000 ohms) at PWP. Associated soil water content must be obtained from a calibration curve.

Granular matrix sensors and dielectric soil moisture sensors are also used in this method.

10. Radiation methods : Neutron scattering and gamma ray attenuation methods are used to determine soil moisture content.

11. Thermal methods : Heat dissipation sensors, heat capacity sensors and soil psychrometers are used to determine soil moisture.

5. **Remote sensing :** Based on infrared or electromagnetic Properties of soil.

Water Resources

World: Ocean cover 3/4th of earth surface. UN estimated total amount of water 1400 million cubic kilometer on earth.

Fresh Water: Only 2.7% of total water on earth, of which 68.7% lies frozen in polar region &30.1% as ground water and rest in lakes, rivers, atmosphere, moisture, soil and vegetation.

India: India occupies only 3.29 M km^2 geographical area which is 2.4% of the world's land area &15% population.

India supports about 1/6th of world population, 1/50th worlds land and 1/25th of water resources (Institution of Engineers 2003).

The total utilizable water flows of India are estimated as 668 BCM by Garg and Hassan (2007) as against 1110 BCM by CWC (1988), 1209-1255 BCM by NCIWRDP (1999) and 1122 BCM by national water Policy of India.

It is estimated that 1.952×10^{11} $m^3$of water is available out of total precipitation of 4×10^{11} m^3. The CWC estimate that ultimate irrigation Potential that can be created through major, medium and minor projects would be around 75.9 M ha. Irrigation Potential with ground water has been assessed as 64 M ha. Thus, the total irrigation potential would be about 139.9 M ha (MOWR 2006). Water budget in its elementary form can be represented by the equation-

Total rainfall input = Surface water flows+Ground water recharge + evapotraspiration.

National comunission for Integrated water resource Development plant, Mowr

Principal annual componets of Indias wate buget

Component	**Volume(Km^3)**	**Precipitation%**
Precipitation	3838	100
Potetial flows in river	1869	48.7
Natural recharge	432	11.3
Available water	1869+432=2301	60.0
Evapotranspiration	3838-(1869+432) =1537	100-(48.7+11.3)=40

Where Indias Av. Annual Raifall-1170 mm

Land area 3.29m Km^2

Total Rainfall input 3838 Km^3

Water resoruces scenario in India

S.No	Resource	Quantity(BCM)
1	Annual Precipitation including Snow fall	4000 (3000 dry Months)
2	Evaporation+ground water	2131
3	Av. Annual Potential flow in rivers	1869
4	Utilisable surface water resources	1122
a	Conventional means	690
b	Replenishable ground water	432
5	Present Utilization	605
6	Future demand by 2025 AD	1093
	2050 AD	1447
7	Possible additional water Utilization through inter –basin water transfer	170-200

$1 Km^3 = 10^9 m^3$ = 1 Billion cubic meter (BCM)=0.10 million ha-m

Ground water resources

Annual Potential G.W. recharge from rainfall in India is about 342.43 Km^3 which is 8.56% of total annual rainfall.

Ground water Resources of India (CGWB,2002)

S .No	Particular	Quantity $Km^3\ yr^{-1}$
1	Total replenishable ground water resource	432
2	Provision for domestic industrial & other uses	71
3	Available G.W. resources for irrigation	361
4	Utilizable G.W. resource forr irri.(90% of sr.3)	325
5	Total Utilizable GW resources (2+4)	396

Problems of water reources:-

1.Spatial & Temporal distribution-Rainfall

- Mousinram,, cherrapunji, Meghalaya-11690 mm

-Jaisalmer, Rajasthan - 150mm

2.Conflicting objectives of water Resource Development

Major & Medium irrigation Projects are multipurpose with hydropower generation, flood control and irrigation. The operational aspects of multipurpose Projects need to be optimized.

Increasing Sectorial competition:-

With increasing Population, change in food habits, life style chages, increasing emphasis on travel/tourism the demand scenario is expected to change.

Pollution of surface & G.W. resources :-

- Effluents form municipal and industries into rivers.
- Indiscriminate use of fertilizers, insecticides,& fungicides
- Disposal of domestic & industrial sewage
- G.W. Pollution is more serious.

Rising & Falling water table:-

60-65% water lost in conveyance in field leadling to rise in water table and ultimately water logging & soil salinity.

Over exploitation of ground water causing decline in water table.

Irrigation Development:-

		Net irri. Area
At the time of Independence	- India -	19.4 Mha
	- Pak -	8.8 Mha

During 2011-12 (Area M ha):-

Net Irrigated area- 65.26, Gross Irri. Area - 91.53.

Net Un irri. area- 75.54,Gross Un Irri. Area – 103.72.

Percent of G.I to total cropped area 46.9, Cropping Intensity 138.7

Important Irrigation Projects (44)				
S.No	**Name**	**Distt &River**	**Capacity at Full Res. Level (M m^3)**	**Remarks**
1	**Andra Pradesh**			
I	Nagarjun Sagar	Nalgonda -Krishna	11561	Biggest in Asia
II	Sriram Sagar (Telangana)	Nizamabad- Godavari	3454	Multipurpose
III	Sri Sailam (Telangana)	Kurnaol-AP-Krishna mehboobnagar	8722	
2	**Gujrat**			
I	Sardar Sarovar	Bharuch-Narmada	(9.5km^3)	2nd largest dam in world
II	Ukai	Tapi- Tapi	8511	
III	Sabarmati(Dharoi) dam	Mehsana-Sabarmati	908	
IV	Kadana	Mahi sagar-Mahi	1542	
3	**Karnataka**			
I	Krishnaraja Sagar(KRS)	Mandya –Kaveri	1400	India’s firest irri-dam vrindavan garden
II	Linganamakki	Lingammakki,Sagara-Sharavathi	4497	Multipurpoe
III	Tungbhadra	Chikmanglur-Tunghadra	3429	
IV	Ghataprabha	Belgaum & Bijapur-Ghatprabha	1440	
V	Malprabha	Belgaum-Malprabha	1068	
VI	Kabini	Mysore-Kabini	553	
VII	Bhadra	Chickmanglur-Bhadra	26	

Important Irrigation Projects (44)				
S.No	**Name**	**Distt &River**	**Capacity at Full Res. Level (M m^3)**	**Remarks**
4	**Kerala**			
I	Idukki	Idukki-Periyar	997	Arch dam, Hydroelectric
5	**Madhya Pradesh**			
I	Ban Sagar	Shahdol -Son		
II	Bargi	Jabalpur -Narmada		
III	Indira Sagar	Khandwa –Narmada	Largest resovior	
IV	Gandhi Sagar	Mandsour-Chambal	7413	
V	Tawa	Hoshangabad-Tawa	2312	
VI	Indira Sagar Medikheda dam	Shivpuri-Sindh		
6	**Maharashtra**	Aurangabad		
I	Jayakwadi	Godavari	2909	
II	Khadakvasla	Pune-Mutha	86	
III	Koyna	Sangli-Koyna	2797	

Important Irrigation Projects (44)				
S.No	**Name**	**Distt &River**	**Capacity at**	**Remarks**
7	**Orissa**			
I	Hira Kund	Sambalpur-Mahanadi	8146	
II	Mach Kund	Koraput-Machkund	971	
III	Balimela	Malkangiri-Sileru	3610	
IV	Salandi/Hadagarh	Kendujhar-Salandi	566	
8	**H.P**			
I	Gobind Sagar	Bilaspur-Sutlej	9351	Beas- Sutlej link
II	Pongdam/Maharana Pratap Sagar	Kangra-Beas	8579	
9	**Rajasthan**			
I	Ranapratap Sagar	Rawatabhata-chambal	2905	
10	**Tamil Nadu**			
I	Lower Bhavani/Bhavani sagar	Erode-Bhavani	929	
II	Mettur	Salem-Cauvery	2647	
III	Vaigai	Theni- Vaigai	193	
IV	Parambikulam	Palakkad-Parambikulam	505	
V	Adiyar	Chennai-Adyar	109	

Important Irrigation Projects (44)				
S.No	**Name**	**Distt &River**	**Capacity at**	**Remarks**
11	**Uttar Pradesh**			
I	Matatila	Lalitpur-Betwa	883	Multipurpose
II	Ramganga/Kewlagarh(U.Khand)	Garhwal-Ramganga	2448	
III	Rihand/Gobind Ballabh Pant Sagar	Sonbhadra-Rihand	10607	
12	**West Bengal**			
I	Mayurakshi (Jharkhand)	Deoghr-Mayurakshi	617	
II	Kangsabati Kumari	Bankura-Kangswnti Kumari	52	Irrigation, flood control
13	DVC			
I	Maithon-Jharkhand	Dhanbad	1275	
II	Panchethill dam- Jharkhand	Dhanbad- Damodar	1475	
III	Konar –Jharkhand	Hazaribagh	336	
IV	Tilaiya-Jharkhand	Koderna	394	

Water Intake : The movement of water from the soil surface into and through the soil is called water intake. It includes infiltration and Percolation.

Infiltration : Infiltration is the Process of water entry into the soil. The water flux into the soil is called infiltration rate (mm/h) or the rate at which water is passing through the surface to the soil.

It is grouped in four categories-

1 Very slow : < 0.25cm h^{-1} –very clay soil

2 Slow : 0.25 to 1.25 cm h^{-1} –high clay

3 Moderate :1.25 to 2.50 cm h^{-1} –sandy loam/ silt loam

4 Rapid : > 2.50cm h^{-1} –deep /sandy silt loam

Typical values of infiltration rate (FIR)final

Soil type	F I R mm h^{-1}
Sands	>20
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Factors affecting infiltration rate;

1. Compactness of soil surface **2.** Impact of raindrop **3.** Soil cover
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5. Salt concentration
6. Organic matter content 7.Soil aggregates .

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ENERGY STATE OF SOIL WATER:

Since the movement of water in soil is quite slow, its kinetic energy (Proportional to the velocity squared) is considered negligible.

The potential energy which is due to its position or internal conditions determines the state and movement of water in soil.

Water potential refers to the ability of water to move in the soil.

More water in soil= more water potential. At saturation potential is near zero. As soil dries values become more negative.

Total potential of soil water is the amount of work that must be done per unit quantity of pure water in order to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water at a specified elevation at atmospheric pressure to the soil water (at the point under consideration) –ISSS (1963)

Soil-water potential (Soil-water tension) is a measure of tenacity with which water is retained in the soil and shows the force per unit area that must be exerted to remove water from soil. It is measured in terms of potential energy of water in soil measured ,with respect to free water .It is expressed in atmosphere, the average air pressure at sea level. Other pressure units i.e. cm or mm of water or mercury are also used.

1 atm= 1036 cm of water= 76.39 mm of mercury.

1 bar= 10^6 dynes cm^{-2} = 1036 cm of water.

1 milli bar= 1/1000 bar

The term **capillary potential or pF** is also used to define the energy with which water is held by soil. The pF function is defined as the numerical value of the negative pressure of the soil moisture expressed in cm of water.

The **total water potential (Ψt)** is the sum of gravitational potential (Ψg), the matric potential (Ψm), the pressure potential (Ψp), and the osmotic/solute potential (Ψo) and any other potential.

$\Psi_t = \Psi g + \Psi m + \Psi p + \Psi o$

The **gravitational potential** is due to the gravitational force field of the earth and is dependent on the vertical location of the water relative to the reference level.

Gravitational potential may be expressed as --- Ψ_g = gZ (mass) or P_w gz (vol.)
Where g = Acceleration due to gravity, cm s^{-2}
Z= height above reference level
P_W= Density of water, g cm^{-3}
When water is above reference level, its Ψ_g is positive,
The matric potential (Ψ_m) is associated with the more or less solid colloidal matrix of the system (Defined as negative pressure/positive suction head). It includes the forces of adsorption and surface tension. Free water has zero Ψ_m and will move into a dry soil. The Ψ_m is negative in unsaturated soil and zero in saturated soil. Thus, removal of water from a soil water system decreases Ψ_m of remaining water.

Ψ_m per unit mass = gh
Ψ_m per unit volume = pwgh
Ψ_m per unit weight = h (submergence depth)

The pressure potential (Ψ_p) results from the external pressure on the soil-water i.e. overlying water or submergence depth (h) and atmospheric pressure is the reference. Ψ_p will be positive in a saturated soil and zero in unsaturated soil.

Ψ_p per unit mass= gh
Ψ_p per unit vol=p (pressure of water)

The osmotic potential (Ψ_o) / solute potential (Ψ_s) results from the solutes dissolved in soil water.

Ψo= π (Osmotic pressure due to dissolved salts or solutes)

Units of potential – Pascal (P_a), Kilopascal (**Kp**a) or megapascal (MPa)
1 Bar= 0.1 MPa or 100 **Kp**a.
Soil water potential is usually negative because of negative matrix potential.

The soil-water potential can be measured in the field with-

1. Tensiometers- o to -80 KPa (-0.8 to -800 cm)
2. Thermocouple psychrometers- -98 to -3000 KPa (-1 to -30 bars)
3. Heat dissipation sensors- -9.8 to -100,000 Kpa (-0.1 to -1000 bars)
4. Electrical resistance blocks – 0 to -890 or – 1500 Kpa (0 to -10 or –15 bars)

Pressure potential in different units (Marshall et al 1996 & Hillel 1982)

Soil , Plant & atm condition	Bars& atmospheres	Kilo Pascals	Relative energy potential
Saturated soil	0	0	High
Field capacity	-0.33	-33	Medium
Available water	-0.33 to -15	-33 to -1500	Medium
PWP	At or below -15	At or below -1500	Low
Air dried soil	-31	-3100	Low
Oven dried soil	Below -31	Below -3100	Low
Root tissue	-3 to -20	-300 to -2000	Low
Leaf tissue	-15 to -30	-1500 to -3000	Low
Atmosphere	-100 to -500	-10000 to -50000	Very low

Soil moisture characteristics: Soil moisture tension does not indicate the moisture content of the soil and the amount of moisture that can be withdrawn for plant use at any particular tension. Knowledge of the amount of moisture is essential to know amount of water available to plants, water that can be absorbed by plants and the amount of water required for irrigation.

Soil-moisture or water characteristic curve :soil-water retention curve are plot of moisture content versus moisture tension which show the amount of moisture in the given soil at various tensions. SWCC-

- Describes relationship between soil-water potential and volumetric water content.
- Can be determined by simultaneous measurement of water content and pressure potential.
- Soil-water retention is a function of pore size distribution.
- At zero pressure potential, the soils volumetric content is said to be saturated water content.
- As soils drains, the larger pores empty first since they have smallest capillary forces.
- Maximum pressure potential at which soil begins to de- saturate is defined as the air entry value of the soil and is determined by largest pores in soil.

  SMCC is strongly affected by soil texture. Greater the clay content, greater the water content at any particular suction and more gradual the slope of the curve. In sandy soils, most of the pores are relatively large and once these pores are emptied only a small amount of water remains.

Soil structure also affects the shape of SMCC particularly at low suction range. Soil compaction decreases total porosity, specially the volume of large interaggregate pores, Hence ‘Saturation water content’ and ‘initial decrease of water content’ at low suction are reduced. Volume of intermediate pores is greater in compacted soil, while interaggregate pores remain unaffected. Hence the curves for compact and uncompacted soil may be identical at high suction. At very high suction water is held by adsorption and retention is textural than a structural attribute.

Soil water characteristic relationship may be obtained by

1. Desorption: Taking an initially saturated sample and applying suction or pressure to de-saturate.
2. Sorption: Gradually wetting an initially dry soil.

   These two pathways produce curbs that in most cases are not identical. The water content in the ‘drying’ curve is higher for given metric potential than that in the wetting branch. This is called **hysteresis**, defined as the phenomenon exhibited by a system in which the reaction of the system to change is dependent upon its past reactions to change.

Capillary movement- Water moves in the form of thin film from wet to dry region, through micropores, until the thickness of film is equal in both regions.

Flow of water in the soil

Flow of water in soil is complex because of

- Various states and direction in which it flows
- The forces that cause it to flow. Water flows downwards due to gravity. It moves in small pores due to capillarity. Because of heat it vapourises and diffuses through soil air. However, rate of flow is greatly affected by soil texture, structure, porosity, soil temperature and soil water content.

Darcy's Law: As per Darcy's low the discharge rate Q, being the volume V, flowing through the column per unit time (t) is directily proportional to the cross-sectional area A and to the hydraulic head drop ΔH, and inversely proportional to the length of the column L,

$$Q= \frac{v}{t} \qquad \frac{A\Delta H}{L}$$

Hydraulic head drop across the systems ΔH = Head at the inflow boundary (Hi) – head at outflow boundary (H_o)

The head drop per unit distance in the direction of flow (Δh/ L) is the **hydraulic gradient** which in fact is the driving force.

The specific discharge rate, Q/A (i.e. the volume of water flowing through a cross sectional area A per unit time t) is called **flux density** (or **flux**) and indicated by q.

Thus the flux is proportional to the hydraulic gradient

$$q= \frac{Q}{A} = \frac{V}{At} \qquad \frac{\Delta H}{L}$$

The proportionality factor K is designated as hydraulic conductivity

$$q= k \ \frac{\Delta H}{L}$$

This equation is known as Darcy's law.

The hydraulic conductivity determines the ability of soil fluid to flow through the soil matrix system under a specified hydraulic gradient; the soil fluid retention characteristics determine the ability of soil system to retain the soil fluid under a specified pressure condition.

H.C. depends on soil texture, structure and saturation.

Limitations of Darcy's law

1. It applies only when flow is laminar and where soil water interactions do not result in a change of permeability with a change in gradient.
2. Management practices like tillage may affect the flow and H.C.
3. Pore spaces may be entrapped by gases under submerged condition.
4. In coarse sands & gravels, hydraulic gradients in excess of unity may result in non laminar flow.

Movement of water in the soil: Water tends to move from an area of higher potential energy to one of lower potential energy.

MoW under saturated condition – Saturated flow occurs when the soil pores are completely filled with water. This water moves at water potentials larger than - 33 KPa. It is caused by gravity pull. It begin with infiltration. In wetted soil percolation occurs. This movement is affected by texture, structure, organic matter content, depth of soil to hard pan, amount of water in soil, temperature and pressure. Rate of flow follow the sequence sand> silt> clay.

Moisture movement under unsaturated condition- In unsaturated soil, moisture movement is also called capillary movement. It is the flow of water held with water potential lower than -33 Kpa. Water will move towards the lower potential. Water moves from wetter to drier areas. It occurs when soil is at field capacity.
Sequence-Sand<Loam<clay.

Water vapour movement

1. **Internal movement** – The change from liquid to the vapour within the soil, that is in the soil pores.
2. **External movement-** The phenomenon occurs at the land surface and the resulting vapour is lost to atmosphere by diffusion & convection.

   Movement of water vapour through diffusion depends on vapour pressure gradient i.e. the difference in vapour pressure of two points, a unit distance apart.

   Vapour transfer is insignificant in high soil water contents, it increases as void space increases. At soil moisture potential of about-15 bars, the continuity of liquid films is broken and water moves only in vapour form. The vapour pressure of soil moisture increases with increase in soil moisture content and temperature, it decreases with increase in soluble salt content. Water vapour movement is significant only in moist range. In wet and dry range it is negligible or very small.

   It is notable that maximum vapour movement in soils is of greatest importance for the growth and survival of plants.

Capillary rise The rise of water in a capillary tube to a level higher that in the container is called capillary rise. This rise is due to combined effect of cohesion, adhesion and surface tension.

$$H = \frac{2T}{Pgr}$$

Where T= Surface tension (dynes/cm)
p= density of water (gm/cm^3)
g= acceleration due to gravity 981cm/sec^2
r= radius of capillary tube (cm)

Plant-water relationships

Plant-water relations deal with the absorption of water by the plant and its loss to the atmosphere through evapotranspitration, The chmical free energy of water in its purest form is also called water potential **(Ψ_s)**. Its value is given as '0' bars. Plants use water potential to transport water to the leaves. Water always move from the system with a higher water potential to that with lower. For transpiration the condition must as-Ψsoil> Ψroot> Ψstem> Ψleaf> Ψatm>.

The water potential is represented by the equation.

$\Psi_w = \Psi_s + \Psi_p + \Psi_g + \Psi_m$

1. **Ψ_s: Solute Potential** (-V_e): when sugar is added to water, the solute potential or energy drops as water molecules bond to sugar. Thus sugar or other molecules accumulated in leaf (relative to root) drop its potential - 1 to -2 MPa'

2. **Ψ_p: Pressure/turgor potential** (+ ve or -ve): As the water is transpired from leaves it creates a negative pressure or tension, Thus is generally less than -2MPa.

3. **Ψ_m: Matric potential** (-V_e): As water adheres to cell walls it lowers its potential. The walls of xylem, made up of carbohydrates, attract water molecules.

4. **Ψ_g: Gravity potential:** This force is not critical at a cellular level but important in tall treas.

New and old terminology

Ψ = (-) DPD - Diffusion pressure deficit

Ψ_s = (-) Op - Osmotic pressure

Ψ_p = TP - Turgor Pressure

Ψ_m = MP - Metric Pressure

Magnitude of water potentials in SPAC (Soil plant atmosphere continuum)

Component	Water potential (bars)
Soils	- 0.1 to -20
Leaf	- 5.0 to -50
Atmosphere	- 100 to -2000

Relative water content (RWC) is the ratio of actual water content to water content at saturation (fully turgid), expressed as percentage.

Actual water content (%) = $\frac{FW-DW}{FW}$X100

Water content at saturation (%) = $\frac{TW-FW}{TW-DW}$ X100

Relative water content (%) = $\frac{FW-DW}{TW-DW}$ X100

FW= fresh wt

TW= Turgid wt

DW= Dry wt

For saturation tissues are to be floated on water for 3 to 24 h. for DW samples are dried in oven at 65^o to 80^oC.

The indirect methods of estimating plant-water status involve measuring leaf temp., canopy temp., canopy air temp. differentials, diffusive resistance, transpiration rate etc. Leaf temp. of stressed plant is high due to reduced transpiration compared with plants adequately irrigated. Thermocouples or infrared thermometers are used for measuring leaf temperature. **Porometers** are used to measure leaf temp. in addition to transpiration and stomata resistance measurements.

Measurement of Plant water potential

1. **Pressure chamber:** Pressure chamber measures the tension on the water condicting tissue (xylem). Tension within the xylem is believed to be equivalent to the pressure in the chamber at the first appearance of water and regarded to be measure of physiological ‘dryness’ of the plant, called the water potential.
2. Psychomotor: It measure the water vapour pressure of a solution or plant sample, on the basis of the principle that evaporation of water cools the surface.
3. Dew point hygrometer
4. Osmometer

5. Leaf temperature measurement
6. Canopy temperature measurement
7. Canopy air temperature differentials
8. Diffusive resistance
9. Transpiration rate measurement etc.

Water absorption by plants

Passive absorption- When water is drawn into the roots by negative pressure in the conducting tissues created by transpiration, the process is known as passive absorption.

Active absorption- The plant roots absorb water by spending energy, it is called active absorption, Under normal condition active absorption is negligible. Certain plant surviving in soil at permanent wilting point are able to absorb moisture from atmosphere. This is known as **aerial absorption** or negative transpiration .

Soil-plant-water relationship-

Water in the soil-plant-atmosphere system moves in response to the differences in energy status of water from one region of the system to the other and always from a region of higher potential to that of a lower potential.

Soil-plant-water-relationship deal with the physical properties_of soil and water that influence the movement, retention and use of water by the plant that must be considered to plan for an efficient irrigation system.

Soil-plant-atmosphere continuum (SPAC) is the pathway for water moving from soil through plant to the atmosphere and back. The SPAC is defined as a concept recognising that the field with all its components (soil, plant, water, atmosphere) constitutes a physically integrated, dynamic system in which the various flow processes involving energy and matter occur simultaneously and independently like links in the chain.

Conductance pathway:_Soil water → Epidermal cells of root → cortical cell and intercellular spaces → conductive cells of xylem → leaf cells --intercellular spaces in leaf → stomata → atmosphere.

Approximate magnitude of - Ψ in the soil – plant – atm system (plant and moreshet, 1973)

Components	Water potential (Bars)
Soil	-0.1 to -20
Leaf	-5.00 to -50
Atmosphere	-100 to -2000

This decrease in water potential from soil to the atmosphere acts as a driving force that decides the flow of water along the direction of decreasing water potential. Under certain conditions water movement is in the reverse direction when soil is dry and atmosphere is saturated i.e. dew or fog on leaves.

Plant characteristics influencing irrigation practices

1. **Root characteristics –** Irrigation methodology should be suitable to the type of root system of the crop i.e. tap root (central primary root and its branches) or

adventitious and depth of roots. The depth of roots is seriously affected by soil characteristics and ground water level. The soil depth from which the crop extracts most of the water needed to meet its evapotranspiration requirement is known as **effective root zone depth.** It is also called as **design moisture extraction depth,** the depth used to determine irrigation water requirement for design.

Rooting depth (cm) of annual field crops on deep, well drained soil.

Shallow		Medium		Deep	
Crop	Root depth (cm)	Crop	Root depth (cm)	Crop	Root depth (cm)
Rice	50-60	Barley	100-150	Cotton	100-170
Onion	30-50	Wheat	80-150	Maize	100-160
Cabbage	40-50	Caster	90-120	Sorghum	100-200
Cauli-flower	30-50	Tobacco	70-100	Pearl millet	100-170
Potatoes	40-60	Chilies	60-90	Sugarcane	100-200
		Peas	60-100	Soybean	100-150
		Tomato	70-150		

2. Moisture extraction Pattern- For most plants, concentration of absorbing roots is in upper root zone and near the base of plants. Extraction of water is most rapid in the zone of greatest root concentration under favorable environment. Usual moisture extraction pattern shows as under:

Moisture extraction %	**Part of root zone**
40	Upper quarter
30	Second quarter
20	Third quarter
10	Fourth bottom quarter

This pattern slightly vary with irrigation frequency. Higher frequency- greater the extraction from upper quarter.

3. Moisture sensitive (critical) periods of crops

Certain periods during the crop growth and development are most sensitive to moisture stress compared with others. These periods are known as moisture sensitive periods.

1. Rice - Panicle initiation and flowering
2. Sorghum – Seedling, panicle initiation, booting, flowering and milk.
3. Maize - Tasseling and silking.
4. Pearl millet - Flowering and grain development.
5. Finger millet - Panicle initiation and flowering
6. Wheat - Crown root initiation and heading
7. Barley - End of shooting and heading
8. Groundnut- Rapid flowering and early pod development.
9. Sesame - Flowering to maturity.
10. Sunflower - Flower bud initiation, flowering and milk.

12. Soybean- Flowering and seed formation
13. Cotton - Flowering and boll development
14. Sugarcane - Formative phone and tillering
15. Tobacco - Entire growth period
16. Chilies - Flowering
17. Potato- Sprouting and tuberisation
18. Onion - Bulb formation to maturity
19. Tomato - Commencement of fruit set.
20. Peas - Flowering and pod development.

21. Cabbage - Head initiation until become firm.

22. Citrus - Flowering, fruit setting, fruit growth.

23. Banana - Early vegetative, flowering and fruit formation.

Water stress and plant growth

The action of excess or deficit of water on plant is known as **water stress.** However, in general, stress is used to imply water deficits, Hsiao (1973) classified water stress into three categories.

1. Mild stress –A drop of relative water content (RWC) by 8 to 10 percent compared to the value in a well-watered plant under conditions of mild evaporative demand of atmosphere. This corresponds to a drop of plant water potential by - 5 to - 6 bars.

2. Moderate stress - A drop of RWC by 10 to 20% compared to the value in a well-watered plant under low evaporative demand of atmosphere. This corresponds to a drop of water potential by -12 to -15 bars.

3. **Severe stress** - A drop of RWC by >20% compared to the value in well watered plant under conditions of low evaporative demand of atmosphere. This corresponds to a drop of water potential by > -15 bars.

Whenever transpiration exceeds the water uptake, stress (deficit) prevails in plants. **Water deficit affects** water relation in plants, Photosynthesis, respiration, metabolic reactions, hormonal reactions, nutrition, growth and development and yield.

1. **Water relations** - Water deficit alters the water status of plants by influencing absorption, translocation and transpiration, Moisture stressed plant show typical

reduction in leaf water potential and relative water content. It cause increase in leaf and canopy temperatures.

2. Photosynthesis - Water deficit cause reduction in photosynthesis due to reduction in photosynthetic rate, chlorophyll content, leaf area and assimilate saturation (storage of carbohydrates).

3. Respiration - Respiration increases with mild stress but decreases with increase in moisture stress.

4. Metabolic reactions - Almost all the metabolic reactions are affected by water deficit. Severe water deficit cause decrease in enzymatic activity. Accumulation of sugars and amino acids takes place due to breakdown of carbohydrates and proteins.

5. **Hormonal relationship -** Under water deficit the activity of growth promoting hormones like cytokinin, gibbrelic acid, indoleacetic acid etc. decrease and growth regulationg hormones like abscisic acid, ethylene etc. increases. With change in hormonal balance, growth of leaves, production of tillers or branches is reduced and stomata closure and leaf senescence are increased.

6. Nutrition - Water deficits cause reduction in fixation, uptake and assimilation of nitrogen in leguminous plants. The uptake of nitrogen, phosphorus and potassium is reduced by moisture stress, NPK uptake and transpiration rate are highly correlated.

7. Growth and development - Generally the organ growing most rapidly at the time of stress is the one most affected. The expansion of cells and cell division are reduced due to moisture stress and results in decreases in growth of leaves, stem and fruits. It affects germination, leaf area, leaf expansion and root growth.

8. Yield - Moisture regime during flowering and grain development determines the number of fruits/grains and individual grain weight, respectively.

Excess water: Excess water causes several changes in soil and plant resulting in reduced growth and in some cases death of plants. The degree of injury depends on type of crop, crop stage, period of water logging and climatic conditions.

The susceptible crops for water logging in descending order are tobacco, tomato, chilies, pulses etc, whereas, rice is the most resistant. Germination and seedling stages are highly susceptible.

Water logging causes plant injury due to low oxygen supply to the roots and accumulation of toxic substances in soil and plant. Mild toxic substances like carbondioxide, hydrocarbon gases, hydrogen sulphide etc are produced due to reduced condition. Shoot elongation, senescence, abscission and production of adventitious roots takes place because of water logging. Respiration in roots change from aerobic to anaerobic. Permeability of roots decreases which result in decreased uptake of water and nutrients.

Crop plant adaptations under moisture stress condition

A Avoidance: Ability of a plant to maintain sufficient water content and turgidity even under severe moisture stress is known as water stress avoidance. It is being achieved in two ways i.e. conserving water in plants and improving water uptake from soil.

(1) **Conserving water:** Changes in anatomical characters of plant for conservation of cell sap against accelerated transpiration due to higher temperature are as under:

a. Stomatal mechanism- Periodic opening of stomata i. e. stomata open only for few hours in morning and remain closed for rest of the day which result in an efficient photosynthesis with least loss of water. The process is observed mostly in cereals, which enable the plant to survive for longer period, but limited to a certain thresh-hold level of water content in plant.

b. Increased Photosynthetic efficiency- The plant types having CO_2 assimilation capacity (C-4 group) like maize, soybean, finger millet, sudan grass etc have capacity to fix most of the CO_2 into the form of organic acids (malic acid etc.) during night and convert it into carbohydrate during day time, the so called C-4 pathway. These physiological changes use to inhibit photorespiration and thereby the net photosynthesis is enhanced.

c. **Low rate of cuticular transpiration-** Plants develop a waxy coating over cuticles for reducing transpiration, as observed in durum wheat, triticale and barley. Cactus have very low rate of cuticular transpiration & survive under stress for quite long period.

d. Decreasing transpiration - Under drought condition soybean plant produce lipid covering on the surface which reduce transpiration (Levitt, 1972)

e. Reduced Leaf area - The water loss through transpiration is directly proportionate to the leaf area. The Xeromorphic plant (cacti, pineapple) reduce their transpiring surface and find fit for stress condition. In some plants rolling and curling of leaves at noon time and taking normal shape in evening time is observed, which excape heat and reduce transpiration. In rice, leaf rolling and unrolling has been suggested as a crierian for scoring drought tolerance.

f. Leaf surface - Development of thick cuticle deposition of more lipids and waxy covering, development of spines are the pronounced changes in leaf surface.

g. Stomata functioning - The drought affected plants use to bear less number of stomata which are located in depressions and they retard the rate of transpiration by avoiding direct contact with hot air.

Awns - Awned varieties of wheat and rice are best adopted under drought conditions, Under drier condition awned varieties of wheat give better yield than awnless. Awns contribute about 12% to the total dry matter production of drought affected plants. These awns possess chloroplasts and stomata.

(2) Accelerating water uptake by roots: well developed and extensive root system can withdraw water from relatively deeper layer.

a. Effective root system - Vertical root growth is more helpful. Deeper roots with well developed laterals and extensive root hairs are more beneficial.

b. High root to top ratio - The water movement to deeper layers in soil results in more root elongation and hence the root growth exceeds considerably from that of stem.

c. Differences in osmotic potential of plants - Plants grown under dry conditions use to have high osmotic pressure and survive for relatively longer period when compared with the plants under irrigated condition.

d. Development of water economy in plants - under reduced availability of water, the rate of transpiration is reduced automatically.

B. Inducing drought tolerance:

1. Mitigating moisture stress - Some plants develop adaptations by maintaining high turgor pressure and avoid dehydration in following ways-

a. Resistance to dehydration- Plants accumulates sufficient solutes which help in maintaining a higher turgor pressure that prevents internal desiccation and the plasma become more drought tolerant. Plants keep on growing in normal way.

b. Prevention of leaf collapse- Morphological Adaptations like thick cell wall, sunken stomata, lipids, spines etc. prevent wilting by reducing transpirational loss of water.

c. Resistance to metabolic setback- The drought tolerance in the plant is tolerated by maintaining turgidity of stomatal guard cells. The plants which reduce their metabolic activity below dehydration compensation point would need lower carbohydrate and would be more drought tolerant. (The dehydration compensation point is a water potential at which the volume of CO_2 evolved during respiration and CO_2 absorbed during photosynthesis becomes equal). Protein loss is avoided by the drought resistant plants by decreasing rate of breakdown.

Escaping drought - The plants with shorter life span can escape the drought**.**
Type of plants according to drought resistance capability

Ephemerals - These are drought escaping plants. Under semiarid regions the seeds germinate with rains and plants complete their life cycle within a few weeks time.

Succulent Plants - These plants are able to survive dry periods on account of large reserves of water accumulated in the inner tissues of the fleshy stems or leaves. They are frequently found in locally dry habitats of semiarid regions and mostly belongs to ***Cactaceae***, ***Euphorbiaceae, Liliaceac, Aizoaceae.***

Drought enduring plants-Only this group of plants can resist the drought injury. Example-Creosote bush (***Lerrea tridentate*)** a dominant plant in semiarid tegions.

Thus the physiological adaptations in plants can be summarised as under-

1. Deeper roots
2. Less number of leaves
3. Smaller leaves
4. Thick cuticles
5. Hypodermal sclerenchyma
6. Close stomata
7. Lower transpiration
8. Leaf modification
9. Thick wax coating over leaf and stem.

Evapotranspiration

Evaporation (E) of water is a diffusive process by which liquid water in the form of vapour is lost to the atmosphere. Two essential requirements for evaporation are: (i) A source of heat to transform liquid water into water vapour. Solar radiation is the principal source of energy (590 cal g^{-1} of water at 20^0C).

(ii) Concentration gradient between evaporating surface and surrounding air.

The climatological parameters for assessing evaporation are- solar radiation, air temperature, air humidity and wind speed.

Datton's law of evaporation

Evaporation (E) = (es - ea) f (u)

Where es = Saturation vapour pressure of water

Ea = Actual vapour pressure of air above

f (u) = function of wind velocity

Evaporation measurements are usually made by piche evaporimeter, atmometer and pan evaporimeter. The standard US Weather Bureau (USWB) class A Pan is the most widely used evaporation pan. It is 122 cm in dia and 25 cm in depth, made up of 22 gauge galvanized iron. Painted white and installed on a wooden frame. Water is filled to a depth of 20 cm, water level is daily measured with a hook gauge in a stilling well, Evaporation is computed as the differences between observed levels, adjusted for any precipitation measured in a rain gauge. Water is added daily to bring the level to a fixed point in the stilling well. The pans have higher rate of evaporation than a large free water surface. Thus a factor of 0.7. is, usually used for converting the observed evaporation to those of large water surface area. This factor is called Pan Coefficient.

Evaporation from land surface is affected by degree of soil saturation, temperature of soil and air, humidity and wind velocity.

Transpiration (T) : Loss of water in the form of vapour from the plant canopy to the atmosphere is termed as transpiration.

Evapotranspiration : The total loss of water from soil surface through evaporation and that as water vapour from plant surface through transpiration, in together refers to evapotranspiration. It has direct correlation with crop yield. Evaporation rate is normally expressed in millimeters (mm) per unit time.

As one hectare	= 10000 m^2
One mm	= 0.001 m
Loss of 1 mm of water	= 10 m^3 water ha^{-1}
Thus 1 mm ET/day	= 10 m^3 $ha^{-1}day^{-1}$

Energy or heat required to vapourise free water, known as latent heat of vapouri sation (λ), Is a function of the water temperature. At 20^0C, λ is about 2.45 MJ kg-^{1}; means 2.45 MJ are needed to vapourise 1 kg or 0.001 m^3 of water. Hence, an energy input of 2.45 MJ per m^2 is able to vapourise 0.001 m or 1 mm of water. Therefore, 1 mm water = 2.45 MJ $m^{-2.}$ Evapotranspiration rate expressed in units of MJ m^{-2} day^{-1} is represented by λ ET, the latent heat flux.

Conversion factors for ET

Expression	Depth mm day^{-1}	Volume per unit area		Energy per unit area MJ m^{-2} day^{-1}
		M^3 ha^{-1} day^{-1}	l $s^{-1}ha^{-1}$	
1 mm day^{-1}	1	10	0.116	2.45
1 M^3 ha^{-1} day	0.1	1	0.012	0.245
1 l S^{-1} ha^{-1}	8.640	86.40	1	21.17
1 MJ m^{-2} day^{-1}	0.408	4.082	0.047	1

Factors affecting evapotranspiration

A. weather/climatic parameters

1. Air temperature
2. Solar radiation
3. Relative humidity
4. Wind velocity
5. Precipitation

B. Crop characteristics

1. Stomata number and size
2. Stomatal opening and closing
3. Canopy cover
4. Adaptive mechanism
5. Rooting characterstics
6. Length of crop growing season

C. Management and environment factors

1. Tillage
2. Irrigation schedule
3. Fertilizers
4. Plant protection
5. Weed management
6. Wind breaks
7. Salinity

8. Antitranspirants
9. Ground water level.

Evapotranspiration and crop yield relationship

Water use-yield relationship – Under adequate water supply the ET is expected to be maximum for realizing potential crop yield, provided other management practices are optimal. Relative yield is the proportion of actual yield (Ya) to the maximum yield (Ym), can be expressed as percentage or as a function by subtracting by one. (1- Ya/Ym). Similarly, relative ET can be expressed as 1- Eta/ ETm. Thus, the relationship equation can be as-

$$= \quad 1 - \frac{ETa}{ETm} \quad = \quad K_y \; 1 - \frac{Ya}{Ym}$$

Where ky is a constant which is the yield response factor and can be estimated if the ET and yield data are available.

Evapotranspiration and consumptive use:

Evapotranspiration (ET) = Evaporation from crop field (E) + Transpiration (T) + intercepted precipitation by crop and lost as evaporation (IP)

Consumptive use (CU) = E.T. + water used by crop plants for metabolic activities (Ww). It is nearly 1%

Evapotranspiration concepts

Potential Evapotranspiration (PET) is the highest rate of evapotranspiration by a short and actively growing crop with abundant foliages completely shading the ground surface with abundant soil water supply under a given climate. This refers to the maximum water loss from the crop field.

Reference crop evapotranspiration (ET_0)- Evapotransiration rate from a reference surface, not short of water is called the reference crop evapo-transpiration. Reference surface is a hypothetical grass reference crop with specific characteristics. The redefined (FAO Penman-Monteith crop evapotranspiration (Allen et al. 1998) is: ‘Evapotranspiration from a hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 sm^{-1} and the albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered.

Actual crop evapotranspiration (ET crop) refers to the rate of evapotranspiration by a particular crop in a given period under prevailing soil water and atmospheric conditions. Crop evapotranspiration under standard condition is the evapotranspiration from a well maintained crop, grown in large fields, under optimum soil moisture condition and able to give maximum production under given climatic condition.

To find the ET crop the following relationship is used

ETc = ETo x Kc

Kc = Crop coefficient

$$Kc = \frac{ETc}{ETo}$$

Crop evaporation under non-standard condition (ETc adj) is the evapotranspiration from crops grown under management and environmental condition that differ from standard condition.

ETc adj is calculated by using a water stress coefficient Ks and /or by adjusting crop coefficient Kc for other stresses and environmental constraints .

The effects of soil water stress are described by multiplying the basal crop coefficient Kcb by the water stress coefficient Ks:

ETc adj = (Ks Kcb+Kc) ETo

Measurement of Evapotranspiration

1. Energy balance and microclimatological methods.
2. Soil water balance
3. Lysimeters
4. Empirical methods (from meteorological data).

1. Energy balance and microclimatological methods

Evaparation of water requires energy in the form of sensible heat or radiant energy. Therefore, the evapotranspiration process is governed by energy exchange at the vegetation surface and is limited by the amount of energy available.

Rn - G - ƛ Et – H = O

Where Rn = net radiation, H = Sensible heat

G = Soil heat flux, ƛ ET = Latent heat flux,

Latent heat flux (ƛET) representing the evapotranspiration fraction can be derived from the ‘energy balance equation’ if all other components are known.’Rn’ and ‘G’ can be estimated from climatic parameters. Measurement of ‘H’ is complex and requires accurate temperature gradients above the surface.

2. Soil water balance : It is an account of all quantities of water added, removed or stored in soil during a given period of time.

Change in soil water = Inputs of water – Losses of water

Water Inputs = P + I + C

Where, P = Precipitation, I = irrigation

C = Contribution from ground water.

Losses of water **=** ET+D +RO

Where ET = Evapotranspiration, D = Deep drainage RO = Surface runoff.

Thus, Change in soil water = (P + I + C) - (ET + D + RO)

Suppose, the amount of water in root zone at the beginning is M_1 and at the end of period is M_2 $M_1 - M_2 = P + I + C – ET - D – RO$

Or $M_1 + P + I + C = ET + D + RO + M_2$

Using this equation any unknown parameter can be computed, if all others are known. This is useful for selecting appropriate water management strategies.

3. Lysimeters : Lysimeters provide the direct measurement of water flux from vegetative surface. Lysimeter is a large tank filled with soil. Rectanular units of 4.0 m^2 are satisfactory for most crops. Total depth ranges between 100-150 cm as per root depth of crops. In general, 50% available soil moisture depletion in root zone should not be exceeded. The crop grown in lysimeter is the same as in surrounding area.

There are two types of lysimeters, weighing and drainage type. In the drainage type, the inflows and drainage are measured, but changes in storage within soil are not measured. In weighing type lysimeters each element i.e. rainfall, irrigation, runoff and ET can be determined by using water balance equation.

ET = Weight change + water added - percolation

4. Empirical methods: Empirical methods to predict the water requirements are primarily based on climetological data and crop factors. There are four methods of predicting ET under different climatic conditions, recommended by FAO group of Scientists (Doorenbos and Pruitt, 1975)

1. Blaney - Criddle method

2. Radiation method

3. Modified penman method

4. Pan evaporation method

Three major steps involved in estimation of ET by empirical methods are

1. Estimation of reference evapotranspiration (ETo)

2. Determination of crop coefficients (Kc)

3. Making adjustments to location specific environments

Modified Penman and radiation methods offer best results for periods as short as 10 days followed by pan evaporation method. Blaney-criddle method is ideal for periods of one month or more in many climates.

Blaney-criddle Formula: Blaney- Criddle (1950) formula is based on mean monthly temperature, daylight hours and locally developed crop coefficients

$$U\ (CU) = \Sigma u = KF = \Sigma kf = \Sigma \frac{ktp}{100}$$

Where,

U or CU = Seasonal consumptive use

u = monthly consumptive use

t = Mean monthly temperature (^{0}F)

p = Monthly daylight hours expressed as percentage of daylight hours of the year.

f = t x P/100, monthly consumptive use factor

k = empirical consumptive use crop coefficient, for the month (= u/f)

Doorenbos and Pruitt (1975) recommended following relationships for 'f' in this formula

f = p (0.46 t +8.13) , using t in ^{0}C

Or

f = 25.4 (p x t) /100, using t in ^{0}F

Thus, finally it become

ET_0 = C [p (0.46 t +8.13]

Where, ET_0 = reference ET (mm day^{-1}) for the month

C = adjustment factor depending on RHmin, daytime wind velocity and ratio of actual sunshine h to maximum possible sunshine hour.

T = mean daily temperature for the month.

P = mean daily percentage of total annual daytime.

Radiation method : This method requires direct measurement of bright sunshine hours, general levels of humidity and wind velocity.

ET_0 = C (W x Rs)

Where, Rs = Measured mean incoming shortwave radiation (mm day^{-1}) – (by pyrenometer) or obtained from Rs = (0.25+0.50x n/N) Ra. Where = Ra is extraterrestrial radiation (mm day^{-1}), N = maximum possible sunshine duration (h day^{-1}), n = measured mean actual sunshine duration (h day^{-1}), W = Temperature and attitude dependent weighing factor

C = Adjustment factor made graphically on w. Rs using estimated values of R H mean and U daytime.

Pan evaporation method : Evaporation from pans provides measurement of integrated effect of radiation, wind, temperature and humidity on evaporation from open water surface. To relate pan evaporation to ET_0, empirically derived Pan coefficients are suggested to account for climate, type of Pan and Pan environments

ETo = K pan x E pan

Where, E pan = evaporation (mm day) from class A Pan

K pan = Pan coefficient.

Modified Penman method : It gives fairly satisfactory results for predicting the effect of climate on ET_0 as it utilises almost all the meteorological Parameters associated with ET.

ET_0 = C [W x Rn + (1- W) x f (u) x (ea - ed)]

Rn = Net radiation (mm day^{-1})

or Rn = 7.5 Rs – Rnl

Rs = Short wave radiation (given earlier)

Rn1 = net long wave radiation (mm day^{-1}) a function of temperature f (T), of actual vapour pressure f (ed) and sunshine duration f (n/N) or Rnl= f (T) x f (ed).

ea - ed = Vapour pressure deficit, the difference between saturation vapour pressure (ea) at T mean (mb) and actual vapour pressure (ed)

f (U) = wind function or f (U) = 0.27 (1- U/100) with U in Km day^{-1} at 2 m ht.

W = Tempreature and altitude dependent weighting factor.

C = Adjustment factor for the ratio U day/U night for RH max and for Rs.

Crop coefficients for estimating ET crop

The conditions that affect crop water loss (ET_C) will also affect evaporation from free water surface in a similar manner. It is then necessary to obtain a crop coefficient (Kc) to estimate ETc.

ETc = ETo x Kc

Actual crop water requirements, in addition to climate, include the effect of crop characteristics and management practices. Crop coefficient is used to account for all these variations. The climatic data required for selection of crop coefficients are wind speed and humidity. The FAO kc curve is constructed by dividing crop growing period into four growing periods and placing straight line segments through initial and mid season periods being horizontal. The four growth periods are initial period, crop development, mid season and late season. However, FAO coefficients (kc) for major crops (Doorenbas and kassam, 1979) are available for use.

CROPWAT : FAO IDP 46 and 49

CROPWAT is a water balance based computer programme to calculate crop water requirements and irrigation water requirements from climatic and crop data. The programme also allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying cropping patterns. Water balance procedures also allow an assessment of effective rainfall and an evaluation of rainfed production through calculated yield decreases through water balance procedures. This also allows yield reduction predictions to be made and taken into account in making irrigation management decisions to optimize crop water productivity and return to investment.

Soil Plant and Meteorological factors determining Water needs of crops

Water requirement (WR): Water requirement of crop is the quantity of water, required by a crop or diversified pattern in a given period of time for their normal growth under field conditions. It includes ET and other economically unavoidable losses.

Consumptive use (CU): It is the sum of the volumes of water used by crop over a given area in producing plant tissue, in transpiration (T), and that evaporated (E) form adjacent soil or plant foliage. Since the volume used in producing plant tissue is negligible (<1%), CU can be approximately equal to ET.

WR= CU = ET

Since , water requirement also include the unavoidable application losses eg. Percolation, seepage, runoff etc. (AL) and water used for special operations (WSO) like land preparation, presowing irrigation etc, it is expressed as - WR = ET + AL + WSO

In terms of source of water it is expressed as - WR = IR + EP + S

Where, IR = Irrigation requirement

EP = Effective precipitation

S = Soil profile moisture contribution

Irrigation requirement (IR) : The total amount of water required to supplement precipitation (EP) and soil moisture contribution (S) to meet crop water needs for optimum growth and yield.

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

Net irrigation requirement: It is the depth of irrigation water exclusive of precipitation and ground water contribution or other gains in soil moisture, that is required for plant growth; the amount of irrigation water required to bring the soil moisture level in the effective root zone to the field capacity.

$$NIR = (CU - EP) + AL$$

Gross Irrigation requirement : It is the net irrigation requirement and losses in conveyance, distribution and application of water in operating system.

$$GIR = \frac{NIR}{\text{Irri: Efficiency}}$$

Optimum water requirement (OWR) : It is the amount of water required during the growing season to produce highest crop yield.

Irrigation frequency : It refers to the number of days between two successive irrigation during the periods without precipitation.

Determination of crop water requirements

A . Direct measurements

1. Transpiration ratio method 2. Depth- interval – yield approach 3. Lysimeter experiments 4. Soil moisture depletion studies 5. Field experimentation

6. Water balance method

B – <u>From climatic data</u>

1. Pan evaporation data 2. Estimation by climatic parameters.

<u>Factors affecting irrigation water needs</u>

1. Climate and crop growing season 2. Crop characteristics 3. Soil factors

4. Crop management practices

1. <u>Climate</u> : Principal climatic factors influencing crop water requirement are precipitation, solar radiation, temperature, wind velocity and relative humidity.

- Well distributed rainfall during the crop season minimises the irrigation need of crops.
- Crop in sunny and hot climate need more water per day than that under cloudy and cool climate.
- Crop water needs are higher under dry weather than the humid.
- High wind velocity increase crop water requirement

2. **<u>Crop characteristics</u> :** Crop water requirements vary according to growth habit, canopy development, leaf area, sensitivity to drought and duration of crops.

- Tall crops and varieties intercept more solar radiation and have more daily water requirement than shorter crops & varieties.
- Crops with deep root system, have higher water requirement than shallow rooted crops.
- High leaf area increases crop water needs.
- Longer the duration, higher crop water need.
- Crop with higher water sensitivity suffer greater reduction in yield.

General sensitivity of crops to drought

Group I- Low sensitive : Safflower, ground nut, pearlmillet.

Group II- Moderate Low: Sorghum, fingermillet cotton, sunflower, castor sugarcane

Group III – Moderate high : Wheat, Pulses, upland rice

Group IV – Highly Sensitive : Lowland rice, Maize

3. Soil factors: Coarse textured and well aggregated soil retain less water and have low hydraulic conductivity; hence they support less E.T.

  - Rideges and furrows minimize evaporation loss.
  - Dark coloured soils absert more heat which lead to higher E.T.

4. Crop management Practices

- Frequent irrigations increases crop water requirements.
- Water requirements with border and check bason irrigation are higher.
- Harrowing or hoeing minimizes water loss.
- Weed management reduce water loss.
- Fertilizer application increases water needs.
- Plant population and row spacing influence E.T.

SCHEDULING IRRIGATION

Irrigation Scheduling : Supply of water in optimum quantity at right time with appropriate application method is called irrigation scheduling.

It enable irrigator to apply exact amount of water ; increases irrigation efficiency. There is accurate measurement of the volume of water applied or depth of application.

Advantages

1. It enables the farmers to schedule water rotation among different fields to minimise water stress and maximise yields.
2. It reduces cost of water and labour through fewer irrigations, thereby making maximum use of soil moisture.
3. Save fertilizer costs by reducing run off and leaching losses.
4. Increases net returns by increasing yield and crop quality.
5. It minimises water logging problems.
6. It assist in controlling root zone salinity problems through controlled leaching.
7. Additional returns by using saved water.

Factors influencing irrigation schedules

1. Soil 2. Plant 3. Climate 4. Managements

When to irrigate

1. Maintanance of soil moisture around field capacity is ideal for many crops.
2. As the soil moisture tension increases crops can't extract needed moisture for optimum growth.
3. Crop starts wilting leading to retard growth and permanent wilting.
4. Crop should not experience moisture stress between two irrigations.
5. By knowing ASM in crop root zone and ET demand, irrigation need can be determined.

Approaches for scheduling irrigation

1. Soil moisture monitoring

(i) Measurement of soil water potential by tensiometer or gypsum blocks etc.

(ii) Soil moisture content by direct methods (gravimetric)

(iii) Feel and appearance method.

2. Atmospheric measurements and water balance technique

(i) Measurement of crop evapotranspiration (ETtc)

(ii) IW/CPE approach

(iii) Lysimeter studies

(iv) Field water balance

3. Plant based monitoring

(i) Contact methods

a. Measuring plant-water status by pressure chamber , Dew point hygrometer, osmometer, tissue water content.

b. Measurement of plant response by sap flow sensors, stomatal conductance (porometers) and plant growth rate.

(ii) Non contact method

a. Site specific crop management and irrigation

b. Plant spectral responses

c. Radiometric sensors

- Multispectral sensors
- Hyperspectral sensors
- Thermal sensing

Plant Indices

1. Visual symptoms
2. Soil cum sand miniplot
3. Plant population
4. Growth rate
5. Indicator plants
6. Critical growth stages .

Delta is the total depth of irrigation to a crop in centimeters. It can be calculated by dividing the volume of irrigation water by the area irrigated.

Duty is the ratio between irrigated area and quantity of water used. It is expressed in litres per second per ha and indicates the flow requirement per hectare of cropped area.