CONSUMPTIVE USE & ESTIMATION OF IRRIGATION WATER REQUIREMENTS OF CROPS

CHAPTER 3

1. Definition of Consumptive Use:

Consumptive use (CU), or Evapotranspiration (ET), is the sum of two terms:

(a) Transpiration:

Water entering plant roots and used to build plant tissue or being passed through leaves of the plant into the atmosphere

(b) Evaporation:

Water evaporating from adjacent soil, water surfaces, and surfaces of leaves of the plant or intercepted precipitation

2. Factors affecting CU or ET:

It consists of:

(a) Evaporation affected by:

- The degree of saturation of soil surface
- Temperature of air and soil
- Humidity
- Wind velocity
- Extent of vegetative cover etc.

(b) Transpiration affected by:

Climate factors:

- Temperature
- Humidity
- Wind speed
- Duration & intensity of light
- Atmospheric vapor pressure

Soil factors:

- Texture
- Structure
- Moisture content
- Hydraulic conductivity

Plant factors:

- Efficiency of root systems in moisture absorption
- The leaf are
- Leaf arrangement and structure
- Stomatal behavior

3. Direct Measurement of ET/CU:

(a) Tank or Lysimeter experiments:

Lysimeter experiments involve the growing of crops in large containers (lysimeters) and measuring their water and grains.

Limitations:

Reproduction of physical conditions such as temperature, water table, soil texture, density etc.

Three types of lysimeters:

(i) Non-weighing constant water table type:

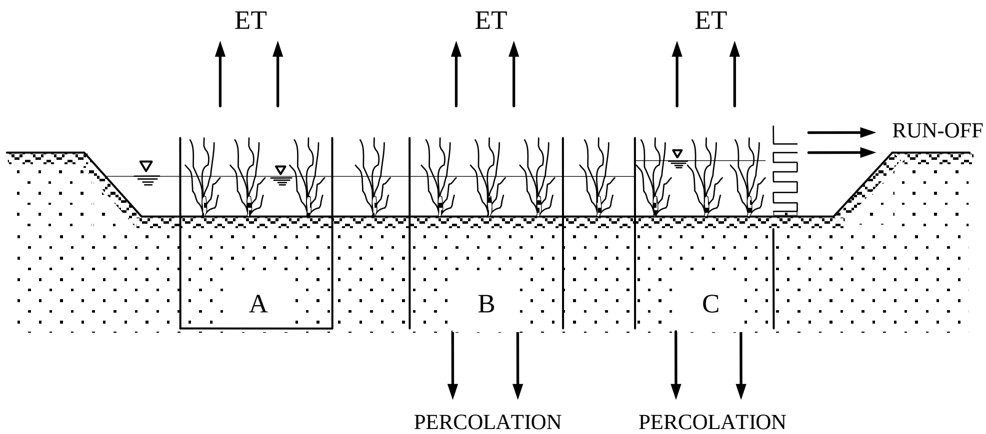


Fig: Non weighing constant water table type lysimeter

- Constant water level is maintained by applying water
- Effective rainfall (Re) and irrigation (I) are measured by rain-gauges and calibrated container
- The overflow (R) and deep percolation (D_r), if any, are measured.

$$ET = I + R_e - R - D_r$$

- R_e, R, D_r, may be zero depending on site condition
- This method is applicable where high water table in soil exists

(ii) Non-weighing percolation type:

Consumptive Use (CU) is computed by adding measured quantities of irrigation water, the effective rainfall received during the season and the contribution of moisture from the soil.

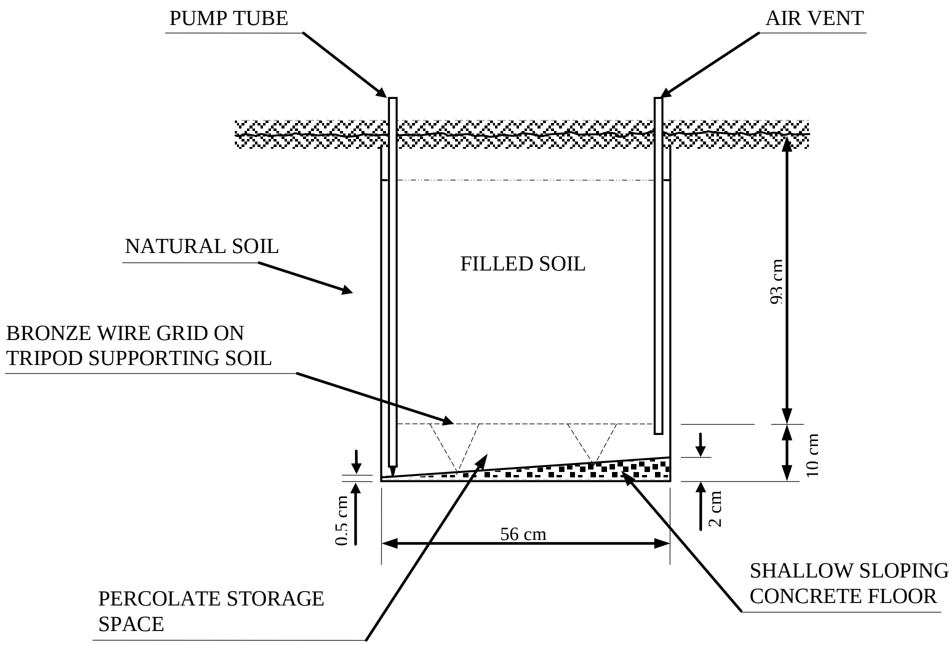


Fig: Non weighing percolation type lysimeter

$$ET = I + Re - Dr + \sum_{i=1}^{n}\left[\frac{M_{bi} - M_{ei}}{100}\right] \times A_i D_i$$

Where, ET = Evapotranspiration

I = Total irrigation water applied (mm)

R_e = Effective rainfall (mm)

M_{bi} = Moisture content at the beginning of the season in the i^{th} layer of the soil

M_{ei} = Moisture content at the end of the season in the i^{th} layer of the soil

A_i = Apparent specific gravity of the i^{th} layer of soil

D_i = Depth of the i^{th} layer of the soil with root zone (mm)

n = No. of soil layers in the root zone

- Applicable for areas having high precipitation
- Special arrangements are made to drain and measure the water percolating through the soil mass

(iii) Weighing type:

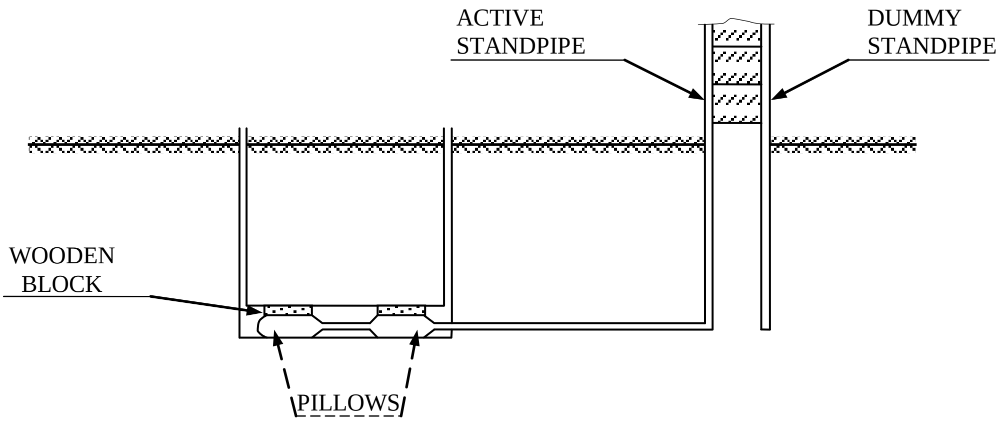


Fig: Non weighing percolation type lysimeter

- ET is determined by taking the weight of the tank and making adjustment for any rain
- Provides the most accurate data for short time periods

(b) Soil Moisture Depletion Studies:

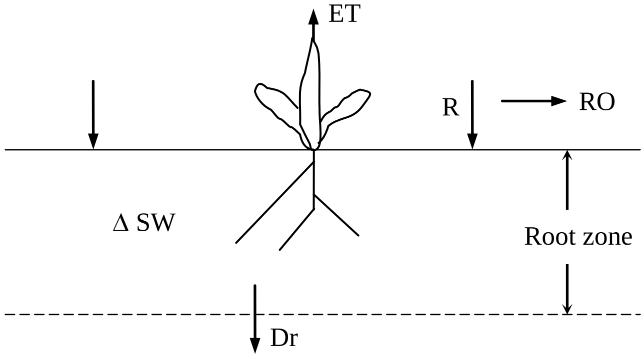


Fig: Soil moisture depletion study facility

- The soil is sampled 2 to 4 days after irrigation and again 7 to 15 days later or just before the next irrigation
- Only those sampling periods are considered in which rainfall is light. This is done to minimize drainage and percolation errors

- The depth to ground water should be such that it will not influence the soil moisture fluctuation within the root zone.
- It cannot be applied where water table is high

$$ET = I + R - R_o - D_r + \Delta SW$$

$$\text{Where, } \Delta SW = \sum_{i=1}^{n}\left[\frac{M_{1i} - M_{2i}}{100}\right] \times A_i D_i$$

M_{1i} = moisture content at the time of 1st sampling in the ith layer
M_{2i} = moisture content at the time of 2nd sampling in the ith layer

4. Estimation of ET using Empirical Equations:

(a) Blaney-Criddle Formula:

- It is used extensively.
- It gives good estimates of seasonal water needs under arid condition as was developed initially.
- Limitation: not suitable for a period shorter than 1 month.

C_u = (k.p)/40 [1.8t + 32]

C_u = Monthly consumptive use in cm.
k = Crop factor, determined by experiments
t = Mean monthly temperature in ^oC
p = Monthly percent of annual day light hours that occur during the period

If (p/40)[1.8t + 32] is represented by f, we get

C_u = k. f

[k values are to be read from Table 7.5 (Israelsen]

Problem-1

Wheat has to be grown at a certain place, the useful climatological conditions of which are tabulated below. Determine the evapo-transpiration and consumptive irrigation requirement of wheat crop. Also determine the field irrigation requirement if the water application efficiency is 80%. Use Blaney-Criddle equation and a crop factor is 0.8.

Month	Monthly temperature (^oC) averaged over the last 5 years	Monthly percent of day time hour of the year computed from the Sun-shine	Useful rainfall in cm averaged over the last 5 years
November	18.0	7.20	1.7
December	15.0	7.15	1.42
January	13.5	7.30	3.01
February	14.5	7.10	2.75

***Solution*:**

Blaney – Criddle Equation is

$$C_u = k \frac{P}{40} [1.8\,t + 32]$$

$$= k.\ \Sigma f$$

Month	t (^oC)	p (hour)	R_e (cm)	f = P/40(1.8t + 32) (cm)
November	18.0	7.20	1.7	11.6
December	15.0	7.15	1.42	10.5
January	13.5	7.30	3.01	10.3
February	14.5	7.10	2.75	10.3
			Σ = 8.38	Σ = 42.7

$C_u = k.\ \Sigma f = 0.8 \times 42.7 = 34.16$ cm

Hence, Consumptive use, $C_u = 34.16$ cm

Consumptive irrigation requirement, C.I.R = $C_u - R_e = 34.16 - 8.38 = 25.78$ cm

Field irrigation requirement, F.I.R = C.I.R/ $\eta_a = 25.78/0.8 = 32.225$ cm

Problem-2:

Determine the volume of water required to be diverted from the head works to irrigate area of 5000 ha using the data given in the table below. Assume 80 % as the effective precipitation to take care of the consumptive use of the crop. Also assume 50 % efficiency of water application in the field and 75 % as the conveyance efficiency of canal.

Month	Temperature (^oF)	% hours of sunshine	Rainfall (mm)	Consumptive coefficient or Crop factor (k)
June	70.8	9.90	75	0.80
July	74.4	10.20	108	0.85
August	72.8	9.60	130	0.85
September	71.6	8.40	115	0.85
October	69.3	7.86	105	0.65
November	55.2	7.25	25	0.65
December	47.1	6.42	0	0.60
January	48.8	8.62	0	0.60
February	53.9	9.95	0	0.65
March	60.0	8.84	0	0.70
April	62.5	8.86	0	0.70
May	67.4	9.84	0	0.75

Solution:

Month	**Temp (^oF)**	**% hours of sunshine**	**Rainfall (cm)**	**Crop factor (k)**	$C_u = kf = \frac{k.p}{40}.t$ **(cm)** {(5) × (3) × (2)}/40
(1)	(2)	(3)	(4)	(5)	(6)
June	70.8	9.90	7.5	0.80	14.02
July	74.4	10.20	10.8	0.85	16.13
August	72.8	9.60	13.0	0.85	14.85
September	71.6	8.40	11.5	0.85	12.78
October	69.3	7.86	10.5	0.65	8.85
November	55.2	7.25	2.5	0.65	6.50
December	47.1	6.42	0	0.60	4.54
January	48.8	8.62	0	0.60	6.31
February	53.9	9.95	0	0.65	8.71
March	60.0	8.84	0	0.70	9.28
April	62.5	8.86	0	0.70	9.68
May	67.4	9.84	0	0.75	12.44
			55.8		124.09 cm

Total consumptive use = 124.09 cm
Useful rainfall = 80 % of total precipitation (given)
= (0.80 × 55.8) cm = 44.64 cm

∴ Net irrigation requirement, N.I.R = $C_u - R_e$ = 124.09 – 44.64 = 79.45 cm
∴ Field irrigation requirement, F.I.R = N.I.R/η_a = 79.45/50% = 79.45/0.5 = 158.9 cm

η_c = conveyance efficiency = 75 % = 0.75

∴ Gross irrigation requirement, G.I.R = F.I.R/η_c = 158.9/0.75 = 211.87 cm

Volume of water requirement for 5000 hectares area = $\frac{211.87}{100}$ m × (5000×10^4 m^2)
= 105.93 × 10^6 m^3

(b) <u>Hargreaves class A pan evaporation method</u>:

- The quantity of water (E_p) evaporated from the standard class A evaporation pan is measured.
- The pan is 1.2 m in diameter, 25 cm deep, and bottom is raised 15 cm above the ground surface.
- The depth of water is maintained such that the water surface is at least 5 cm, and never more than 7.5 cm, below the top of the pan.

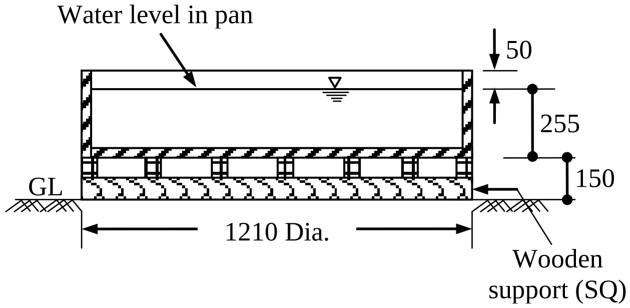


Fig: Class A evaporation pan

- Evapotranspiration is related to pan evaporation by a constant k, called consumptive use co-efficient.

$$\frac{\text{Pan evaporation } (E_p)}{\text{Evapotranspiration } (E_t \text{ or } C_u)} = k$$

$$\Rightarrow E_t \text{ or } C_u = k \times E_p$$

- Consumptive use co-efficient, k varies with crop type; crop growth etc. values of k are found from Table 3.1.

Table 3.1: Hargreasive's Average Values of Consumptive Use Coefficient k ($E_t = k \times E_p$)

% of crop growing season	Consumptive use coefficient (k) to be multiplied by class A Pan Evaporation (Ep), i.e. $E_t = k \times E_p$							
	Group A	Group B	Group C	Group D	Group E	Group F	Group G	Rice
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0	0.20	0.15	0.12	0.08	0.90	0.60	0.50	0.80
5	0.20	0.15	0.12	0.08	0.90	0.60	0.55	0.90
10	0.36	0.27	0.22	0.15	0.90	0.60	0.60	0.95
15	0.50	0.38	0.30	0.19	0.90	0.60	0.65	1.00
20	0.64	0.48	0.38	0.27	0.90	0.60	0.70	1.05
25	0.75	0.56	0.45	0.33	0.90	0.60	0.75	1.10
30	0.84	0.63	0.50	0.40	0.90	0.60	0.80	1.14
35	0.92	0.69	0.55	0.46	0.90	0.60	0.85	1.17
40	0.97	0.73	0.58	0.52	0.90	0.60	0.90	1.21
45	0.99	0.74	0.60	0.58	0.90	0.60	0.95	1.25
50	1.00	0.75	0.60	0.65	0.90	0.60	1.00	1.30
55	1.00	0.75	0.60	0.71	0.90	0.60	1.00	1.30
60	0.99	0.74	0.60	0.77	0.90	0.60	1.00	1.30
65	0.96	0.72	0.58	0.82	0.90	0.60	0.95	1.25
70	0.91	0.68	0.55	0.88	0.90	0.60	0.90	1.20
75	0.85	0.64	0.51	0.90	0.90	0.60	0.85	1.15
80	0.75	0.56	0.45	0.90	0.90	0.60	0.80	1.10
85	0.60	0.45	0.36	0.80	0.90	0.60	0.75	1.00
90	0.46	0.35	0.28	0.70	0.90	0.60	0.70	0.90
95	0.28	0.21	0.17	0.60	0.90	0.60	0.55	0.80
100	0.20	0.20	0.17	0.60	0.90	0.60	0.50	0.20

(c) FAO Penman-Monteith equation:

$$ET_o = \frac{0.408 \times \Delta \times (R_n - G) + \gamma \times \left(\frac{900}{T + 273}\right) \times u_2 \times (e_s - e_a)}{\Delta + \lambda \times (1 + 0.34 \times u_2)}$$

Where,
ET_o = Reference crop (green grass) evapotranspiration (mm/day)
Δ = Slope of saturation vapor pressure vs temperature curve at mean air temperature, kPa per ^oC
(**Fig 7.4 in book by Micheal**)

R_n = Net radiation, MJ/m^2 per day, can be calculated from actual sunshine hour and other weather data
G = Soil heat flux, MJ/m^2 per day
γ = Psychometric constant, the ratio of specific heat of air to the latent heat of evaporation of water, kPa per ^oC
T = Mean air temperature, ^oC
u_2 = Wind speed at 2 m height (m/s)
e_s = Saturation vapor pressure of the evaporating surface at mean air temperature, kPa
e_a = Actual vapor pressure, kPa

For monthly value, $G = 0.14 \times (T_i - T_{i-1})$

Where, Ti = Mean air temperature for the month (^oC)
T_{i-1} = Mean air temperature for the previous month (^oC)

G = 0 for 10 days or short period

$$e_s = \frac{e^o \times T_{max} + e^o \times T_{min}}{2}$$

$$e^o(T) = 0.611 \times \exp\left[\frac{17.27 \times T}{T + 237.3}\right] \text{kpa}$$

$$e_a = \frac{RH_{mean}}{100} \times e_s$$

Where, RH_{mean} = Mean relative humidity

ET of a specific crop,

$$ET_{crop} = K_c \times ET_o$$

Where, K_c = Crop co-efficient

The crop co-efficient is basically the ratio of the crop ET to reference ET and represents the integral effects of four primary characteristics:

- Crop height
- Albedo
- Canopy resistance
- Evaporation from soil

The K_c value of a crop varies with growth stages of crops

FAO developed software, CROPWAT
Input data: Latitude, altitude, temperature, relative humidity, daily sunshine, wind speed
Sample output:

5. Effective Rainfall (R_e):

Precipitation falling during the growing period of a crop that is available to meet the evapotranspiration needs of the crop is called effective rainfall.

It is that part of rainfall which is available to meet ET needs of the crop

$$R_e = R - R_r - D_r$$

Where, R = Precipitation
R_r = Surface runoff
D_r = Deep percolation

Factors affecting R_e:

- Rainfall characteristics (intensity, frequency and duration)
- Land slope
- Soil characteristics
- Ground water level
- Crop characteristics (ET rate, root depth, stage of growth, ground cover)
- Land management practices (bunding, terracing, mulching reduce runoff and increase R_e)
- Carryover of soil moisture (from previous season)
- Surface and sub-surface in and out flows
- Deep percolation etc.

Generally a percentage of total rainfall is taken as effective rainfall

6. Net Irrigation Requirement (NIR):

$$NIR = ET_c - R_e - G_e - \Delta SW$$

Where, ET_c = Consumptive use by crop
R_e = Effective rainfall
G_e = Ground water contribution
ΔSW = Stored soil-moisture

In irrigation planning and design, G_e and ΔSW are ignored to be on safe side

7. Consumptive Irrigation Requirement (CIR):

Irrigation water required in order to meet the evapo-transpiration needs of the crop during its full growth.

$$CIR = (C_u) - (R_e)$$

8. Field Irrigation Requirement (FIR):

It is the amount of water required to be applied to the field

$$FIR = NIR + \text{water application losses}$$
$$= NIR/E_a$$

Where, E_a = Water application efficiency

9. Gross Irrigation Requirement (GIR):

It is the amount of water required at the head of a canal

$$GIR = FIR + \text{conveyance loss}$$
$$= FIR/E_c$$

Where, E_c = Conveyance efficiency

10. Irrigation Efficiencies:

- **Efficiency of water-conveyance (η_c)**: It is the ratio of the water delivered into the fields from the outlet point of the channel, to the water pumped into the channel at the starting point.
- **Efficiency of water application (η_a)**: It is the ratio of the quantity of water stored into the root zone of the crops to the quantity of water actually delivered into the field.
- **Efficiency of water-storage (η_s)**: It is the ratio of the water stored in the root zone during irrigation to the water needed in the root zone prior to irrigation.
- **Efficiency of water use (η_u)**: It is the ratio of the water beneficially used including leaching water, to the quantity of water delivered.
- **Uniformity coefficient or water distribution efficiency(η_d)**: The effectiveness of irrigation may also be measured by its water distribution efficiency, which is defined below:

$$\eta_d = (1 - d/D)$$

Where, η_d = Water distribution efficiency
D = Mean depth of water stored during irrigation
d = Average of the absolute values of deviations from the mean.

Problem-3

The depths of penetrations along the length of a border strip at points 30 meters apart were measured. Their values are 2.0, 1.9, 1.8, 1.6 and 1.5 meters. Compute the distribution efficiency.

***Solution*:**

Mean depth, D = (2.0 + 1.9 + 1.8 + 1.6 + 1.5)/5 = 1.76 m

Values of deviations from the mean are (2.0 – 1.76), (1.9 – 1.76), (1.8 – 1.76), (1.6 – 1.76), (1.5 – 1.76)
= 0.24, 0.14, 0.04, – 0.16, – 0.26

The absolute values of these deviations from the mean are 0.24, 0.14, 0.04, 0.16, and 0.26

The average of these absolute values of deviations from the mean,

d = (0.24 + 0.14 + 0.04 + 0.16 + 0.26)/5 = 0.168 m

The water distribution efficiency, $\eta_d = \left(1 - \frac{d}{D}\right) = \left(1 - \frac{0.168}{1.76}\right) = 0.905 \times 100 = 90.5\%$

Problem-4

One cumec of water is pumped into a farm distribution system, 0.8 cumec is delivered to a turn-out, 0.9 kilometer from the well. Compute the conveyance efficiency.

***Solution*:**

By definition,

η_c = Output/input × 100 = 0.8/1.0 × 100 = 80 %

Problem-5

10 cumec of water is delivered to a 32 hectare field, for 4 hours. Soil probing after the irrigation indicates that 0.3 meter of water has been stored in the root zone. Compute the water application efficiency.

***Solution*:**

Volume of water supplied by 10 cumec of water applied for 4 hours = (10×4×60×60) m^3
= 144000 m^3
= 14.4 × 10^4 m^3
= 14.4 m × 10^4 m^2
= 14.4 hectare-meter

∴ Input = 14.4 hectare-meter

Output = 32 hectares land is storing water upto 0.3 m depth

∴ Output = 32 × 0.3 hectare-meter = 9.6 hectare-meter

Water application efficiency (η_a) = Output/input × 100 = (9.6/14.4) × 100 = 66.67 %

Problem-6

A stream of 130 liters per second was diverted from a canal and 100 liters per second were delivered to the field. An area of 1.6 hectares was irrigated in 8 hours. The effective depth of root zone was 1.7 m. The runoff loss in the field was 420 m^3. The depth of water penetration varied linearly from 1.7 m at the head end of the field to 1.1 m at the tail end. Available moisture holding capacity of the soil is 20 cm per meter depth of soil. It is required to determine the (a) **water conveyance efficiency**, (b) **water application efficiency**, (c) **water storage efficiency** and (d) **water distribution efficiency**. Irrigation was started at a moisture extraction level of 50% of the available moisture.

***Solution*:**

(a) Water conveyance efficiency (η_c) = $\frac{\text{Water delivered to the fields}}{\text{Water supplied into the canal at the head}} \times 100$

$= \frac{100}{130} \times 100 = 77\%$

(b) Water application efficiency (η_a) = $\frac{\text{Water stored in the root zone during irrigation}}{\text{Water delivered to the field}} \times 100$

Water supplied to field during 8 hours @ 100 liters per second = 100× 8×60×60 liters
= 2.88× 10^6 liters
= 2.88× $10^6/10^3$ m^3
= 2880 m^3

Runoff loss in the field = 420 m^3

$\therefore$ The water stored in the root zone = 2880 – 420 m^3 = 2460 m^3

$\therefore$ Water application efficiency (η_a) = $\frac{2460}{2880} \times 100 = 85.4\%$

(c) Water storage efficiency (η_s) = $\frac{\text{Water stored in the root zone during irrigation}}{\text{Water needed in the root zone prior to irrigation}} \times 100$

Moisture holding capacity of soil = 20 cm per m length × 1.7 m height of root zone = 34 cm

Moisture already available in root zone at the time of start of irrigation = $\frac{50}{100} \times 34 = 17$ cm

Additional water required in root zone = 34 – 17 = 17 cm

Amount of water required in root zone = Depth × Plot area = $\frac{17}{100} \times (1.6\times10^4)\ m^3 = 2720\ m^3$

But actual water stored in root zone = 2460 m^3

$\therefore$ Water storage efficiency (η_s) = $\frac{2460}{2720} \times 100 = 90\%$ (say)

(d) Water distribution efficiency, $\eta_d = \left(1 - \frac{d}{D}\right)$

Mean depth of water stored in the root zone, D = (1.7 + 1.1)/2 = 1.4 m

Average of the absolute values of deviations from the mean, d = $\frac{|1.7-1.4| + |1.1-1.4|}{2} = \frac{0.3+0.3}{2} = 0.3$ m

$\therefore$ Water distribution efficiency, $\eta_d = \left(1 - \frac{d}{D}\right) = \left(1 - \frac{0.30}{1.4}\right) = 0.786 \times 100 = 78.6\%$

11. Irrigation Scheduling:

Irrigation schedule is a decision making process involving:

- When to irrigate?
- How much water to apply each time?
- How to apply (method of irrigation)?

- **Available Water (AW):**
  The water contained in the soil between FC and PWP is known as the available water.
- **Total Available Water (TAW):**
  The amount of water which will be available for plants in root zone is known as Total Available Water (TAW). It is the difference in volumetric moisture content at FC and that at PWP, multiplied by root zone depth.
- **Management Allowable Depletion (MAD):**
  MAD is the degree, to which water in the soil is allowed to be depleted by management decision and expressed as,

  $$MAD = f \times TAW$$

  Where, f = Allowable depletion (%)
- **Reference crop Evapotranspiration (ET_o):**
  The rate of evapotranspiration from an extensive surface of 8 ~ 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water is known as reference crop evapotranspiration (ET_o)
- **Crop Evapotranspiration (ET_c):**
  The depth of water need to meet the water loss through evapotranspiration of a disease free crop, growing in large fields under non-restricting soil conditions including water and fertility and achieving full production potential under the given growing environment.
- **Crop Co-efficient (k_c):**
  The ratio of crop evapotranspiration (ET_c) to the reference evapotranspiration (ET_o) is called Crop co-efficient (k_c).

  $$\therefore k_c = ET_c/ET_o$$

Water Requirements of Crops

- Arid Region and Semi Arid Region
- Water requirements of a crop mean the total quantity and the way in which a crop requires water from the time it is sown to the time it is harvested.
- Water requirements depend on: *water table, crop, ground slope, intensity of irrigation, method of application of water, place, climate, type of soil, method of cultivation and useful rainfall.*

Crop Period or Base Period

- The time period that elapses from the instant of its sowing to the instant of its harvesting is called the **crop period**.
- The time between the first watering of a crop at the time of its sowing to its last watering before harvesting is called the **base period**.

Duty and Delta of a Crop

Delta: The total quantity of water required by the crop for its full growth may be expressed in hectare-meter or simply as depth to which water would stand on the irrigated area if the total quantity supplied were to stand above the surface without percolation or evaporation. This total depth of water is called delta (Δ).

Problem – 7:
If rice requires about 10 cm depth of water at an average interval of about 10 days, and the crop period for rice is 120 days, find out the delta for rice.
Solution:

No. of watering required = 120/10 = 12
Total depth of water required in 120 days = $10 \times 12 = 120$ cm
Δ for rice = 120 cm

Problem – 8:
If wheat requires about 7.5 cm of water after every 28 days, and the base period for wheat is 140 days, find out the value of delta for wheat.
Solution:

No. of watering required = 140/28 = 5
Total depth of water required in 140 days = $7.5 \times 5 = 37.5$ cm
Δ for wheat = 37.5 cm

Duty: It may be defined as the number of hectares of land irrigated for full growth of a given crop by supply of 1 m^3/s of water continuously during the entire base of that crop.

Simply we can say that, the area (in hectares) of land can be irrigated for a crop period, B (in days) using one cubic meter of water.

Factors on which duty depends

- Type of crop
- Climate and season
- Useful rainfall
- Type of soil
- Efficiency of cultivation method

Importance of Duty

It helps us in designing an efficient canal irrigation system. Knowing the total available water at the head of a main canal, and the overall duty for all the crops required to be irrigated in different seasons of the year, the area which can be irrigated can be worked out.

Inversely, if we know the crops area required to be irrigated and their duties, we can work out the discharge required for designing the channel.

Measures for improving duty of water

The duty of canal water can certainly be improved by effecting economy in the use of water by resorting to the following precautions and practices:

Precautions in field preparation and sowing:

- Land to be used for cultivation should, as far as possible, be leveled
- The fields should be properly ploughed to the required depth
- Improved modern cultivation methods may preferably be adopted
- Porous soils should be treated before sowing crops to reduce seepage of water
- Manure fertilizers should be added to increase water holding capacity of the soil

Precautions in handling irrigation supplies:

- The source of irrigation water should be situated within the prescribed limits
- Canals carrying irrigation supplies should be lined to reduce seepage and evaporation
- Water courses may preferably be lined to reduce on field requirement of water
- Irrigation supplies should be economically used by proper control on its distribution
- Free flooding of fields should be avoided and furrow irrigation method may preferably be adopted, if surface irrigation is resorted to.
- Sub surface irrigation and Drip irrigation may be preferred to ordinary surface irrigation.

Relation between Duty and Delta

Let,

There be a crop of base period *B* days and

1 m^3/s of water is applied to this crop on the field for *B* days.

Now, the volume of water applied to this crop during *B* days, $V = (1 \times 60 \times 60 \times 24 \times B)\ m^3$

$= 86{,}400\ B\ m^3$

This quantity of water (V) matures D hectares of land or 10^4 D m^2 of area

The depth of water applied on this land

$$= \frac{\text{Volume}}{\text{Area}} = \frac{86{,}400B}{10^4 D} = \frac{8.64B}{D} \text{ meters}$$

By definition, this total depth of water is called delta (Δ)

$$\Delta = \frac{8.64B}{D} \textbf{ meters}$$

$$\Delta = \frac{864B}{D} \textbf{ cm}$$

Where, Δ is in cm

B is in days

D is duty in hectares/cumec

Problem – 9:

Find the delta for a crop when its duty is 864 hectares/cumec on the field, the base period of this crop is 120 days.

Solution: In this question, B = 120 days and D = 864 hectares/ cumec

$\therefore\ \Delta = 864B/D = 864 \times 120/864 = 120$ cm

Crop Season

From the agricultural point of view, the year can be divided into two principal cropping seasons:

Rabi → Starts from 1st October and ends on 31st March

→ Kharif crops are also called "summer crops"

Example: Rabi crops are rice, bajra, jowar, maize, cotton, tobacco, groundnut etc

Kharif → Starts from 1st April and ends on 30th September

→ Rabi crops are "winter crops"

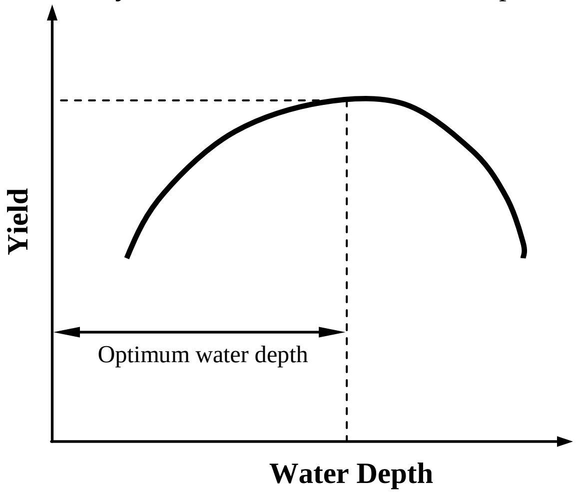
Example: Kharif crops are wheat, barley, gram, linseed, mustard, potatoes etc

Cash Crop

A cash crop may be defined as a crop which has to be en-cashed in the market for processing as it cannot be consumed directly by the cultivators. All non food crops are thus included in cash crops. Examples: Jute, Tea, Cotton, Tobacco etc.

Optimum Utilization of Irrigation Water

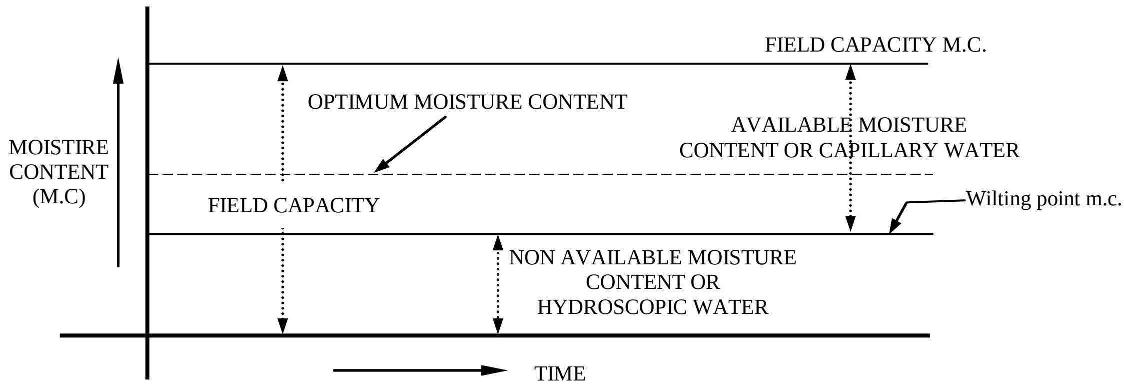
In an identical situation, yield is going to vary with the application of different quantities of water. The yield increases with water, reaches maximum value and then falls down. *The quantity of water at which the yield is maximum, is called the optimum water depth.*



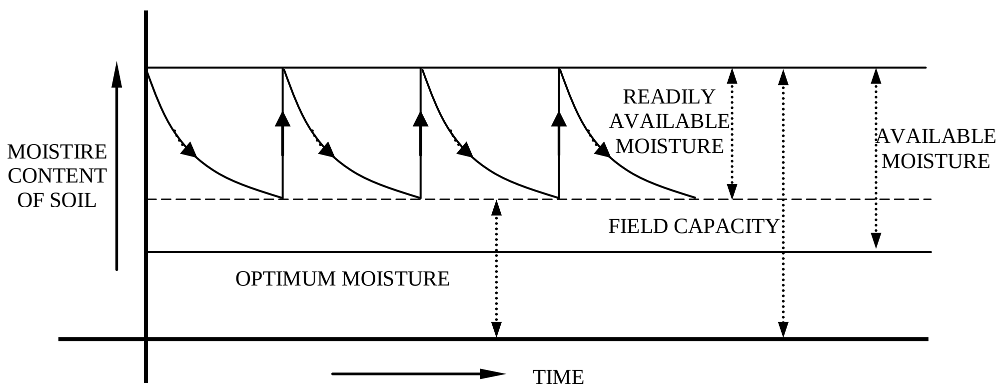
Optimum utilization of irrigation generally means, getting maximum yield with any amount of water. The supplies of water to the various crops should be adjusted in such a fashion, as to get optimum benefit ratio, not only for the efficient use of available water and maximum yield, but also to prevent water-logging of the land in question. To achieve economy in the use of water, it is necessary that the farmers be made acquainted with the fact only a certain fixed amount of water gives best results.

Estimating depth and frequency of irrigation on the basis of soil moisture regime concept

Water or soil moisture is consumed by plants through their roots. It, therefore, becomes necessary that sufficient moisture remains available in the soil from the surface to the root zone depth.



The irrigation water should be supplied as soon as the moisture falls up to this optimum level (fixing irrigation frequency) and its quantity should be just sufficient to bring the moisture content up to its field capacity, making allowance for application losses (thus fixing water depth)



Water will be utilized by the plants after the fresh irrigation dose is given, and soil moisture will start falling. It will again be recouped by a fresh dose of irrigation, as soon as the soil moisture reaches the optimum level, as shown below.

<u>Permanent wilting point</u>

It is that water content at which plant can no longer extract sufficient water for its growth, and wilts up. It is the point at which permanent wilting of plants take place.

<u>Available moisture</u>

It may be defined as the difference in water content of the soil between field capacity and permanent wilting point.

<u>Readily available moisture</u>

It is that portion of the available moisture which is most easily extracted by the plants, and is approximately 75 to 80 % of the available moisture.

<u>Field Capacity</u>:

Immediately after a rain or irrigation water application, when all the gravity water drained down to the water table, a certain amount of water is retained on the surfaces of soil grains by molecular attraction and by loose chemical bonds (i.e. adsorption). This water cannot be easily drained under the action of gravity, and is called the field capacity. The field capacity is thus the water content of a soil after free drainage has taken place for a sufficient period. This period of free gravity drainage is generally taken as 2 to 5 days.

The field capacity water further consists of two parts. One part is that which is attached to the soil molecules by surface tension against gravitation forces, and can be extracted by plants by capillarity. This water is called capillary water. The other part is that which is attached to the soil molecules by loose chemicals bonds. This water which cannot be removed by capillarity is not available to the plants, and is called the hygroscopic water.

Derivation

The field capacity water (i.e. the quantity of water which any soil can retain indefinitely against gravity) is expressed as the ratio of the weight of water contained in the soil to the weight of the dry soil retaining that water: i.e.

$$\text{Field Capacity} = \frac{\text{Wt. of water retained in a certain vol. of soil}}{\text{Wt. of the same volume of dry soil}} \times 100 \text{ ------------------- (1)}$$

If we consider 1 m^2 area of soil and d meter depth of root zone,

$\therefore$ The volume of soil = $d \times 1 = d$ m^3

If the dry unit wt. of soil = γ_d kN/m^3

$\therefore$ Wt. of d m^3 of soil = $\gamma_d \times d$ kN

If F is the field capacity,

$$\therefore F = \frac{\text{Wt. of water retained in unit area of soil}}{\gamma_d \times d}$$

$\Rightarrow$ Wt. of water retained in unit area of soil = ($\gamma_d \times d \times F$) kN/$m^2$

$\Rightarrow$ Volume of water stored in unit area of soil $\times \gamma_w$ = ($\gamma_d \times d \times F$) kN/$m^2$

$\Rightarrow$ Volume of water stored in unit area of soil = $\left(\frac{\gamma_d \times d \times F}{\gamma_w}\right)$ meter

$\therefore$ Total water storage capacity of soil in (m depth of water) = $\left(\frac{\gamma_d \times d \times F}{\gamma_w}\right)$ meter

Hence, the depth of water stored in the root zone in filling the soil up to field capacity

$$= \left(\frac{\gamma_d \times d \times F}{\gamma_w}\right) \text{meters}$$

Problem-10

After how many days will you supply water to soil in order to ensure sufficient irrigation of the given crop, if,

- Field capacity of the soil = 28%
- Permanent wilting point = 13%
- Dry density of soil = 1.3 gm/cc
- Effective depth of root zone = 70 cm
- Daily consumptive use of water for the given crop = 12 mm.

***Solution*:**

We know, by definition of available moisture, that

Available moisture = Field Capacity – Permanent wilting point

= 28 – 13

= 15 %

Let us assume that the readily available moisture or the optimum soil moisture level is 80 % of available moisture

i.e. Readily available moisture = 0.80 × 15 % = 12 %

∴ Optimum moisture = 28 – 12 = 16 %

It means that the moisture will be filled by irrigation between 16 % and 28 %.

Depth of water stored in root zone between these two limits = $\frac{\gamma_d \times d}{\gamma_w}$ [FC – OMC] ----------- (i)

Now, $\frac{\gamma_d}{\gamma_w} = \frac{\rho_d \times g}{\rho_w \times g}$

$= \frac{\rho_d}{\rho_w}$

$= \frac{1.3}{1}$ [∵ ρ_w = 1 gm/cc]

= 1.3 gm/cc

From equation (i) ⇒ Depth of water = $\frac{\gamma_d}{\gamma_w} \times d$ [FC – OMC]

= 1.3 × 0.7 × [0.28 – 0.16]

= 0.1092 m = 10.92 cm

Hence, water available for evapo-transpiration = 10.92 cm

1.2 cm of water is utilized by the plant in 1 day

10.92 cm of water will be utilized by the plant in = 1×10.92/1.2 days = 9.1 days ≈ **9 days**

Hence, after **9 days**, water should be supplied to the given crop

Problem-11

Wheat is to be grown in a field having a field capacity equal to 27% and the permanent wilding point is 13%. Find the storage capacity in 80 cm depth of the soil, if the dry unit weight of the soil is 14.72 kN/m^2. If irrigation water is to be supplied when the average soil moisture falls to 18 %, find the water depth required to be supplied to the field if the field application efficiency is 80 %. What is the amount of water needed at the canal outlet if the water lost in the water-courses and the field channels is 15 % of the outlet discharge?

***Solution*:**

Maximum storage capacity or available moisture = $\frac{\gamma_d \times d}{\gamma_w}$ [FC – OMC]

$= \frac{14.72}{9.81} \times 0.8$ [0.27 – 0.13] [∵ $\rho_w = 9.81\ kN/m^3$]

= 0.168 m = 16.8 cm

Since the moisture is allowed to vary between 27 % and 18 %, the deficiency created in this fall

$$= \frac{14.72}{9.81} \times 0.8\ [0.27 - 0.18]$$

$$= 0.108\ \text{m} = 10.8\ \text{cm}$$

Hence, 10.8 cm depth of water is the net irrigation requirement.

Quantity of water requirement to be supplied to the field (F.I.R) = NIR/η_a

F.I.R = N.I.R/η_a =10.8/0.80 = 13.5 cm (ans)

Quantity of water needed at the canal outlet = F.I.R/η_a =13.5/0.85 = 15.55 cm (ans)

Practice Problems:

Problem – 1

A reservoir with a storage capacity of 300 million cubic meters is able to irrigate 40,000 hectares with 2 fillings each year. The crop season is 120 days. What is the duty?

Problem – 2

A channel is to be designed for irrigating 5000 hectares in Kharif crop and 4000 hectares in Rabi crop. The water requirement for Kharif and Rabi are 60 cm and 20 cm, respectively. The base period for Kharif is 3 weeks and for Rabi is 4 weeks. Determine the discharge of the channel for which it is to be designed.

Problem – 3

The left branch canal carrying a discharge of 20 m^3/s has culturable commanded area of 20,000 hectares. The intensity of Rabi crop is 80 % and the base period is 120 days. The right branch canal carrying discharge of 8 m^3/s has culturable commanded area of 12,000 hectares, intensity of irrigation of Rabi crop is 50 % and the base period is 120 days. Compare the efficiencies of the two canal systems.

Problem – 4

A loam soil has field capacity of 22 % and wilting coefficient of 10 %. The dry unit weight of soil is 1.5 gm/cc. If the root zone depth is 70 cm, determine the storage capacity of the soil. Irrigation water is applied when moisture content falls to 14 %. If the water application efficiency is 75 %, determine the water depth required to be applied in the field.

Problem – 5

Compute the depth and frequency of irrigation required for a certain crop with data given below:

Root zone depth	100 cm
Field capacity	22 %
Wilting Point	12 %
Specific gravity of soil	1.5
Consumptive use	25 mm/day
Efficiency of irrigation	50 %

Assume 5% depletion on available moisture before application of irrigation water at field capacity.

Problem – 6

Uniformly distributed soil sample was collected from a field 2 days after irrigation when the soil moisture was near FC.

Inside dimensions of core sampler: 7.5 cm diameter and 15 cm depth

Weight:

Cylinder + moist soil = 2.76 kg

Cylinder + oven dry soil = 2.61 kg

Core sampling cylinder alone = 1.56 kg

Calculate available moisture holding capacity of soil

<u>Problem – 7</u>

The following data were obtained in determining soil moisture content at successive depths in root zone prior to irrigation:

Depth of sampling (cm)	Weight of moist sample (gm)	Oven dry weight of sample (gm)
0 – 25	134.00	126.82
25 – 50	136.28	127.95
50 – 75	122.95	115.32
75 – 100	110.92	102.64

The bulk density of soil in root zone = 1.50 gm/cc
Available moisture holding capacity of soil = 17.8 gm/m depth of soil
Calculate:

(i) The moisture contents at different depths in root zone
(ii) Moisture available in root zone just after irrigation
(iii) Net depth of water to be applied to bring the moisture content to FC
(iv) GIR at an estimated Field Irrigation Efficiency of 70%

<u>Problem – 8</u>:

A sandy load soil holds water at 140 mm/m depth between FC and PWP
Root depth of the crop = 30 cm
Allowable depletion of water = 35%
Daily water use by the crop = 5 mm/day
The area to be irrigated = 60 hectares
Water can diverted @ 28 LPS
Surface irrigation application efficiency + 40%
Assume no rainfall and ground water contribution

Calculate:

Allowable depletion depth between irrigations
Frequency of irrigation
Net application depth of water
Volume of water required
Time to irrigation 4 hectares plot

<u>Problem – 9</u>:

The depth of penetration along the length of a border strip at points 30 m apart were probed. The observed values are 2.0, 1.9, 1.8, 1.6 and 1.5 m. Compute water distribution efficiency

<u>Problem – 10</u>:

A stream of 130 lps was diverted from a canal and 100 lps was delivered to field. An area of 1.6 hectares was irrigated in 8 hours.

Effective depth of root zone = 1.7 m
Runoff loss in the field = 420 m3
Depth of water penetration varied linearly from 1.7 m at the head end of the field to 1.1 m at the tail end of the field
Available moisture holding capacity of soil = 20 cm/m depth of soil
Compute:

Conveyance efficiency, application efficiency, storage efficiency, distribution efficiency,
Irrigation was started at a moisture extraction level of 50% of available moisture