

CHAPTER – 3

Consumptive Use and Estimation of water requirements of crops

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LECTURE 7

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

Factors affecting CU or ET

(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 area
- Leaf arrangement and structure
- Stomatal behavior

Direct Measurement of CU/ET

(a) Tank or Lysimeter experiments:

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

Limitations:

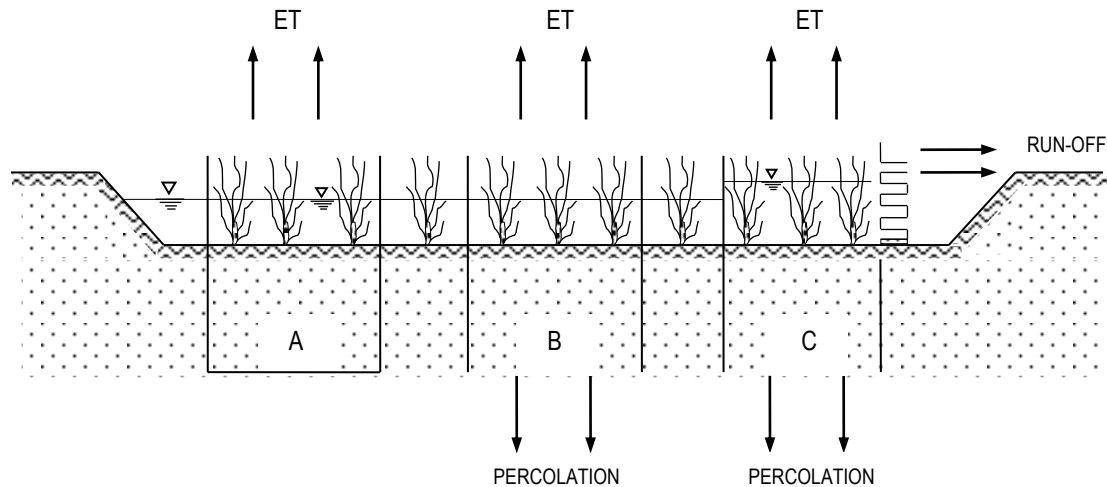
Reproduction of physical conditions such as temperature, water table, soil texture, density etc.

Types of Lysimeters

There are types of lysimeters:

- Non-weighing constant water table type:
- Non-weighing percolation type:
- Weighing type:

Non-weighing constant water table type

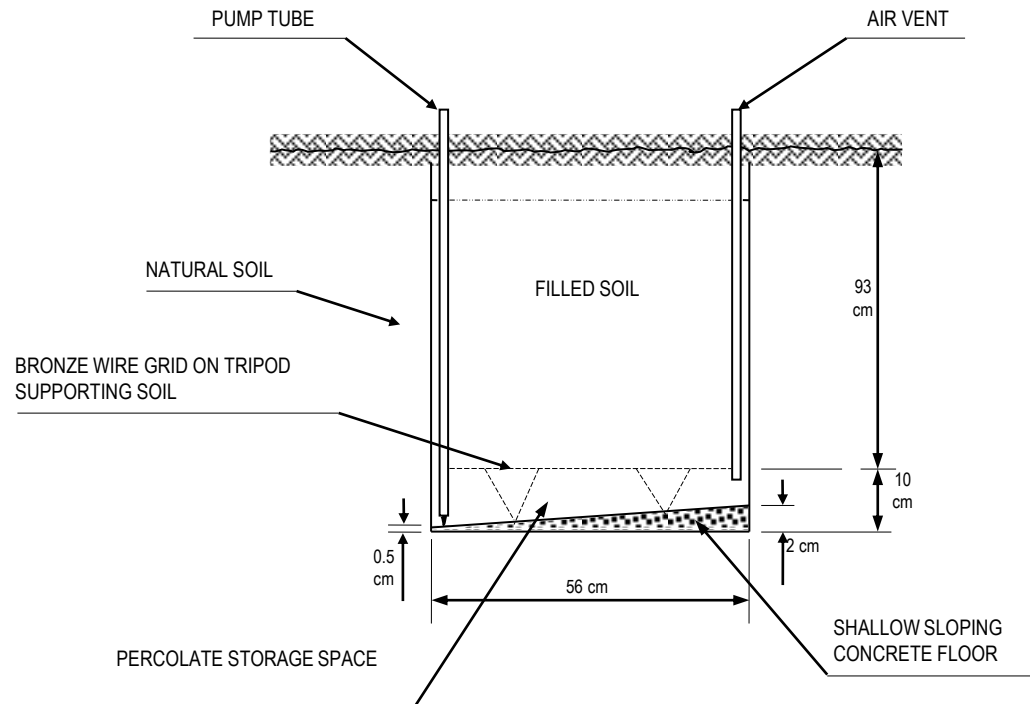


- ❑ Constant water level is maintained by applying water
- ❑ Effective rainfall (R_e) and irrigation (I) are measured by rain-gauges and calibrated container
- ❑ The overflow (R) and deep percolation (D_r), if any, are measured.

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

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

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

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

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

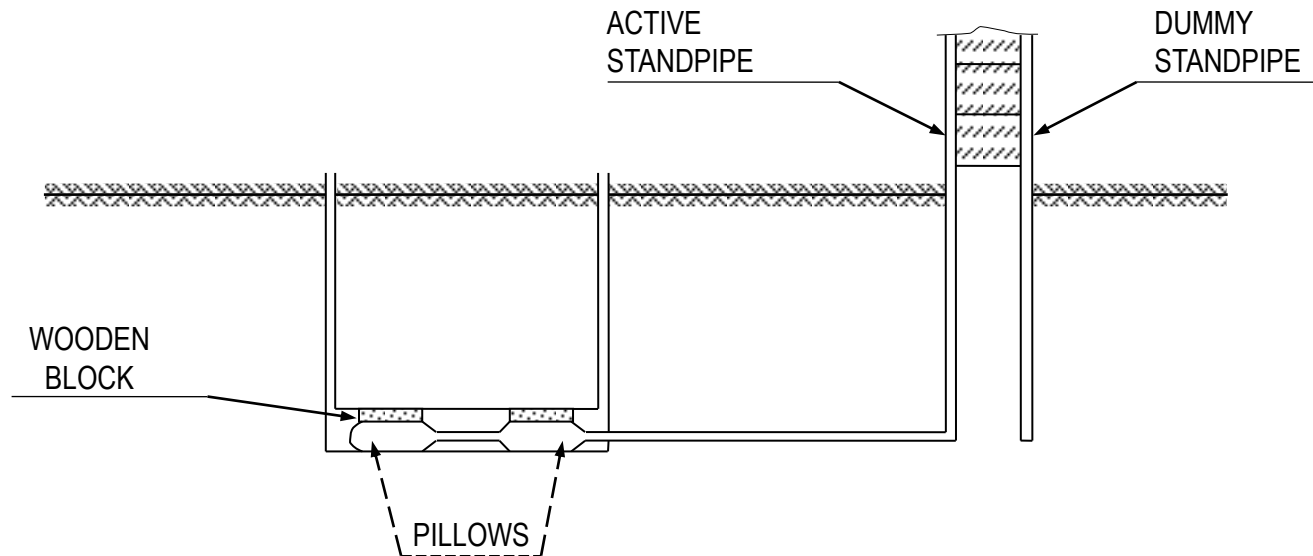
A_i = Apparent specific gravity of the i^{th} layer of soil

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

n = No. of soil layers in the root zone

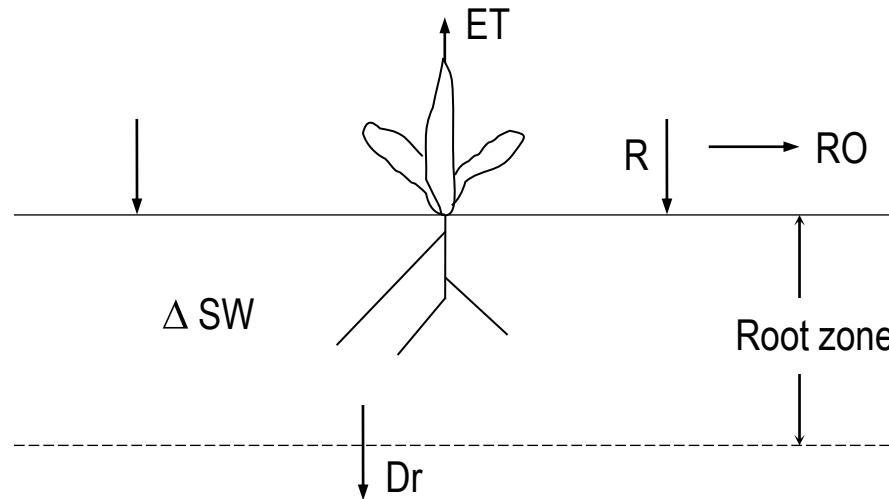
- Applicable for areas having high precipitation
- Special arrangements are made to drain and measure the water percolating through the soil mass

Weighing type



- ❑ 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

Soil moisture depletion studies



- 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 i^{th} layer

M_{2i} = moisture content at the time of 2nd sampling in the i^{th} layer

Some important definitions

Effective rainfall:

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

Consumptive Irrigation Requirement (CIR):

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

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

Net Irrigation Requirement (NIR):

It is the amount of irrigation water required in order to meet the evapo-transpiration need of the crop as well as the other needs.

$NIR = (C_u) - (R_e) + \text{Water lost as percolation in satisfying other needs such as leaching.}$

Field Irrigation Requirement (FIR):

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

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

$$= NIR/E_a \quad \text{Where, } E_a = \text{Water application efficiency}$$

Gross Irrigation Requirement (GIR):

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

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

$$= FIR/E_c \quad \text{Where, } E_c = \text{Conveyance efficiency}$$

Estimation of ET using empirical equation

(a) Blaney – Criddle Equation:

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

C_u = Monthly consumptive use in cm.

k = Crop factor, determined by experiments

t = Mean monthly temperature in $^{\circ}\text{C}$

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

$$C_u = k. f$$

Problem

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 (°C) 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
Nove	18.0	7.20	1.7
Dec	15.0	7.15	1.42
Jan	13.5	7.30	3.01
Feb	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 (°C)	p (hr)	R _e (cm)	f = P/40(1.8t + 32) (cm)
Nov	18.0	7.20	1.7	11.6
Dec	15.0	7.15	1.42	10.5
Jan	13.5	7.30	3.01	10.3
Feb	14.5	7.10	2.75	10.3
			ΣR _e = 8.38	Σf = 42.7

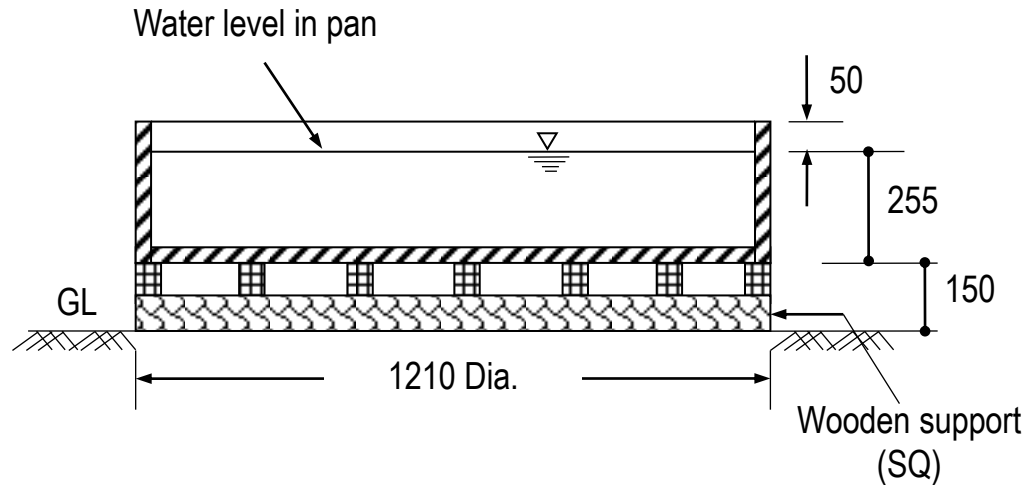
$$C_u = k. \Sigma f = 0.8 \times 42.7 = 34.16 \text{ cm}$$

Hence, Consumptive use, $C_u = 34.16 \text{ cm}$

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

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

(b) Hargreaves class A pan evaporation method:



- ❑ 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.

Continue..... Hargreaves class A pan evaporation method:

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

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

$$\text{Or. } E_t \text{ or } C_u = k E_p$$

- Consumptive use co-efficient, k varies with crop type, crop growth etc. values of k are found from Table 2.9 (S. K Garg).

(b) FAO Penman-Monteith equation :

$$ET_0 = \frac{0.408 \times \Delta \times (R_n - G) + \gamma \times \left(\frac{900}{T + 273} \right) \times u_2 \times (e_s - e_a)}{\Delta + \lambda \times (0.34 + u_2)}$$

Where,

ET_0 = Reference crop (green grass) evapotranspiration (mm/day)

Δ = Slope of saturation vapor pressure vs temperature curve at mean air temperature, kPa per °C

R_n = Net radiation, MJ/m² per day, can be calculated from actual sunshine hour and other weather data

G = Soil heat flux, MJ/m² per day

γ = Psychometric constant, kPa per °C

T = Mean air temperature, °C

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, $G = 0.14 (T_i - T_{i-1})$ Where, T_i = Mean air temperature for the month (°C)

T_{i-1} = Mean air temperature for the previous month (°C)

$G = 0$ for 10 days or short period

LECTURE 8

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-1: The depths of penetrations along the length of a boarder 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,

$$d = (0.24 + 0.14 + 0.04 + 0.16 + 0.26)/5 = 0.168 \text{ m}$$

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

Problem (Home Work)

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)

$$\eta_c = \frac{\text{Water delivered to the fields}}{\text{Water supplied into the canal at the head}} \quad 100 = \frac{100}{130} \quad 100 = 77\%$$

(b) Water application efficiency (η_a)

$$\eta_a = \frac{\text{Water stored in the root zone during irrigation}}{\text{Water delivered to the field}} \quad 100$$

Water supplied to field during 8 hours @ 100 liters per second
= 100 8 60 60 liters = 2.88 10⁶ liters
= 2.88 10⁶/10³ m³ = 2880 m³

Runoff loss in the field = 420 m³

∴ The water stored in the root zone = 2880 – 420 m³ = 2460 m³

$$\therefore \text{Water application efficiency } (\eta_a) = \frac{2460}{2880} \quad 100 = 85.4\%$$

(c) Water storage efficiency (η_s)

$$\eta_s = \frac{\text{Water stored in the root zone during irrigation}}{\text{Water needed in the root zone prior to irrigation}} \times 100$$

Moisture holding capacity of soil = 20 cm per m length \times 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 \times Plot area = $\frac{17}{100} \times (1.6 \times 10^4) \text{ m}^3 = 2720 \text{ m}^3$

But actual water stored in root zone = 2460 m³

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

(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, $d = \frac{|1.7 - 1.4| + |1.1 - 1.4|}{2}$

Average of the absolute values of deviations from the mean,

$$d = \frac{|1.7 - 1.4| + |1.1 - 1.4|}{2} = \frac{0.3 + 0.3}{2} = 0.3 \text{ m}$$

$$\begin{aligned} \therefore \text{Water distribution efficiency, } \eta_d &= \left(1 - \frac{d}{D}\right) \\ &= \left(1 - \frac{0.30}{1.4}\right) \\ &= 0.786 \quad 100 = 78.6\% \end{aligned}$$

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):

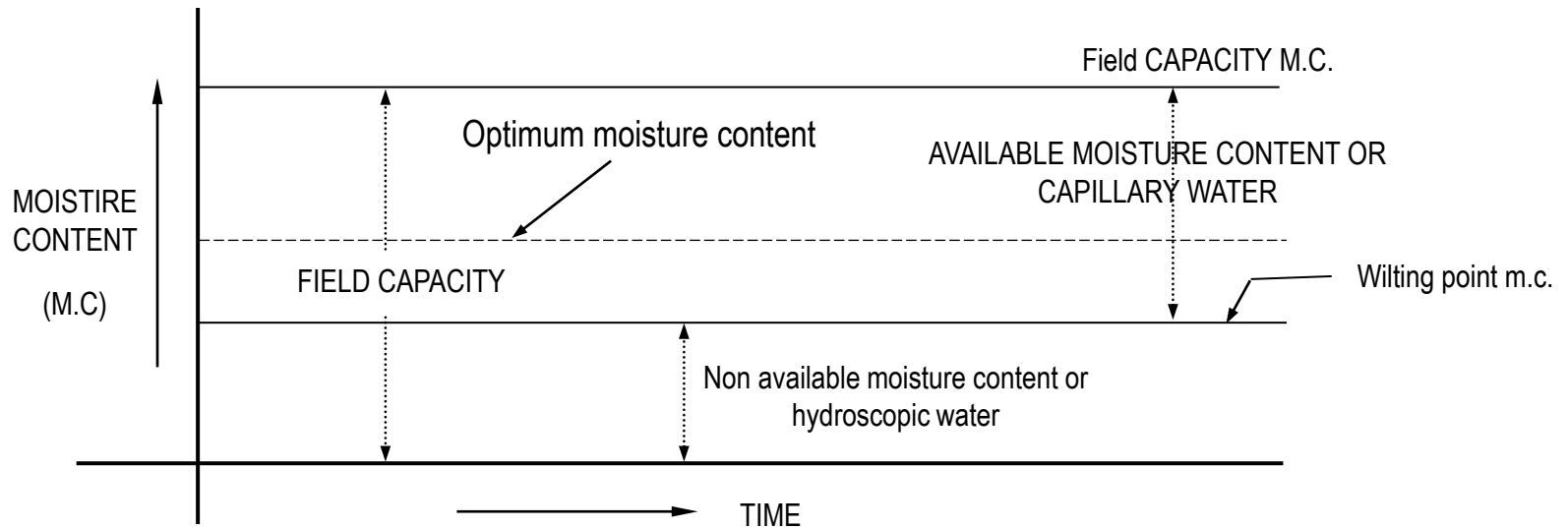
The water contained in the soil between FC and PWP is known as the available water. **(Fig. in the next slide)**

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. **(Fig. in the next slide)**

Available Water (AW):

The water contained in the soil between FC and PWP is known as the available water.



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,

$$\text{MAD} = f \quad \text{TAW} \quad \text{Where, } f = \text{Allowable depletion (\%)}$$

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 a Crop

- ❑ Arid Region and Semi Arid Region
- ❑ Water requirements of a crop means 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 depends 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: 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

Duty: The area (in hectares) of land can be irrigated for a crop period, B (in days) using one cubic meter of water.

Relation Between Duty and Delta

Let there be a crop of base period B days.

Let one cumec of water be applied to this crop on the field for B days.

Now , the volume of water applied to this crop during B days

$$= V = (1 \times 60 \times 60 \times 24 \times B) \text{ m}^3$$

$$= 86\,400 B \text{ (cubic meter)}$$

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

The depth of water applied on this land

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

$$= 8.64 B/D \text{ meters}$$

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

$$\Delta = 8.64 B / D \text{ meters}$$

$$\Delta = 864 B / D \text{ cm}$$

Problem:

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

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

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.

LECTURE 9

Crop Season & Cash Crop

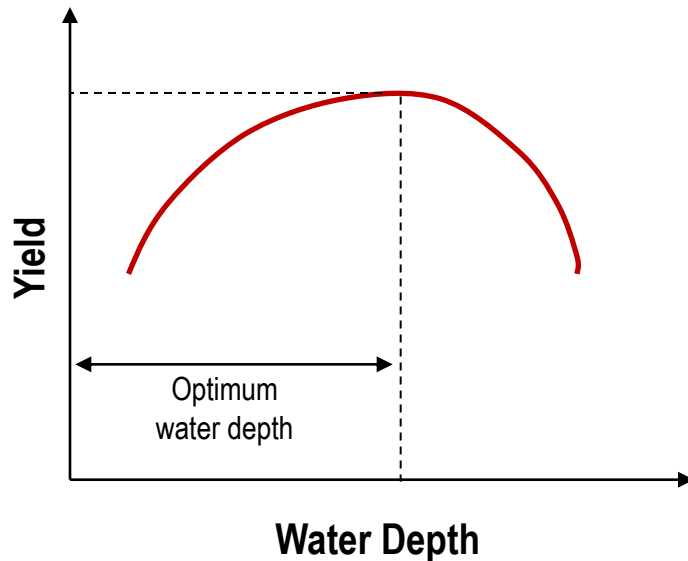
Crop Season

Rabi (October to March) and Kharif (April to September)

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.

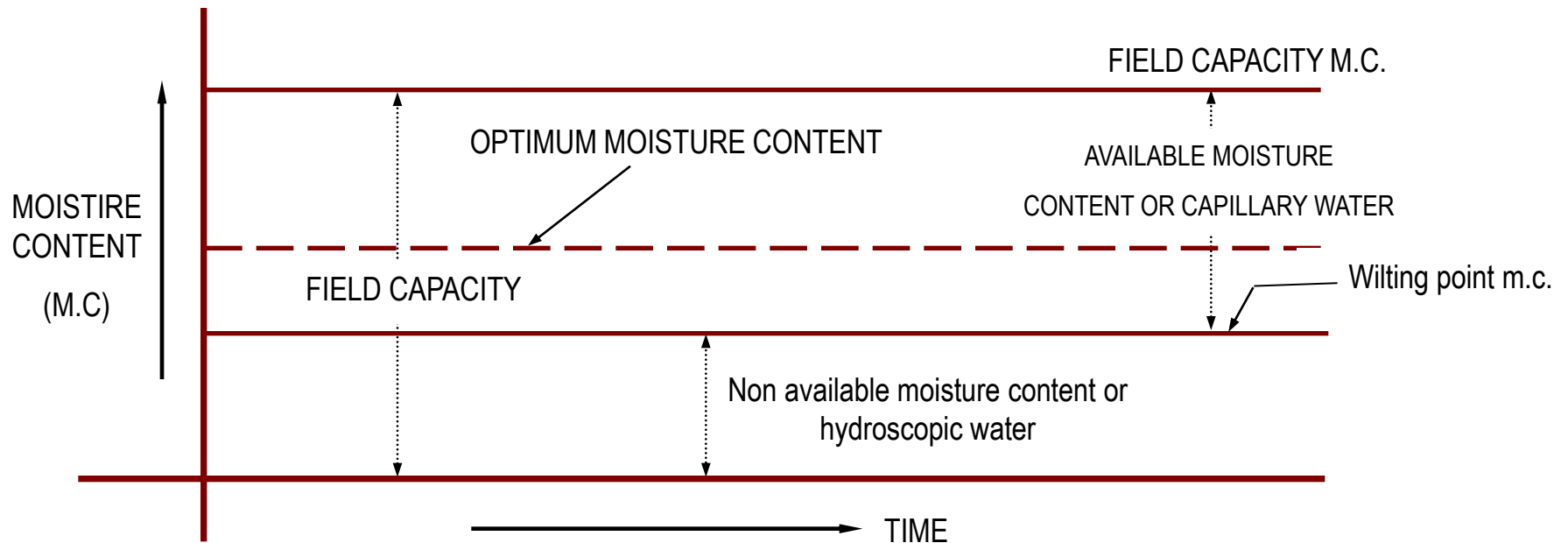
Optimum Utilization of Irrigation Water



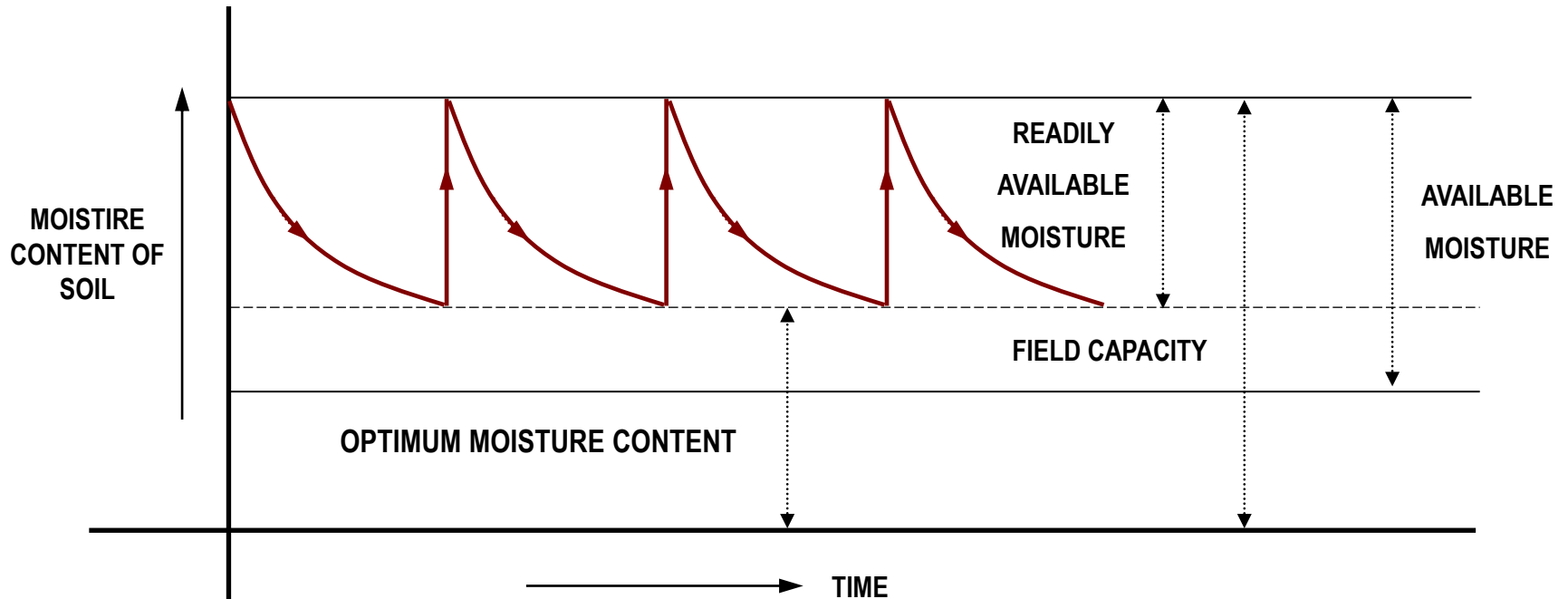
In an identical situation, yield is going to vary with the application of different quantities of water. The yield increases with water, reaches maximum value and then falls down.

The quantity of water at which the yield is maximum, is called the optimum water depth.

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



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



Field Capacity

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.

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

If we consider 1 m² area of soil and d meter depth of root zone,

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

If the dry unit wt. of soil = γ_d kN/m³

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

If F is the field capacity,

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

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

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

$$\Rightarrow \text{Volume of water stored in unit area of soil} = \frac{\gamma_d \times d \times F}{\gamma_w} \text{ meters}$$

$$\therefore \text{Total water storage capacity of soil} = \frac{\gamma_d \times d \times F}{\gamma_w} \text{ meters}$$

(m depth of water)

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

$$\text{capacity} = \frac{\gamma_d \times d \times F}{\gamma_w} \text{ meters}$$

Problem

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

$$= \frac{\gamma_d \times d}{\gamma_w} [FC - OMC] \text{----- (i)}$$

Now,

$$\frac{\gamma_d}{\gamma_w} = \frac{\rho_d \times g}{\rho_w \times g} = \frac{\rho_d}{\rho_w} = \frac{1.3}{1} \quad [\rho_w = 1 \text{ gm/cc}]$$
$$= 1.3 \text{ gm/cc}$$

$$\text{From equation (i)} \Rightarrow \text{Depth of water} = \frac{\gamma_d \times d}{\gamma_w} \quad [\text{FC} - \text{OMC}]$$
$$= 1.3 \times 0.7 \quad [0.28 - 0.16]$$
$$= 0.1092 \text{ m} = 10.92 \text{ cm}$$

Hence, water available for evapo-transpiration = 10.92 cm

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

$$10.92 \text{ cm of water will be utilized by the plant in} = 1 \times \frac{10.92}{1.2} \text{ days}$$
$$= 9.1 \text{ days}$$
$$\approx \mathbf{9 \text{ days}}$$

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

End of Chapter – 3