Irrigation and Drainage

Lecture No:06 Field Water Balance

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Water Balance at Field Plot

The water balance equation at the field plot level, from the mass conservation law, over any time period:

$$SW_i + P + I + U_w = SW_f + R_s + D + ET(\text{or } E)$$

P = rainfall/precipitation

I = irrigation water applied

U_w = upward flux or capillary rise into the root zone

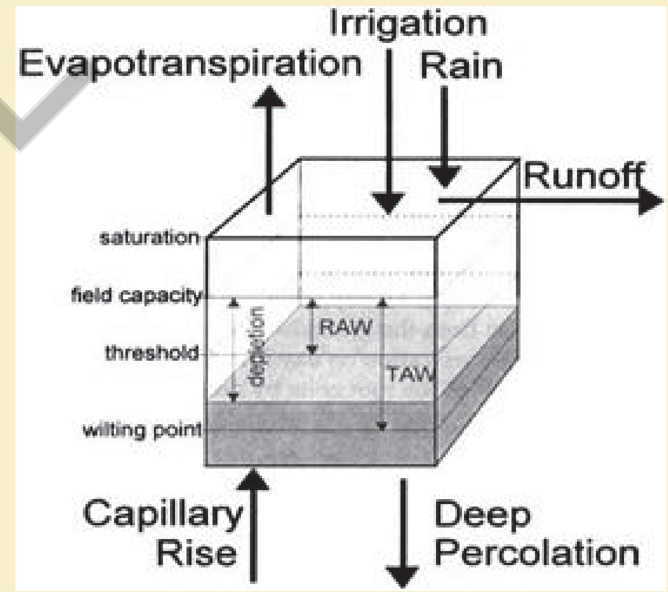
R_s = surface runoff from the field plot

D = deep percolation or downward drainage

ET = evapotranspiration from cropped soil

E = evaporation from the bare soil

SW = soil-water content within a defined root zone; and f and i subscripts represent the end (final) and beginning (initial) of a time period, respectively



http://hydrology.usu.edu/giswr/archive04/zaccaria/termproject/

Water Balance at Field Plot

From an agricultural point of view, it is generally most appropriate to consider the water balance of the crop root zone.

$$\Delta S + \Delta V = (P + I + U_{\mathrm{w}}) - (R_{\mathrm{s}} + D + \mathrm{ET})$$

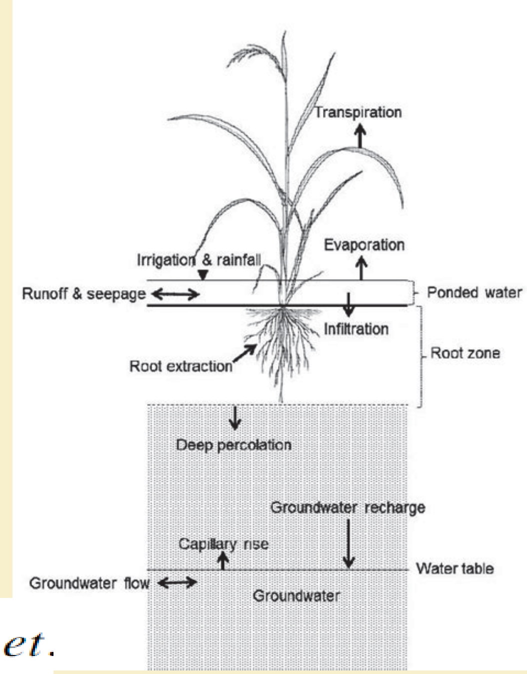
ΔS = change in soil moisture storage in the soil profile (i.e., SW_i - SW_f)

ΔV = water incorporated in the plants (as metabolic activities and/or change in plant water)

U_w and *D*

$$\Delta S = P + I \pm D - R_{\mathrm{s}} - \mathrm{ET}$$

Rate of change in soil moisture storage $\frac{\mathrm{d}s}{\mathrm{d}t} = p + i \pm d - r_{\mathrm{s}} - et.$



Siva Sivapalan (2015)

Measuring Precipitation/Rainfall (P)

Rain-Gauges

Symons Rain-Gauge

Float type Rain-Gauge

Tipping bucket Rain-Gauge

Farm Rain-Gauge

Measuring Irrigation Water (I)

Flowmeter for inflow

Bucket-Stop watch for Inflow

Flume for Outflow

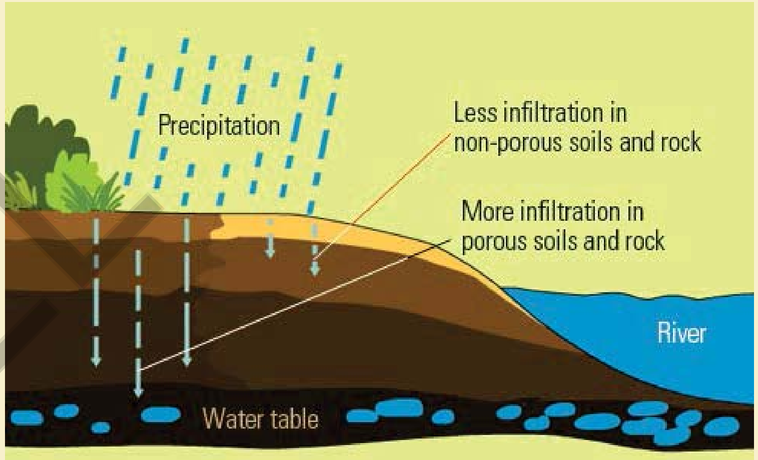
Infiltration

Infiltration is the process by which water enters into the soil from ground surface

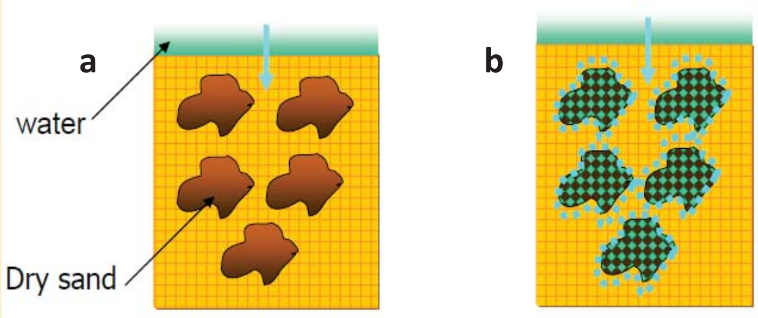
Mainly **three forces governs**: Gravity, suction and capillarity

Factors Affecting Infiltration

✓Soil and land factors
✓Flow Conditions
✓Fluid Factors
✓Management Practices



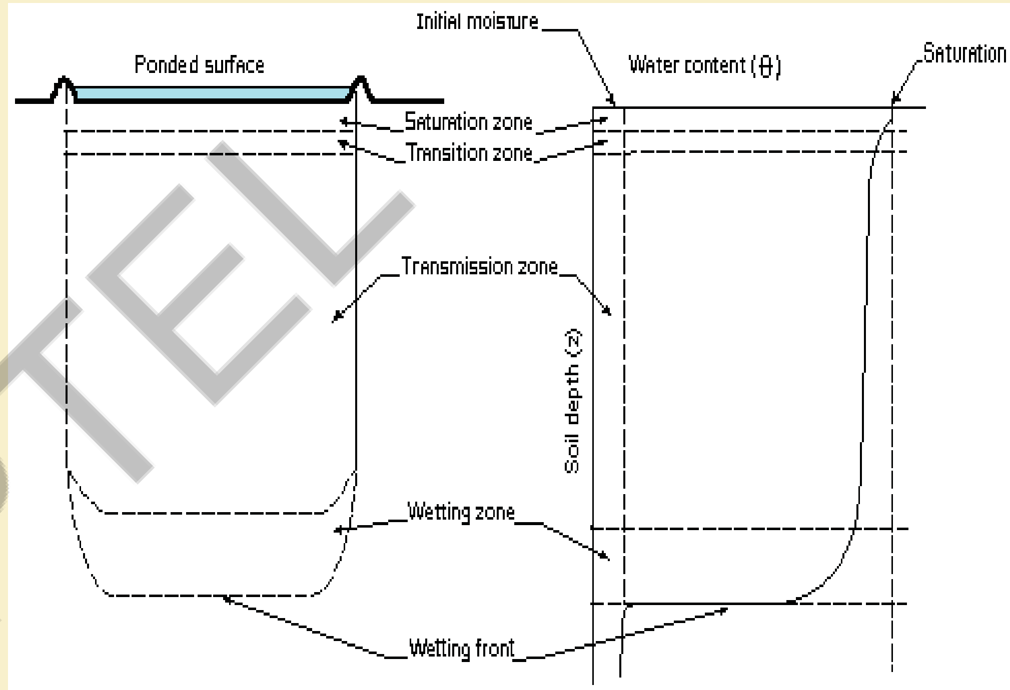
http://www.eschooltoday.com/water-cycle/what-is-infiltration.html



Infiltration Process

Zones during the infiltration process

1. Saturation zone-
   Extends only to a depth of a few millimeters
2. Transition zone
   Rapid decrease in water content with depth
3. Transmission zone
   Water content does not change appreciably with depth
4. Wetting zone
   Sharp decrease in the water content with depth
5. Wetting front
   Lower boundary of the water penetration



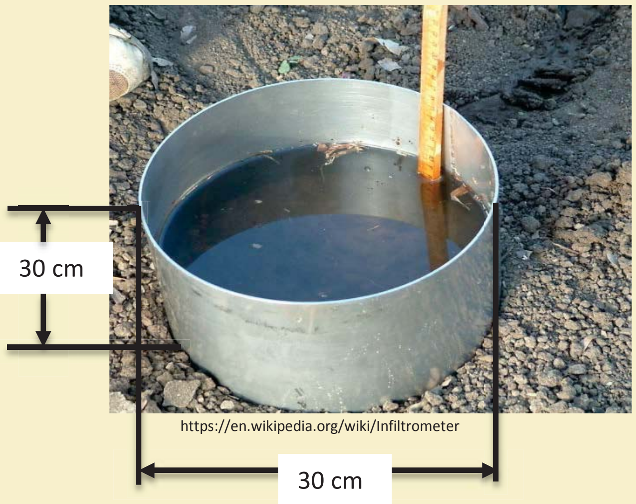
http://slideplayer.com/slide/4740148/

Soil water distribution profile during the infiltration process for a homogeneous soil under ponded condition

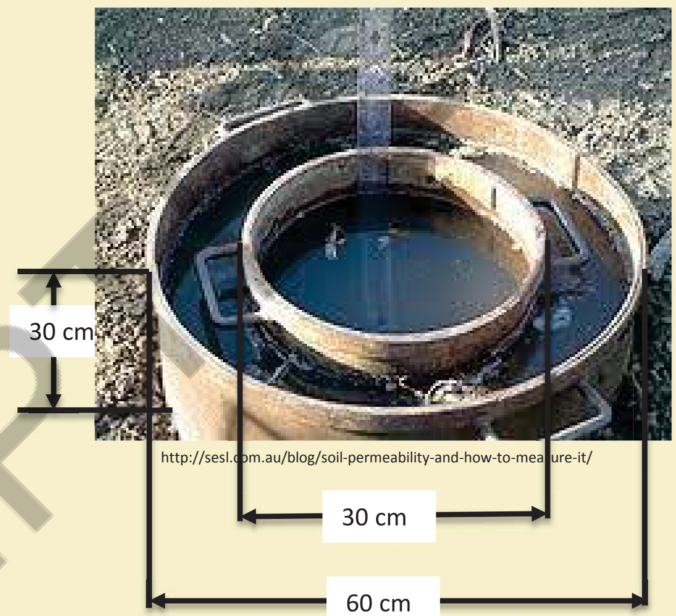
Infiltration: Terminologies

- ✓ **Infiltration rate (mm/h):**
  - The rate at which a particular soil is able to absorb rainfall or irrigation.
  - It is related to the saturated hydraulic conductivity of the near-surface soil.
- ✓ **Cumulative infiltration (mm):**
  - Accumulated depth of water infiltrating during given time period
- ✓ **Infiltration capacity (mm/h):**
  - Maximum rate at which water can enter a soil in a given condition.
  - If the precipitation rate exceeds the infiltration capacity, runoff will usually occur.
- ✓ **Basic infiltration rate (mm/h):**
  - Infiltration capacity declines rapidly during the early part of a storm and then tends to constant value, which is referred to as basic infiltration rate.

Measuring Infiltration



Single ring Infiltrometer



Double ring Infiltrometer

Ring Infiltrometer Data Analysis

Sl. No. (1)	Clock Time (2)	Time Elapsed (min) (3)	Time Interval (min) (4)	Actual Reading (cm) (5)	Drop in Water Level (cm) (6)	Remarks (7)	Cumulative Infiltration (mm) (8)	Infiltration Rate (mm/h) (9)=(6)/(4)
1	8:40:00 AM	0	0	28	0		0	0
2	8:45:00 AM	5	5	27.07	0.93		9.3	111.6
3	8:50:00 AM	10	5	26.6	0.47		14	56.4
4	8:55:00 AM	15	5	26.25	0.35		17.5	42
5	9:00:00 AM	20	5	27.67	0.33	Refilling	20.8	39.6
6	9:05:00 AM	25	5	27.35	0.32		24	38.4
7	9:10:00 AM	30	5	27.07	0.28		26.8	33.6
8	9:20:00 AM	40	10	26.57	0.5		31.8	30
9	9:30:00 AM	50	10	26.14	0.43		36.1	25.8
10	9:40:00 AM	60	10	27.7	0.3	Refilling	39.1	18
11	9:55:00 AM	75	15	27.2	0.5		44.1	20
12	10:10:00 AM	90	15	26.71	0.49		49	19.6
13	10:25:00 AM	105	15	27.68	0.32	Refilling	52.2	12.8
14	10:40:00 AM	120	15	27.38	0.3		55.2	12
15	11:10:00 AM	150	30	26.59	0.79		63.1	15.8
16	11:40:00 AM	180	30	27.47	0.53	Refilling	68.4	10.6
17	12:10:00 PM	210	30	26.8	0.67		75.1	13.4
18	12:40:00 PM	240	30	27.4	0.6	Refilling	81.1	12
19	1:40:00 PM	300	60	26.35	1.05		91.6	10.5
20	2:40:00 PM	360	60	27	1	Refilling	101.6	10
21	3:40:00 PM	420	60	26	1		111.6	10
22	4:40:00 PM	480	60	26.78	1.22	Refilling	123.8	12.2
23	5:40:00 PM	540	60	27	1	Refilling	133.8	10

Ring Infiltrometer Curve

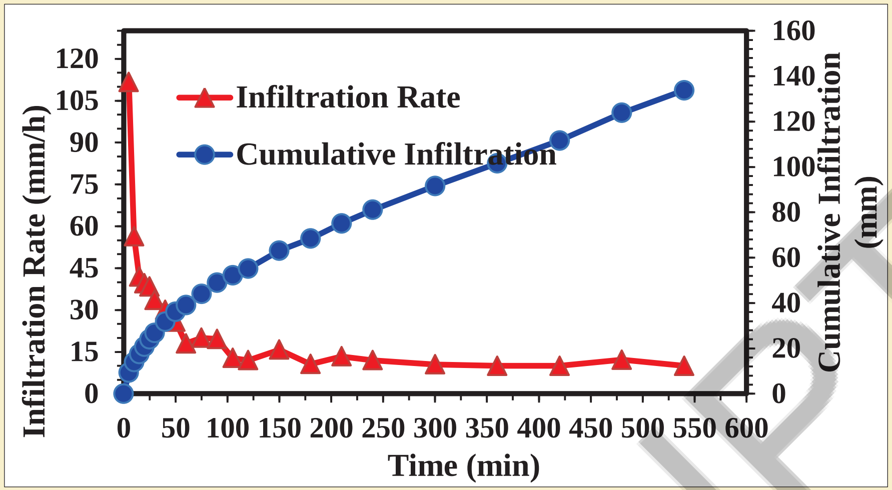


Fig: Infiltration characteristic curve

Table 2: Typical steady infiltration rates for general soil textural groups

Soil type	Steady infiltration rate (cm/h)
Sandy soil	>2.0
Sandy loam	1.0–2.0
Loam	0.5–1.0
Silt loam	0.5–0.8
Clayey soil	0.1–0.5

- Basic Infiltration Rate is 10.7 mm/h

Estimating Infiltration

Table 3: Selected infiltration estimation models

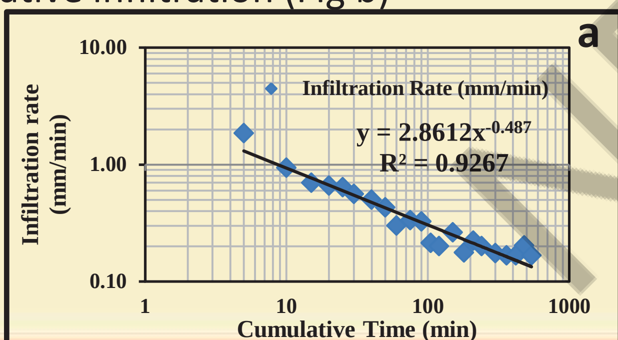
Method name	Equation	Terminology
Green and Ampt	$f = K + \frac{\eta S_c K}{F}$	f = Infiltration rate, K = hydraulic conductivity of the wetted zone, S_c= capillary suction at the wetting front, η = porosity, F = Cumulative Infiltration
Philip Two-Term Model	$F = St^{0.5} + At$ $f = \frac{1}{2}St^{-0.5} + A$	S = Sorptivity, A = parameter depending upon soil properties, t = time
Kostiakov's equation	$f = a \times t^{-b}$ $F = \frac{a}{1-b}\, t^{1-b}$	a (>0) and b (0 to 1) = empirical constants depends on the soil and soil conditions including initial moisture content
Horton Model	$f = f_c + (f_0 - f_c)\exp(-kt)$	f_c= a final or equilibrium capacity, f_0 = initial infiltration capacity, t=time from beginning of storm, k = decay coefficient

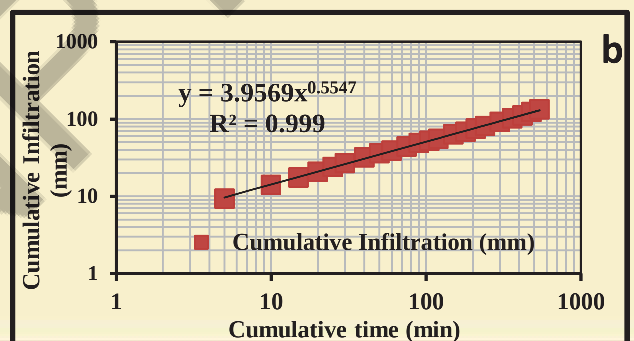
Kostiakov Infiltration Model

Example 6.1:

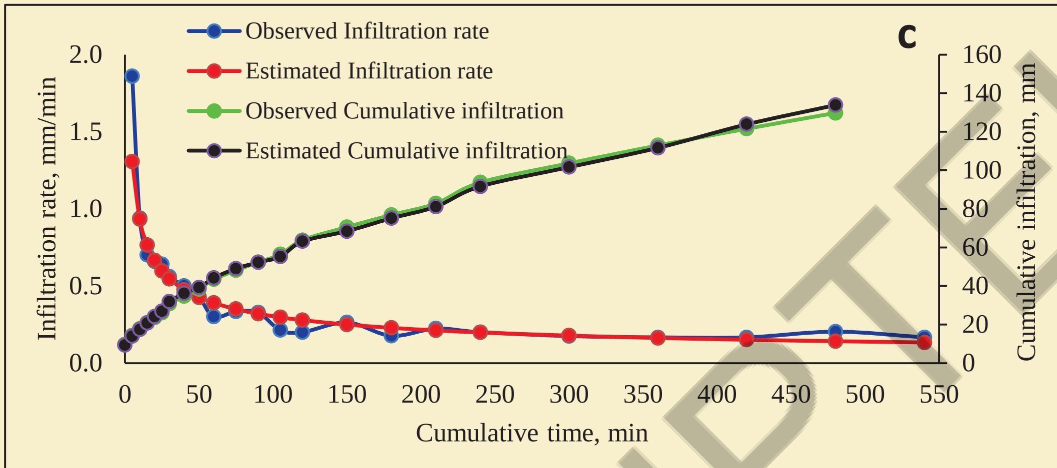
Determine the parameters for Kostiakov's equation from the data of table 1 obtained during a double ring infiltrometer test conducted in a plot at IIT Kharagpur and test the model for the data

Solution: A plot of infiltration rate vrs time is drawn on a log- log paper (Fig a) and similarly for cumulative infiltration (Fig b)





Kostiakov Infiltration model



Parameters	a	b
Infiltration Rate	2.864	0.487
Cumulative Infiltration	3.9569	0.5547

The parameters a and b are used for prediction of Infiltration rate and cumulative infiltration (Fig c)

Example 6.2:

Determine the Green-Ampt infiltration model parameters (K and φ) for the following ring infiltration data (Tables a and b) obtained at an experimental site of AgFE department, IIT Kharagpur.

Table a: Infiltration data for ponding depth of 6 cm

Time (min)	F (cm)	Observed, f (cm/min)
0	0	
10	0.2	0.020
20	0.4	0.020
30	0.6	0.020
40	0.7	0.018
50	0.8	0.016

Table b: Infiltration data for ponding depth of 12 cm

Time (min)	F (cm)	Observed, f (cm/min)
0	0	
5	0.2	0.040
15	0.4	0.027
30	0.6	0.020
45	0.8	0.018

Solution:

Green-Ampt infiltration model $$f = K + \frac{\Delta\theta\ (H + \varphi)\ K}{F}$$

Table: Infiltration data for ponding depth of 6 cm

Time (min)	F (cm)	Observed, f (cm/min)	1/F	Estimated, f (cm/min)
0	0			
10	0.2	0.020	5.000	0.021
20	0.4	0.020	2.500	0.019
30	0.6	0.020	1.667	0.018
40	0.7	0.018	1.429	0.018
50	0.8	0.016	1.250	0.018

Table: Infiltration data for ponding depth of 12 cm

Time (min)	F (cm)	Observed, f (cm/min)	1/F	Estimated, f (cm/min)
0	0			
5	0.2	0.040	5.000	0.040
15	0.4	0.027	2.500	0.025
30	0.6	0.020	1.667	0.021
45	0.8	0.018	1.250	0.018

Green-Ampt Infiltration Parameters Estimation

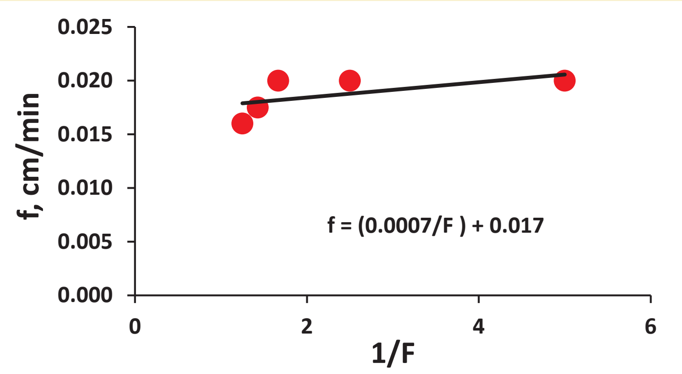


Fig: Scatter plot of f vs 1/F at 6 cm ponding depth

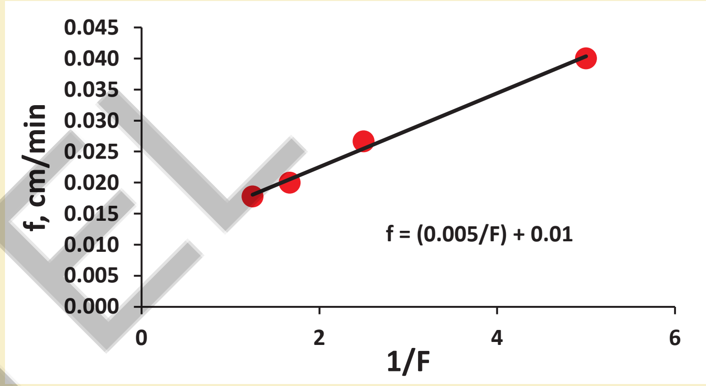


Fig: Scatter plot of f vs 1/F at 12 cm ponding depth

Table: Green-Ampt infiltration model parameters

Parameter	6 cm ponding depth	12 cm ponding depth
K	0.017	0.0107
$\Delta\theta(H+\varphi)K$	0.0007	0.0059

Green-Ampt Infiltration Parameters Estimation

For 6 cm ponding depth

$$f = 0.017 + \frac{0.0007}{F}$$

$$\Delta\theta(H + \varphi)K = 0.0007$$

$$\Delta\theta\ (6 + \varphi) = \frac{0.0007}{0.017}$$

$$\Delta\theta\ (6 + \varphi) = 0.041 \quad (1)$$

For 12 cm ponding depth

$$f = 0.0107 + \frac{0.0059}{F}$$

$$\Delta\theta(H + \varphi)K = 0.0059$$

$$\Delta\theta\ (12 + \varphi) = \frac{0.0059}{0.0107}$$

$$\Delta\theta\ (12 + \varphi) = 0.55 \quad (2)$$

From Eqs. 1 and 2,

φ = - 0.468 cm

Hence wetting front suction head is **-0.468 cm**.

Thank You!!

IIT KHARAGPUR

NPTEL ONLINE CERTIFICATION COURSES

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Irrigation and Drainage

Lecture No:07 Evapotranspiration

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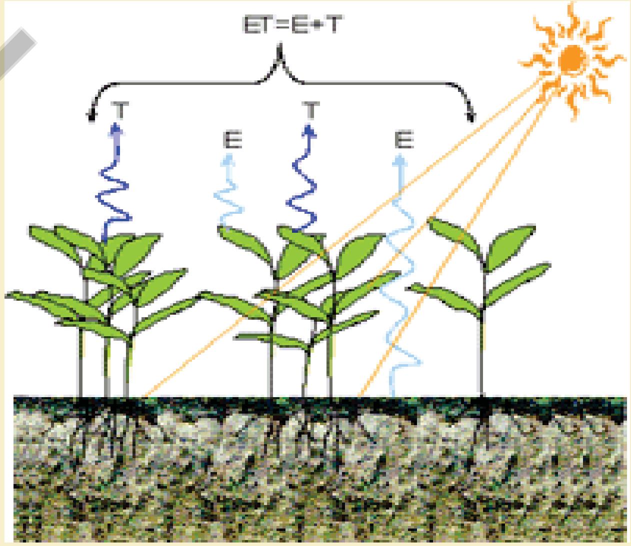
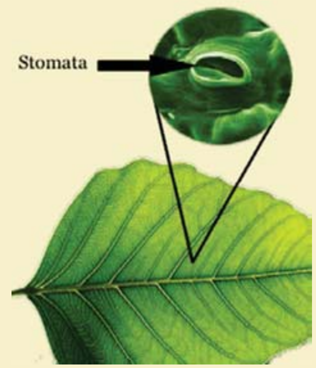
Evapotranspiration (ET)

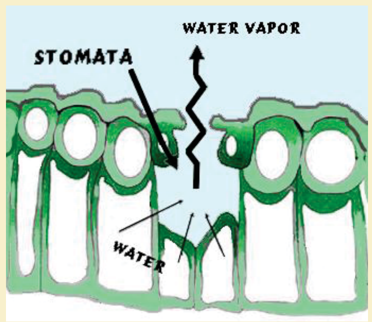
- ✓ In a crop field, evaporation from the soil and transpiration through plants occur simultaneously
- ✓ Evaporation from the soil surface of the crop field and the transpiration through the crop plant in a combined manner is evapotranspiration(ET)
- ✓ The knowledge of ET is an important practical consideration in the planning, designing, and operation of irrigation and water management systems



Evapotranspiration (ET)

- ✓ **Evaporation**
  - ✓ It is the change of water from liquid to vapor form
    - ✓ Evaporation occurs from all moist or wet surfaces, including soil, water, plant, and other surfaces
- ✓ **Transpiration**
  - ✓ It is evaporation from plant leaves through small openings in the leaves called stomata
- ✓ Both evaporation and transpiration occur in response to climate demand





Consumptive use (CU)

- ✓ Consumptive use includes water used in all of the plant process (rather than just transpiration) as well as direct evaporation from soil and plant surface
- ✓ CU exceeds ET by the amount of water used for digestion, photosynthesis, transport of minerals and photosynthates, structural support and growth
- ✓ The difference between ET and CU is usually 1%
  - ✓ Hence ET and CU are assumed to be equal

Evapotranspiration (ET)

Factors Influencing Evapotranspiration

- ✓ **Crop factor**
  - ✓ Ground cover, root density, plant height
- ✓ **Weather factor**
  - ✓ Solar radiation, temperature, humidity, wind speed, day length
- ✓ **Soil factor**
  - ✓ Soil moisture, salinity, presence of impermeable layer
- ✓ **Management factors**
  - ✓ Mulching, shading, weeding, irrigation and fertilizer application

Determining ET

- ✓ **Direct measurement**
  - ✓ Involves isolating a portion of the crop from its surroundings and determining ET by measurement

- ✓ **Indirect measurement**
  - ✓ Calculated from crop and climate data
  - ✓ Theoretical and empirical equations
  - ✓ Used for crops where measured ET data are not available

Direct measurement of ET

- ✓ **Field Measurement (Field water balance)**

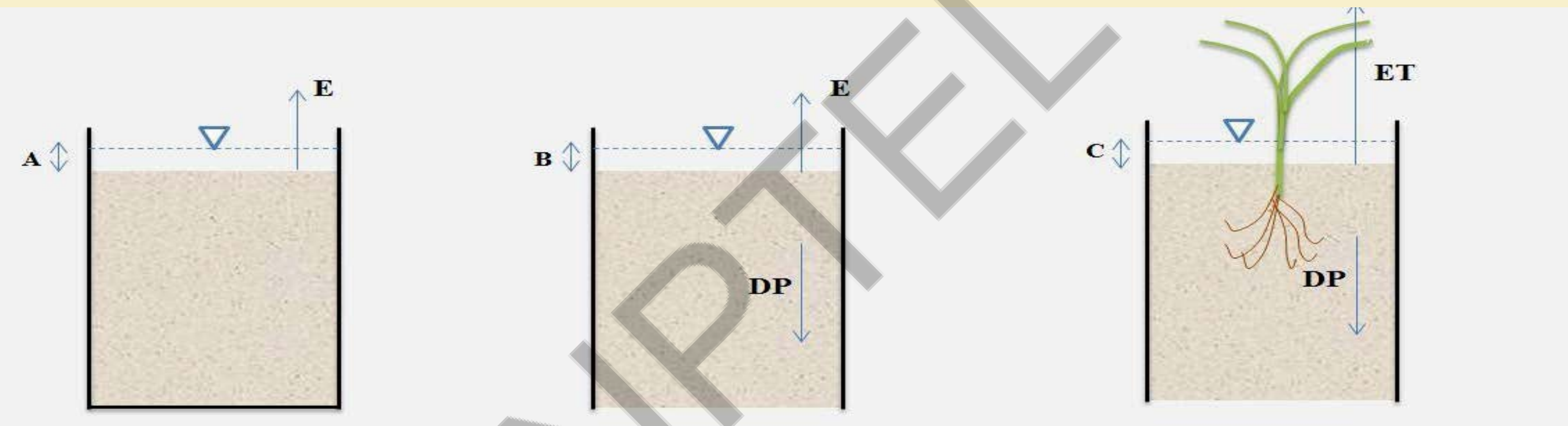
$$\mathrm{ET}_{\Delta T} = SM_1 - SM_2 + IR + R_e + U - D - \mathrm{SR},$$

$$SM_t = \sum_{i=1}^{n} (V_{wi} \times \rho_{si} \times z_i) \times 100,$$

ET $_{\Delta T}$ is the ET for the time period; ΔT (between time of SM1 and SM2 reading, mm); SM1, the soil water content of the field plot root zone at the beginning of the time period DT (mm); SM2, the soil water content of the field plot root zone at the end of the time period DT (mm); IR, the irrigation amount applied within the time period (mm); Re, the effective rainfall within this time period (mm); U, the upward flux or capillary rise within the time period (mm); D, the deep drainage or percolation within the period (mm); and SR, the surface runoff within the period (mm); V_{wi} is the percent moisture content in weight basis (w/w) for the layer i, ρ_{si} is the bulk density of soil of layer i, is the depth of soil layer i (m) and the density of soil-water is considered as 1 gm/cc or 1,000 kg/m^3 ; z is the depth of soil layer i (m); n is the total number of soil layers within the rootzone.

Direct measurement of ET

✓ **Measurement by Lysimeter**



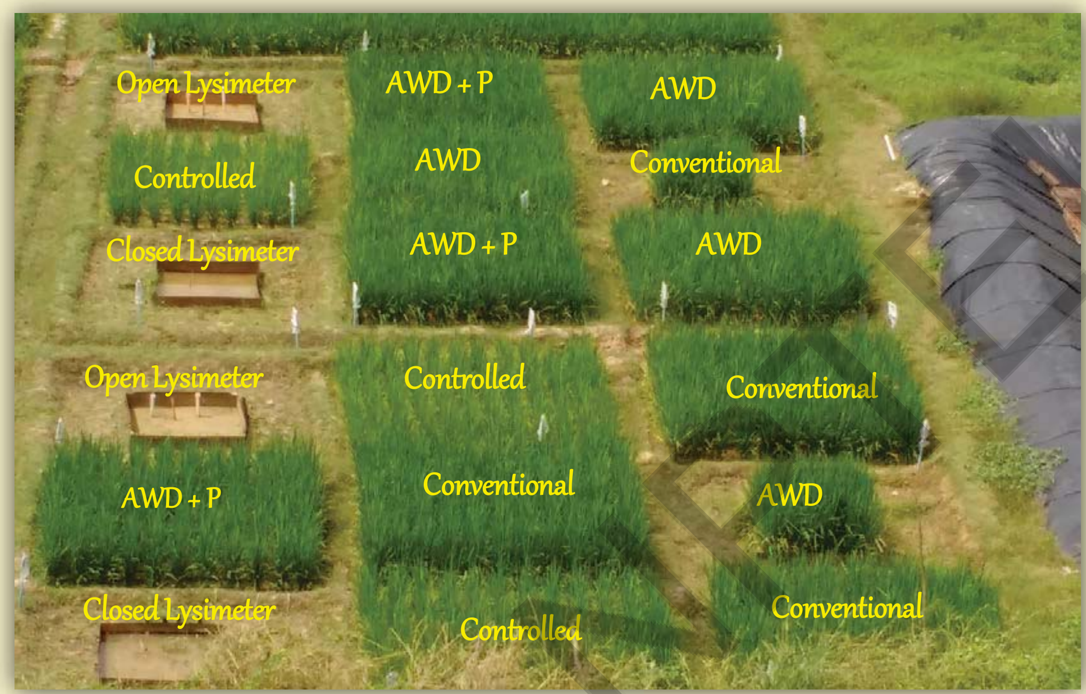
A. Bottom closed Lysimeter
(Evaporation)

B. Bottom Open Lysimeter
(Evaporation + Deep Percolation)

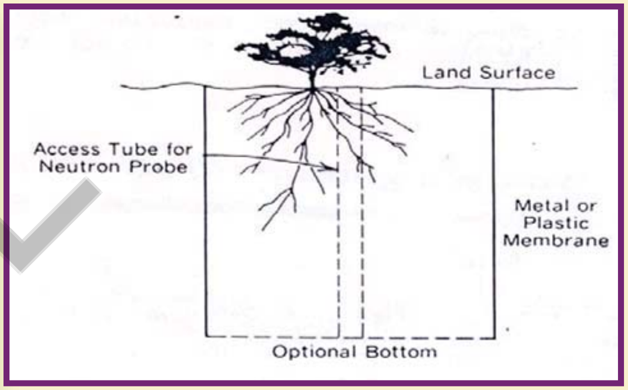
C. Bottom Open Lysimeter with crop
(Evapotranspiration + Deep Percolation)

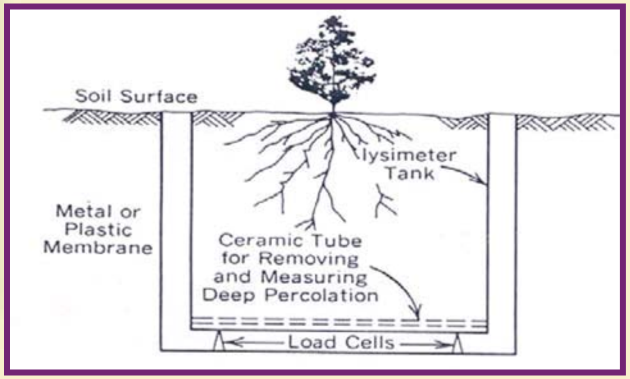
Evaporation= A; Deep percolation (DP)= B-A; Evapotranspiration (ET)= C- (B-A)

❑Measurement by Lysimeter



Non-weighing lysimeter study for paddy





ET: Terminologies

- ✓ **Potential Evapotranspiration (PET)**
  - ✓ Maximum rate at which water, if available, can be removed from soil and plant surfaces (under no-stress condition)
- ✓ **Actual Evapotranspiration (AET)**
  - ✓ The ET under existing atmospheric, soil and vegetation condition (under stress condition)
- ✓ **Reference crop evapotranspiration (ET_o)**
  - ✓ The rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water

Indirect measurement of ET

- ✓ Computing ET involves the following equation

$$ET_c = K_c \times ET_0$$

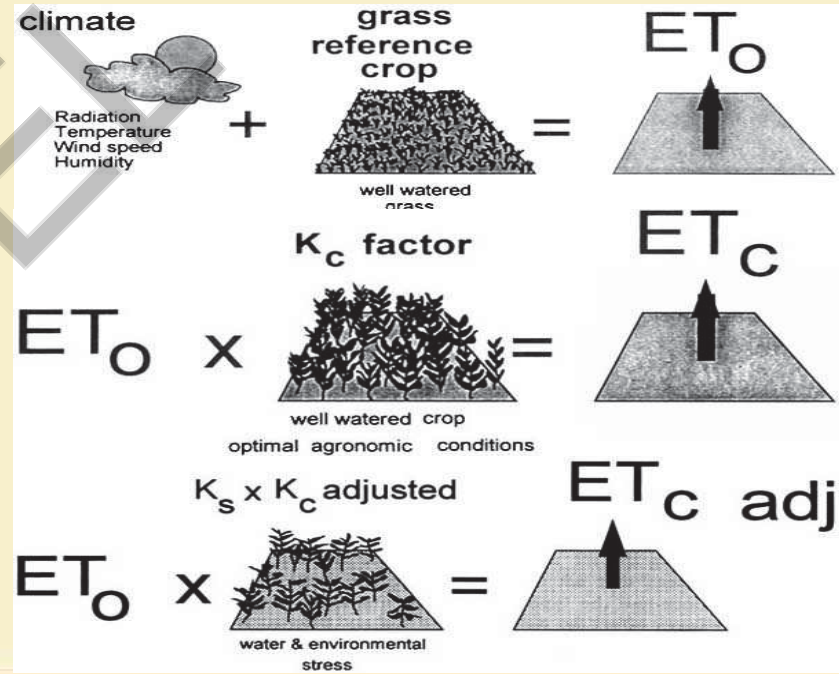
ET_c = Evapotranspiration for a specific crop (mm);

K_c = Crop coefficient

- ✓ Adjusting for soil moisture

$$ET_c = K_c \times K_s \times ET_0$$

K_s = Coefficient that depends upon available soil moisture



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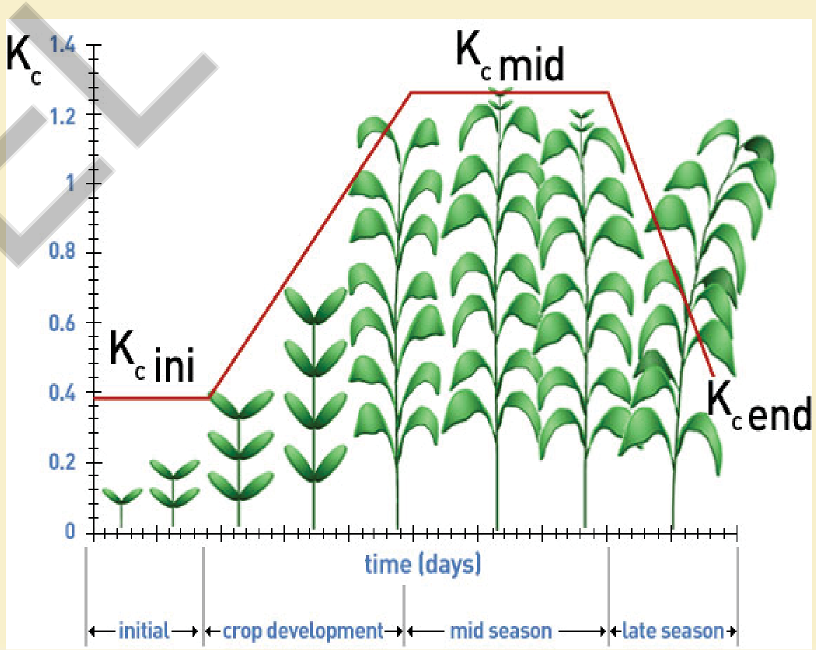
Indirect measurement of ET

Table : Single crop coefficients for grass reference crop and mean maximum plant heights for well managed no stressed condition in sub-humid regions (RH_{min} = 45% and u_2 = 2 ms^{-1}) (Source: Allen et. al, 1998)

Crop	Kc_ini	Kc_mid	Kc_end	Maximum crop height, h (m)
Bean, green	0.5	1.05	0.90	0.4
Cabbage	0.7	1.05	0.95	0.4
Cauliflower	0.7	1.05	0.95	0.4
Green Onion	0.7	1.00	1.00	0.3
Tomato	0.6	1.15	0.70 – 0.90	0.6
Cucumber	0.5	1.00	0.90	0.3
Potato	0.5	1.15	0.75	0.6
Groundnut	0.4	1.15	0.60	0.4
Lentil	0.4	1.10	0.30	0.5
Soybeans	0.4	1.15	0.50	0.5-1.0
Cotton	0.35	1.15-1.20	0.70-0.50	1.2-1.5
Sesame	0.35	1.10	0.25	1.0
Sunflower	0.35	1.0-1.15	0.35	2.0
Wheat	**0.3**	**1.15**	**0.25 – 0.40**	**1.0**
Small grains	0.3	1.00	0.30	1.5
Maize (grain)	0.3	1.20	0.60, 0.35*	2.0
Rice	1.05	1.20	0.90-0.60	1
Alfalfa	0.40	0.95	0.90	0.70
Sugarcane, ratoon	0.40	1.25	0.75	3
Banana, Ist yr	0.50	1.10	1.00	3
Grapes	0.30	0.85	0.45	2



Different ET Methods

S. No	CLASSI-FICATION	METHODS	REFERENCES
1.	Temparature	(1) Thornthwaite	Thornthwaite (1948); Thornthwaite and Mather(1955)
		(2) SCS Blaney-Criddle	USDA (1970)
		(3) FAO-24 Blaney-Criddle	Doorenbos and Pruitt (1977); Allen and Pruitt (1986)
		(4) Hargreaves	Hargreaves et al. (1985); Hargreaves and Samani(1985)
2.	Radiation	(1) Turc	Turc (1961); Jensen (1966b)
		(2) Jensen-Haise	Jensen and Haise (1963); Jensen et al. (1971)
		(3) Priestly-Taylor	Priestly and Taylor (1972)
		(4) FAO-24 Radiation	Doorenbos and Pruitt (1977)
3.	Evaporation	(1) Christiansen Pan	Christiansen (1968); Christiansen and Hargreaves(1969)
		(2) FAO-24 Pan	Doorenbos and Pruitt (1977)
		(3) Pan Evaporation	-----------

Different ET Methods

S. No	CLASSI-FICATION	METHODS	REFERENCES
4.	Combination	(1) Penman VPD#1	Penman (1948, 1963)
		(2) Businger-van Bavel	Businger (1956); Van Bavel (1966)
		(3) Penman VPD #3	Penman (1963)
		(4) Penman-Monteith	Monteith (1965); Allen (1986); Allen et al. (1989)
		(5) 1972 Kimberly-Penman	Wright and Jensen (1972)
		(6) FAO-24 Penman (c =1)	Doorenbos and Pruitt (1975, 1977)
		(7) FAO-24 Corrected Penman	Doorenbos and Pruitt (1977)
		(8) FAO-PPP-17 Penman	Frere and Popov (1979)
		(9) 1982 Kimberly-Penman	Wright (1982)
		(10) CIMIS Penman	Snyder & Pruit (1992)
		(11) FAO-56 Penman Monteith	FAO-56

a) FAO-56 Penman-Monteith

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.3u_2)}$$

ET_o = Reference evapotranspiration [mm day^{-1}]; R_n = Net radiation at the crop surface [MJ m^{-2} day^{-1}]; G = Soil heat flux density [MJ m^{-2} day^{-1}]; T = Mean daily air temperature at 2 m height [°C]; u_2 = Wind speed at 2 m height [m s^{-1}]; e_s = Saturation vapour pressure [kPa]; e_a = Actual vapour pressure [kPa]; e_s - e_a = Saturation vapour pressure deficit [kPa]; Δ = Slope vapour pressure curve [kPa °C^{-1}]; γ = Psychometric constant [kPa °C^{-1}].

b) Hargreaves and Samani Method

$$\mathrm{ET}_0 = (0.0023R_\mathrm{a})(T_\mathrm{mean} + 17.8)TD^{0.5}$$

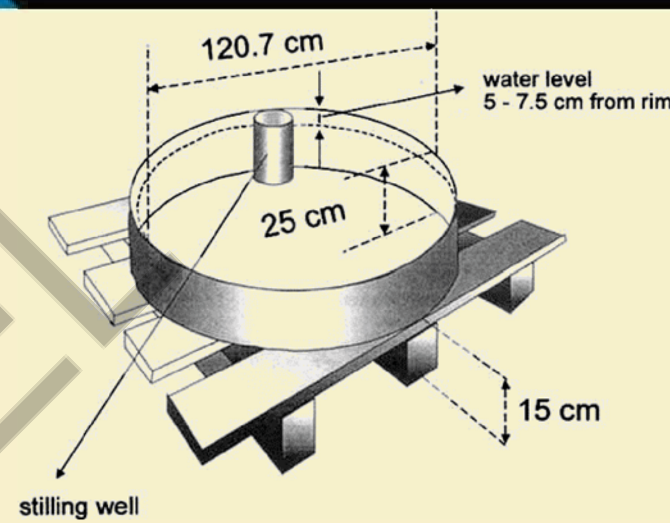
where Ra is extra-terrestrial radiation in equivalent mm of water evaporation for the period, Tmean is the mean temperature in C, and TD is the difference between maximum and minimum temperatures.

c) Blaney Criddle Method

PET = $p\,(0.46\,Tmean + 8.188)$

PET is the potential evapotranspiration [mm day−1] (monthly); T_{mean} is the mean daily temperature [°C] $(T_{max} + T_{min})/2$

p is the mean daily percentage of annual daytime hours



d) Pan-Evaporation Method

✓ **Using Class A Pan**

$$ET_0 = K_p\, E_{pan}$$

where E_{pan} is the pan evaporation in mm/day, and K_p is the adjustment factor (= 0.7).

Example 7.1

A class A Pan was setup adjacent to a lake. The depth of water in the Pan at beginning was 195 mm. In that week, a rainfall of 45 mm was observed and 15 mm of water was removed from the Pan to keep the water level in the specified depth. If the depth of water at the end of the week was 190 mm, calculate the Pan evaporation using a suitable Pan coefficient and estimate lake evaporation of the week.

Solution:

Total water present in the Pan = 195 + 45 – 15 = 225 mm

Evaporation from the Pan = 225 – 190 = 35 mm

Assume a Pan coefficient of 0.7

Evaporation from Lake= 0.7 x 35 = 24.5 mm

Estimation of Crop Coefficient (K_c)

a) Single Crop Coefficient

The K_c includes the effect of evaporation from both plant and soil surfaces

$$K_c = \frac{ET_{crop}}{ET_0}$$

b) Dual Crop Coefficient

The K_c is splitted into two coefficients: one is for crop transpiration, termed as basal crop coefficient (K_{cb}), and the other is for soil evaporation (K_e):

$$K_c = K_{cb} + K_e.$$

Example 7.2

Compute the ET value in the month of July at a place 28°N latitude if the long term data of temperature for the month of July is 30.5°C. The value of consumptive use coefficent for the month may be taken as 0.6. compute the value separately, using Blaney-Criddle method.

Solution:

$$\text{PET} = p\,(0.46\,T_{mean} + 8.188)$$

Where,

PET is the potential evapotranspiration [mm day^{-1}] (monthly)

Tmean is the mean daily temperature [°C] given as Tmean $= (T_{max} + T_{min})/2$

p is the mean daily percentage of annual daytime hours

$$\text{PET} = 9.58(0.46 \times 30.5 + 8.188)$$
$$= 9.58 \times 22.218$$
$$= 212.71\ mm\ day^{-1}$$
$$Consumptive\ use = 0.6 \times 212.71$$
$$= 127.62$$

Thank You!!

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Irrigation and Drainage

Lecture No:08 Crop Water Requirement

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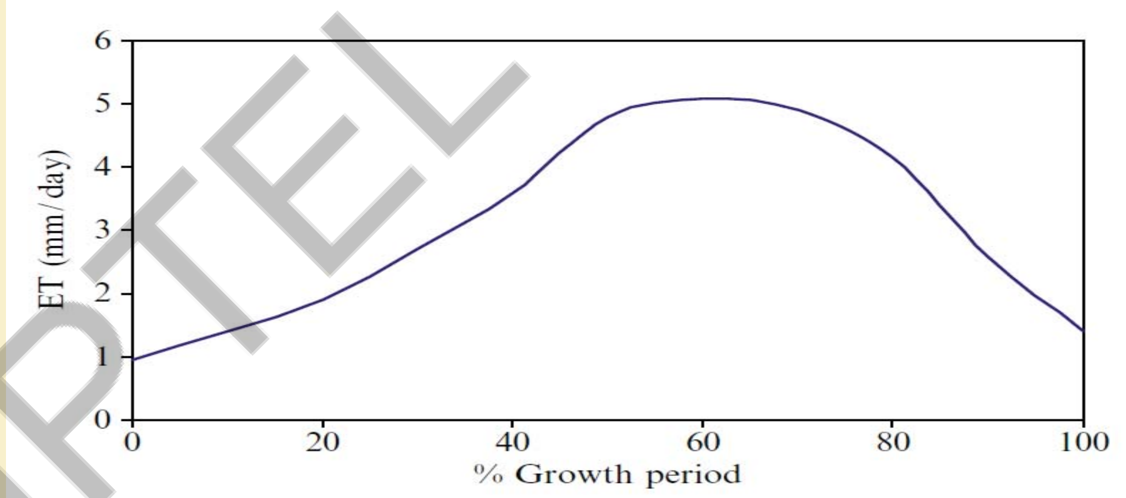
Crop Water Requirement

- ✓ The amount of water needed to compensate the evapotranspiration (ET) loss from the crop field is termed as crop water requirement (CWR)
- ✓ CWR represents the ET under ideal crop growth condition
- ✓ CWR varies with time and space, as the ET demand varies with local climate and crop condition

Factors Affecting CWR

- ✓ **Crop Factors**
  - ✓ Type of crop
  - ✓ Cultivar/species
  - ✓ Growing stage
  - ✓ Leaf area
  - ✓ Root length, root density

- ✓ **Weather Factors**
  - ✓ Temperature
  - ✓ Radiation
  - ✓ Humidity
  - ✓ Wind speed



Typical pattern of ET demand during the growth period of cereal crop

Calculating CWR

Crop water requirement for a given crop, *i*, for the whole growing season:

$$CWR_i = ET_i = \sum_{t=0}^{m} (ET_{0t} \times K_{ct}),$$

- ✓ CWR_i = crop water requirement for the growing period (mm)
- ✓ ET_i = crop evapotranspiration for the growing period (mm)
- ✓ t is the time interval (days)
- ✓ m = days to physiological maturity from sowing or transplanting (total effective crop growth period)
- ✓ ET_{0t} = reference crop evapotranspiration of the location concern for the day t (mm), and
- ✓ K_{ct} = crop coefficient for the time t day

CWR vs IWR

- ✓ CWR and irrigation water requirement (IWR) can be best described as
  - ✓ CWR = *f* (weather, crop)
  - ✓ IWR = *f* (weather, crop, soil, rainfall, irrigation method, depth to water-table)
  - ✓ CWR < IWR

The typical CWR values of major crops

Crop	Water requirement (cm)	Crop	Water requirement (cm)
Alfalfa	150–160	Wheat (winter)	30–40
Bean	30–40	Wheat (spring)	40–55
Corn	50–70	Rice	110–160
Cotton	70–100	Sorghum /millet	40–50
Lentil	15–25	Soybean	30–50
Maize	40–60	Sugarcane	150–200
Groundnut	30–40	Sugar beet	75–90
Onion	30–40	Sunflower	40–55

IWR

- ✓ Net irrigation water requirement is the quantity of water required for successful crop growth
- ✓ **Weather, crop**, and soil factors influence in determining IWR
- ✓ **Soil factors**
  - ✓ Soil type (storage and release properties of water)
  - ✓ Organic matter content (control its storage and release properties
  - ✓ Soil Texture (seepage and percolation rate : sandy soil > silt > clay soil)
- ✓ **Other factors :**
  - ✓ Effective rainfall
  - ✓ Water required for leaching of salt
  - ✓ Water required for land preparation or land soaking

Components of TIWR

- **Total irrigation water requirement (TIWR)** is the amount of water required during the cropping period for successful crop cultivation
  - Water for land preparation
  - Water for land soaking
  - Crop water demand (includes ET and seepage and percolation)
  - Water for leaching requirement (specially in saline soil)
  - Water for special use such as crop cooling, freeze protection

Components of TIWR

a) Water for land soaking

$$WR_{LS} = \frac{W_s + C \times ET_0 + P - R_e}{E_a}$$

- ✓ WR_{LS} = irrigation water required for land soaking (mm)
- ✓ W_s= water required to saturate the soil (mm)
- ✓ ET_0 = reference evapotranspiration during the time of soil saturation (mm)
- ✓ C = evaporation coefficient (= 0.9)
- ✓ P= deep percolation loss during the soil saturation (mm)
- ✓ R_e= effective rainfall during the period (mm)
- ✓ E_a = application efficiency

Components of TIWR

b) Water required for land preparation

$$\mathrm{WR}_{\mathrm{LP}} = \frac{D_{\mathrm{s}} + C \times \mathrm{ET}_0 + P - R_{\mathrm{e}}}{E_{\mathrm{a}}}$$

D_s = water depth for submergence (mm)

c) Water required for leaching

$$\mathrm{LR} = \mathrm{EC_w}/(5\mathrm{EC_t} - \mathrm{EC_w})$$

EC_w = salinity of the applied irrigation water, and
EC_t = threshold salinity (average soil salinity tolerated by the crop)

Components of TIWR

d) Total depth of water for a season to meet irrigation and leaching requirement

$$AW = ET/(1 - LR)$$

AW= depth of applied water (cm/season)

ET = total seasonal demand (cm/season)

LR =leaching requirement (fraction)

Components of TIWR

e) Irrigation Water Requirement for Normal Growth Period (IWR_{nci})

$$IWR_{nc} = \sum [(K_c \times ET_0) + P - (R_e + GW_c)]$$

IWR_{nc} = irrigation requirement for normal growth period (from sowing/transplanting to last watering, mm)

GW_c = groundwater contribution during the period (mm)

P = deep percolation loss during the period concerned (mm)

Components of TIWR

f) Total Net Irrigation Water Requirement (NIWR)

$$NIWR = WR_{LS} + WR_{LP} + WR_{nc} + WR_{L}$$

NIWR = total net irrigation requirement for successful cultivation of a crop (mm)

WR_{LS}= depth of water required for land soaking (mm)

WR_{LP}= depth of water required for land preparation (mm)

WR_{nc} = depth of water required for crop ET demand (mm)

WR_{L} = depth of water required for leaching (mm)

Components of TIWR

g) Net Irrigation Water Requirement based on moisture deficit ($NIWR_m$)

$$\mathrm{NIWR_m} = \frac{\sum_{i=1}^{n} (\mathrm{FC}_i - \mathrm{SM}_i) \times d_i}{100(1 - \mathrm{LF})}$$

Where FC_i is the field capacity (water holding capacity) of soil of i layer, in percent volume, SM_i is the present soil moisture content, in percent volume, d is the depth of i layer, in cm, LF is the leaching fraction.

Components of TIWR

h) Gross Irrigation Water Requirement (GIWR)

Gross water requirement is the water required for irrigation considering field application loss and conveyance loss

$$\mathrm{GIWR} = \frac{\mathrm{NIWR}}{E_{\mathrm{a}} \times E_{\mathrm{c}}}$$

Ec = field conveyance efficiency

Ea = field application efficiency

Steps required for TIWR

1. Identify the climatic zone and/or agro-ecological zone of the project area
2. Select the appropriate crop/cropping pattern for the area
3. Collect long-term climatic data and the soil information
4. Calculate reference evapotranspiration for the crop period
5. Collect crop coefficient value from the literature or from similar crops/varieties, if available
6. Calculate crop evapotranspiration (ET_c) (i.e., crop water demand)
7. Calculate other special water requirement, if any (e.g., land preparation/soaking, leaching requirement for salt balance)
8. Determine total water requirement (net water requirement, NIR)
9. Estimate overall water conveyance efficiency (E_c) and water application efficiency (E_a)
10. Determine total irrigation water requirement (gross irrigation water requirement) by dividing the NIR by E_c and E_a.

Example 8.1

The following information is available for a land:

- Depth of water required to saturate 20 cm soil = 6 cm
- Daily reference evapotranspiration = 5 mm
- Time from water application to deplete field capacity = 6 h
- Deep percolation loss during soil saturation = 4 mm
- Rainfall during the period = 0

Determine the irrigation water requirement for land soaking

Solution

Irrigation water requirement for land soaking, IWR_{ls} =

$$(W_s + C \times ET_0 + P - R_e)/(E_a \times E_c)$$

Given:

W_s = 6 cm = 60 mm; P = 4 mm; R = 0; ET_0/day = 5 mm; ET_0/6 h = 2.5mm; E_a = 95%; E_c = 80%.

Assuming C=0.95 and substituting the above values in the equation, IWR_{ls} = 87.3 mm

Example 8.2

For winter wheat crop grown in spring, the following information is gathered for a particular growth phase:

Reference evapotranspiration for the growth phase = 30 mm,

Crop coefficient for that phase = 1.0,

Deep percolation for water application = 4 mm,

Groundwater contribution = 0.

Find:

(a) Net irrigation required

(b) Gross irrigation required, if application efficiency = 85%, and conveyance efficiency = 75%

Solution

Given:

ET_0=30mm; K_c=1.0; P=4mm; R_e=5mm; GW_c=0; E_a= 85%; E_C = 70%

a) Net Irrigation Required:

$WR_{nc} = (K_c \times ET_0) + P - (R_c + GW_c)$

Puttting the values, WR_{nc}= (1 x30) + 4- (5+0) = 29 mm

(b) Gross irrigation water required, TIWR = $WR_{nc}/(E_a \times E_c)$= 29/(0.85 x0.7) = 45.5 mm

Thank You!!

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Irrigation and Drainage

Lecture No:09 Irrigation Scheduling

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Irrigation Scheduling

The objective:

- ✓ To maximize yield, irrigation effectiveness /efficiency, and crop quality by applying the exact amount of water needed by the crop or to replenish the soil moisture to the desired level.

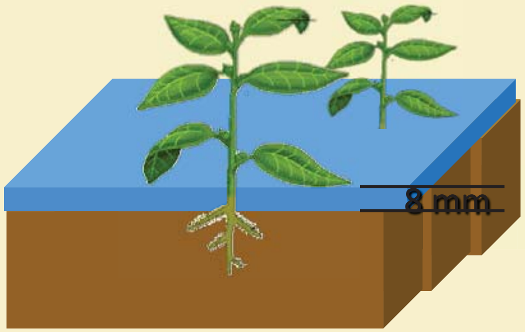
- ✓ Three questions
  - ✓ When to Irrigate?
  - ✓ How much to irrigate?
  - ✓ How to irrigate?

Irrigation Scheduling to meet the goals

- ✓ Maximizing yield per unit area (Land-limiting condition)
- ✓ Maximizing yield per unit water applied (Water-limiting condition)
- ✓ Maximum yield per unit energy (Abundant water and land condition)
- ✓ Maximizing net profit
    - ✓ Important for farming enterprise
    - ✓ Not popular for day-to-day scheduling

Irrigation Scheduling

- ✓ If irrigation water need of a crop is 8 mm/day
  - ✓ Every day crop needs a water layer of 8 mm over the whole cropped area
  - ✓ Longer irrigation interval
    - ✓ Save labour & time
      - ✓ 24 mm every 3 day
      - ✓ 40 mm every 5 days
  - ✓ In principle, the irrigation amount in one application is the amount of water used by plants since the previous irrigation



Irrigation Scheduling

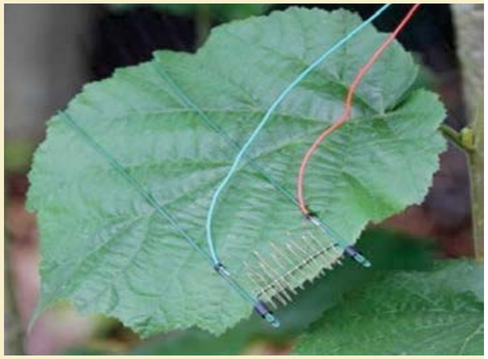
Proper irrigation scheduling minimizes the following:

- ✓ Yield reduction
- ✓ Wastage of water (deep percolation & runoff) & energy
- ✓ Irrigation cost
- ✓ Excess groundwater withdrawal (aquifer exploitation)
- ✓ Pollution of surface and groundwater by agro-chemicals
- ✓ Drainage requirement
- ✓ Water-logging and salinity hazard
- ✓ Environmental and health hazard (disease)

Indicators of Irrigation Need

Commonly used indicators or symptoms are as follows:

- ✓ Plant leaf appearance
- ✓ Soil moisture status
- ✓ Soil-water potential
- ✓ Leaf-water potential
- ✓ Leaf temperature



Irrigation Scheduling Methods

- ✓ Climatic approach/ET based
- ✓ Pan evaporation
- ✓ **Soil moisture basis**
- ✓ Deficit irrigation concept
- ✓ Soil-water potential
- ✓ Leaf water potential
- ✓ Stress-day index
- ✓ Irrigation calendar
- ✓ **Check-book or soil-moisture balance approach**
- ✓ Modeling approach
- ✓ Real-time irrigation scheduling

Irrigation Scheduling Methods

a) Climatic approach/ET based

- ✓ ET is calculated based on the historical weather data for a crop period in advance (or current weather condition)
- ✓ Irrigation is applied with equal to ET amount, or a fraction or multiples of ET
- ✓ Amount of water equivalent to 0.5 of the peak ET rate gave the highest yield (Fischbach and Somerhalde, 1974)
- ✓ A number of weather parameters are needed to determine ET value
- ✓ Data may be difficult to obtain, costly and existence of uncertainty

Irrigation Scheduling Methods

b) Pan evaporation

- ✓ Open pan evaporation may be used to estimate evapotranspiration
  - ✓ Irrigation is applied simply equal to the cumulative pan evaporation (**CPE**) at several days interval (e.g 3, 5, 7, 10, or 15 days)
- ✓ Irrigation is also applied according to the pre-determined ratio of applied irrigation amount (**IW**) to CPE
- ✓ This concept is simple, farmer friendly and needs no technical hand and no sophisticated instrument

Example 9.1:

Pan evaporation data recorded at a certain location over a period of one week are 4.0, 4.3, 4.6, 4.9, 5.12, 5.18, and 6.21 mm. If irrigation scheduling based on ratio of irrigation water (IW) to cumulative pan evaporation (CPE) is practiced, the depth of irrigation at an interval of a week for IW/CPE = 0.9 is **(GATE 2013)**

Solution:

Pan evaporation data at a certain location = 4.0, 4.3, 4.6, 4.9, 5.12, 5.18, and 6.21 mm

cumulative pan evaporation = 34.31 mm

$$\frac{\text{irrigation water (IW)}}{\text{cumulative pan evaporation (CPE)}} = 0.9$$

$$\frac{\text{irrigation water (IW)}}{34.31} = 0.9$$

$$\text{irrigation water (IW)} = 0.9 \times 34.31 = 30.88\ mm$$ **(Ans.)**

Irrigation Scheduling Methods

c) Stress day index

$$SDI = \sum_{i=1}^{n} SD_i \times CS_i$$

- ✓ **The stress day factor (SD)** is a measure of the degree and duration of plant water deficit
- ✓ **The crop susceptibility factor (CS)** indicates the plant susceptibility to a given water deficit and depends on the species and stage of development of the given crop
- ✓ **n** is the number of growth periods considered

Irrigation Scheduling Methods

- ✓ **The stress day factor (SD)**

$$SD = \frac{E}{E_d}$$

  - ✓ E is the transpiration rate, E_d is the potential evaporation

- ✓ **The crop susceptibility factor (CS):**
  - ✓ plot the crop yield (abscissa) vs. cumulative SD for a given growth period (ordinate).
  - ✓ the value of CS for each period is the slope of the plot related to that period

$$CS_i = \frac{SD}{Yield}$$

Irrigation Scheduling Methods

d) Soil moisture balance/Checkbook method

Field ID		Crop		Emergence date
Growth stage	Days after emergence	Effective rooting depth (mm)	Water-holding capacity in root zone (mm)	Total water within root zone at present soil moisture that can be allowed to deplete at this stage (mm)
Stage 1				
....				
Stage n				

Days after emergence	Date	Total water within root zone (mm)	Crop water use (mm)	Rainfall (mm)	Irrigation applied (mm)	Resultant moisture (mm)
(1)	(2)	(3)	(4)	(5)	(6)	(7) = (3)–(4) + (5) + (6)
1						
:						

Determination of Irrigation Schedule

e) Book Keeping method

- ✓ Moisture status of the soil is calculated at various times using the **estimated values of evapotranspiration**
- ✓ Crop is irrigated when estimated soil moisture attains a **predetermined value**
- ✓ **EXAMPLE:** A crop has 200 mm of available water in the root zone at field capacity and it has to be irrigated at deficit of 100 mm

Date	Age of Crop (days)	Estimated ET (mm/day)	Accumulated deficit (mm)
1	20	4	4
2	21	6	10
3	22	7	17
4	23	5	22
…	…	…	…
15	34	4	100 (to be irrigated)

- ✓ If the average values of ET are considered

  The estimate of irrigation interval (I): $$I = \frac{(S_{FC} - S_I)D}{ET}$$

  S_{FC} and S_I are soil moisture content (volume basis) at field capacity and at the permissible depletion; D is root zone depth.

- ✓ Method is similar to the popular IW/CPE ratio

  Here IW is fixed, say 6 cm; IW/CPE ratio is fixed , say 0.8

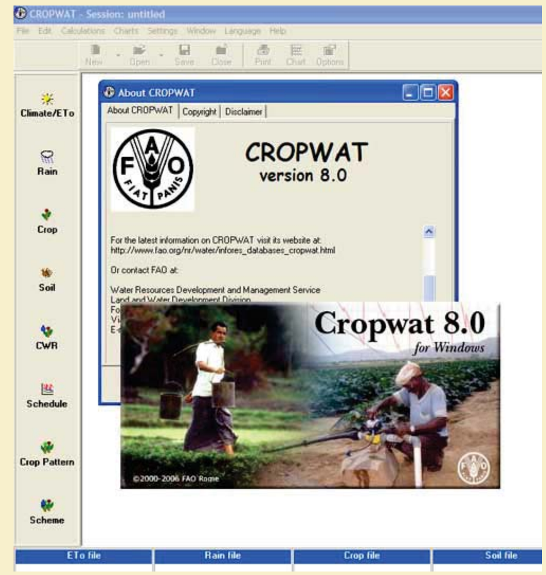
  Then, CPE =7.5

  Irrigate when CPE is 7.5 cm

Irrigation Scheduling Methods

f) Modeling Approach

- ✓ **FAO CROPWATT 8.0**
  - ✓ Assessing water demand and irrigation scheduling
- ✓ **CROSOWAT** (Joshi et al. 1995)
  - ✓ Numerical model
  - ✓ Estimating irrigation water requirement in humid basins under various management options
- ✓ **IRRI ORYZA 2000**
  - ✓ Irrigation management in rice crop



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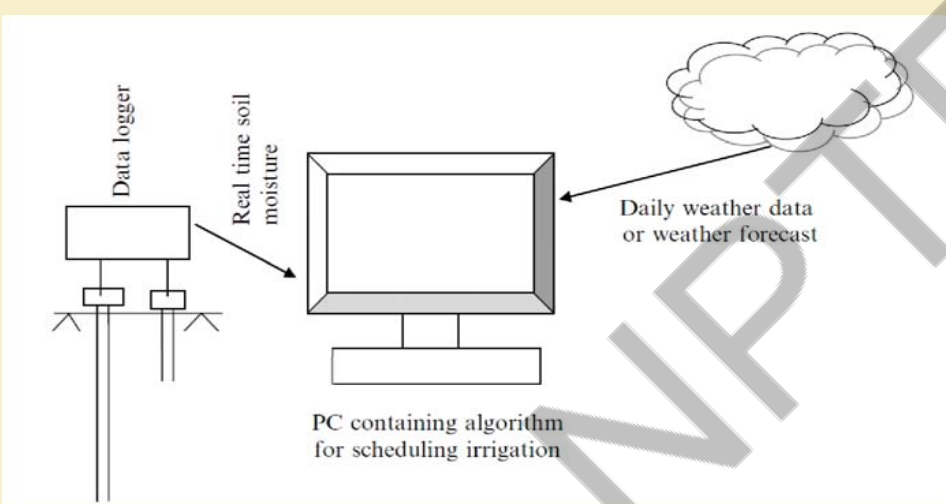
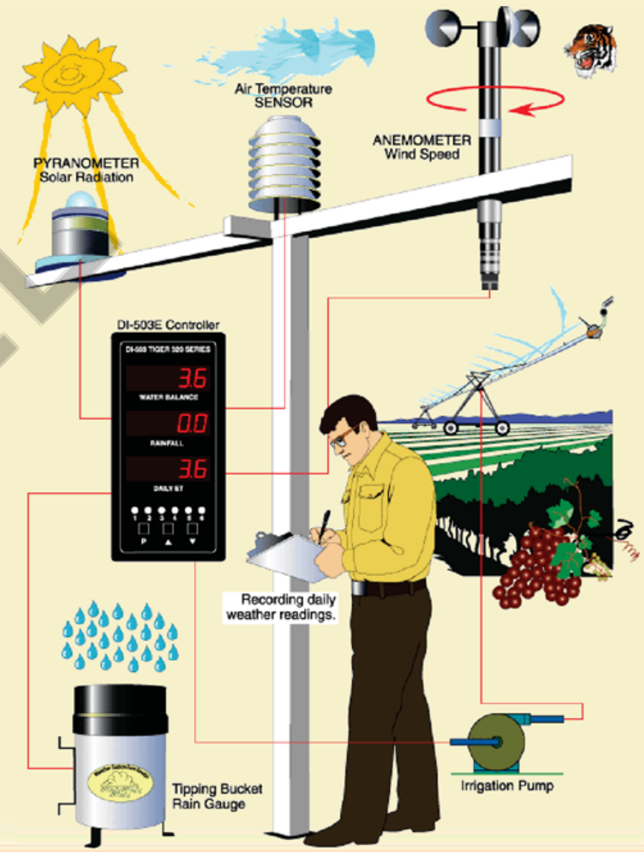
Irrigation Scheduling Methods

g) Real-Time Irrigation Scheduling





Scheduling Strategies

- ✓ **Full Irrigation**
  - ✓ Entire irrigation
  - ✓ Maximum production

- ✓ **Deficit Irrigation**
  - ✓ Allowing planned water stress
  - ✓ Partially supplying the irrigation requirement
  - ✓ When irrigation system limits water availability
  - ✓ Adequate water during critical stage

When to Irrigate - General Approaches

- ✓ Plant indicators
- ✓ Soil indicators
- ✓ Water budget technique

a) Plant indicators

- ✓ Appearance and growth
- ✓ Leaf temperature
- ✓ Leaf water potential

When to Irrigate - General Approaches

b) Soil indicators

- ✓ Determining the current water content of the soil
  - ✓ Appearance and feel
  - ✓ Gravimetric sampling
  - ✓ Tensiometers
  - ✓ Porous blocks
  - ✓ Neutron scattering
- ✓ Comparing it to a predetermined minimum water content (such as θ_c)
- ✓ Irrigate to maintain soil water contents above the minimum level

✓ Appearance and feel

- ✓ Take field samples and feel them by hand
- ✓ Advantages: low cost; Multiple locations
- ✓ Disadvantages: experience required; Not highly accurate

✓ Gravimetric

- ✓ Measures mass water content
- ✓ Take field samples →weigh → oven dry → weigh
  - ✓ Advantages: accurate; Multiple locations
  - ✓ Disadvantages: Labor; Time delay

c) Water budget technique

- ✓ Similar to soil indicator methods
- ✓ Instead of measuring soil water content, it is computed using

$$\theta_i = \theta_{i-1} - 100\left(\frac{ET - P_e}{D_{rz}}\right)$$

Where

θ_i, θ_{i-1} = the soil water content in percent by volume at the end of day i and day i-1, respectively.

D_{rz} = depth of root zone (cm, in)

ET = evapotranspiration (cm, in)

P_e = effective precipitation (cm, in)

Different methods of irrigation scheduling.

Method	Measured parameter	Equipment needed	Irrigation criterion	Advantages	Disadvantages
Hand feel and appearance of soil.	Soil moisture content by feel.	Hand probe	Soil moisture content.	Easy to use; simple; can improve accuracy with experience.	Low accuracies; field work involved to take samples.
Gravimetric soil moisture sample.	Soil moisture content by taking samples.	Auger, caps, oven	Soil moisture content.	High accuracy.	Labor intensive including field work; time gap between sampling and results.
Tensiometers.	Soil moisture tension.	Tensiometers including vacuum gauge.	Soil moisture tension.	Good accuracy; instantaneous reading of soil moisture tension.	Labor to read; needs maintenance; breaks at tensions above 0.7 atm.
Electrical resistance blocks.	Electric resistance of soil moisture.	Resistance blocks AC bridge (meter).	Soil moisture tension.	Instantaneous reading; works over larger range of tensions; can be used for remote reading.	Affected by soil salinity; not sensitive at low tensions; needs some maintenance and field reading.
Water budget approach.	Climatic parameters: temperature, radiation, wind, humidity and expected rainfall, depending on model used to predict ET.	Weather station or available weather information.	Estimation of moisture content.	No field work required; flexible; can forecast irrigation needs in the future; with same equipment can schedule many fields.	Needs calibration and periodic adjustments, since it is only an estimate; calculations cumbersome without computer.
Modified atmometer	Reference ET.	Atmometer gauge.	Estimate of moisture content.	Easy to use, directreading of reference ET.	Needs calibration; it is only an estimation.

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Irrigation and Drainage

Lecture No:10 Tutorial W2

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Example W2.1:

Water –budget technique of determining when to irrigate

Given

Daily ET and P_e in the following table

D_{rz} = 24 inches

Soil water content on the morning of July 1 is 23% by volume; θ_c = 14%

Required

Date of next irrigation

Date (July)	ET, in	$P_{e,}$ in
1	0.33	0
2	0.32	0.05
3	0.26	0
4	0.29	0
5	0.30	0
6	0.33	0
7	0.23	0.10
8	0.30	0

Solution:

Sample calculation (for day 1) $\theta_i = \theta_{i-1} - 100\left(\frac{ET - P_e}{D_{rz}}\right)$

$$\theta_i = 23 - 100\left(\frac{0.33 - 0}{24}\right) = 21.63\,\%$$

Conclusion: Irrigate on the morning of July 8

Amount to apply per irrigation $I = \frac{D_{rz}(fc - \theta)}{E_i}$

θ = percent water content of the soil prior to irrigation

$$I = \frac{24(26 - 15.05)}{80} = 3.29 \text{ in}$$

3.29 inches of water should be applied the morning of **July 8**

Date (July)	ET	P_e	θ^a (%)
1	0.33	0	21.63
2	0.32	0.05	20.51
3	0.26	0	19.43
4	0.29	0	18.22
5	0.30	0	16.97
6	0.33	0	15.59
7	0.23	0.10	15.05
8	0.30	0	13.80

Problem W2.2:

A 50 km long canal with an average width of 25 m is used for irrigation. Mean daily evaporation as measured from a Class A evaporation pan is 5 mm/d. Considering the pan coefficient as 0.80, the mean daily evaporation loss from this canal is **(GATE 2007)**

Solution:

Length of canal = 50 km = 50000m, Width = 25 m

Class A evaporation pan value = 5 mm/d, Pan coefficient = 0.80

Area of canal $= 50 \times 1000 \times 25$

$= 1250000$

Mean daily evaporation loss $= 1250000 \times 0.005 \times 0.8$

$= 6250 \times 0.8$

$= 5000$

$= 5.00 \times 10^3 \text{ m}^3/\text{d}$ **(Ans.)**

Example W2. 3:

The soil moisture at field capacity (FC) is 25% (w/w) and the moisture content at the time of irrigating is 15% (w/w). The apparent sp. gravity is 1.25 and the depth of soil to be wetted is 40 cm. How much water in ha-cm per hectare must be applied?

Solution:

$$FC = 25\% \ (by \ wt.)$$

$$Apparent \ sp. gravity = 1.25$$

$$\text{Moisture at FC by vol. basis} = 25 \times 1.25 = 31.25\%$$

Moisture content at irrigation time, $SM_a = 15\% \left(\frac{w}{w}\right) = 15 \times 1.25 = 18.75\%$ by vol.

Depth of soil to be wetted, $d = 40 \ cm$

Thus; water depth required to fill up to FC

$$= (FC - SM_a) \times \frac{d}{100} = (31.25 - 18.75) \times \frac{40}{100} = 5 \ cm$$

Water in required depth per hectare =1 ha × 5 cm = 5 ha-cm (Ans.)

Problem W2.4

Potato is irrigated with water having an electrical conductivity of 1.1 dsm^{-1}. The application efficiency is 70%. The seasonal crop evapotranspiration and seasonal rainfall are 350 mm and 125 mm, respectively. Average soil salinity tolerated by the crop is 1.6 dsm^{-1}. the seasonal irrigation requirement is. **(GATE 2006)**

Solution: $$Seasonal\ irrigation\ requirement = \frac{(ET - P_c)\ (1+LR)}{E_a}$$

$$Leaching\ reuirement\ (LR) = \frac{EC_w}{(5EC_t - EC_w)} = \frac{1.1}{(5 \times 1.6 - 1.1)} = 0.16$$

$$Seasonal\ irrigation\ requirement = \frac{(350 - 125)\ (1 + 0.16)}{0.70}$$

$= 372.86\ mm$ **(Ans.)**

Problem W2.5

A check basin of size 15 m × 12 m is to be irrigated using a stream of 26 litre per second. The depth of crop root zone is 1.3 m and the apparent specific gravity of the root zone soil is 1.6. the water holding capacity of the soil is 16%. Irrigation is to be applied when the soil moisture content in the crop root zone attains 12%. Deep percolation loss is neglected. Determine i) the net irrigation requirement in mm and ii) the duration of the irrigation in minutes to replenish up to field capacity. **(GATE 2009)**

Solution:

Discharge = 26 litre per second = 26×10^{-3} m^3 per sec

Area of check basin = 15 m × 12 m =180 m^2

Depth of crop root zone = 1.3 m

Apparent specific gravity of the root zone soil = 1.6

Water holding capacity of the soil = 16%

Soil moisture content in the crop root zone=12%

i. $Depth\ of\ irrigation = \frac{(16-12)\times1.6\times1.3}{100} = \frac{8.32}{100} = 0.0832\ m$

Net $irrigation\ requrment = 83.2$ mm

ii. $Discharge = \frac{Area\ \times \text{Net}\ irrigation\ requrment}{Time}$; $26 \times 10^{-3} = \frac{180\ \times 0.0832}{Time}$

$$Time = \frac{180\ \times 0.0832}{26\times10^{-3}} = \frac{14.976}{26\times10^{-3}} = 576\ sec = \frac{576}{60}\ min$$

$$= 9.6\ min$$

$The\ duration\ of\ the\ irrigation = 9.6\ min$

Example W2.6:

A bean crop is grown in clay loam soil and is completely developed. The groundwater table is more than 10 m below the surface. At the beginning of mid season stage of crop, the moisture content is at field capacity. Reference crop evapotranspiration and precipitation values for the 10 day period are given below. Using the above information develop irrigation schedule based on a fixed interval of a week and MAD.

Day	1	2	3	4	5	6	7	8	9	10
ET_o mm/d	5.6	5.4	5.9	5.8	5.6	5.8	5.9	5.8	5.2	5.4
P, mm/d	0	0	0	0	5	0	0.2	0	0	0

Solution:

- ✓ Assume no runoff occurs during the precipitation event ($r < f$)
- ✓ Bean crop is fully developed at the beginning of mid season stage and thus root system is also fully developed
- ✓ For Bean crop, effective root zone depth = 60 cm and $Kc_{mid} = 1.05$
- ✓ For Clay loam soil, $\theta_{fc} = 36\%$ and $\theta_{wp} = 18\%$ and MAD = 0.5

Total available water, $TAW = (\theta_{fc} - \theta_{wp}) \times D_{rz}$
$= (0.36 - 0.18)(60) = 10.80$ cm

Allowable depletion, $AD = MAD \times TAW$
$= (0.5) \times (10.80) = 5.4$ cm

- ✓ At beginning soil moisture is at FC and thus $SMD_{i-1} = 0$

Calculation for each day as follow

Day	SMD_{i-1} (mm)	ETo_i (mm)	Kc_i	Ks_i	ETc_i (mm)	DP_i (mm)	I_i (mm)	Pe_i (mm)	SMD_i (mm)
1	0.0	5.6	1.05	1.0	5.9	0.0	0.0	0.0	5.9
2	5.9	5.4	1.05	1.0	5.7	0.0	0.0		11.6
3	11.6	5.9	1.05	1.0	6.2	0.0	0.0		17.7
4	17.7	5.8	1.05	1.0	6.1	0.0	0.0		23.8
5	23.8	5.6	1.05	1.0	5.9	0.0	0.0	5.0	24.7
6	24.7	5.8	1.05	1.0	6.1	0.0	0.0		30.8
7	30.8	5.9	1.05	1.0	6.2	0.0	0.0	0.2	36.8
8	36.8	5.8	1.05	1.0	6.1	0.0	0.0		42.9
9	42.9	5.2	1.05	1.0	6.0	0.0	0.0		48.4
10	48.9	5.4	1.05	1.0	6.2	0.0	0.0		54.0

For MAD based scheduling, 54.0 mm of irrigation would be required on the morning of 11th day, whereas irrigation amount would be 36.8 mm after a week

Example W2.7:

Develop irrigation schedule using the information from previous Problem, for bean crop during its development stage. At the end of initial stage root zone depth is 15 cm, which reaches its maximum effective depth at the end of development stage.

Solution:

- ✓ Assumed that root depth increases during the development stage at a constant rate. Length of development stage for bean crop is 30 days .
- ✓ For bean crop, Kc_{ini} = 0.5 and Kc_{mid} = 1.05. Therefore, linear increase in K_c is also assumed.
- ✓ Allowable depletion limit would change each day in response to increasing root zone depth.

The water-balance calculation for each day is shown below:

Day	SMD_{i-1} (mm)	ETo_i (mm)	Kc_i	Ks_i	ETc_i (mm)	DP_i (mm)	I_i (mm)	Pe_i (mm)	SMD_i (mm)	Drz_i (mm)	AD_i (mm)
1	0.0	5.6	0.52	1.0	2.9	0.0	0.0	0.0	2.9	16.5	14.9
2	2.9	5.4	0.54	1.0	2.9	0.0	0.0		5.8	18.0	16.2
3	5.8	5.9	0.56	1.0	3.3	0.0	0.0		9.1	19.5	17.6
4	9.1	5.8	0.57	1.0	3.3	0.0	0.0		12.4	21.0	18.9
5	12.4	5.6	0.59	1.0	3.3	0.0	0.0	5.0	10.7	22.5	20.3
6	10.7	5.8	0.61	1.0	3.5	0.0	0.0		14.3	24.0	21.6
7	14.3	5.9	0.63	1.0	3.7	0.0	0.0	0.2	17.8	25.5	23.0
8	17.8	5.8	0.65	1.0	3.8	0.0	0.0		21.5	27.0	24.3
9	21.5	5.2	0.67	1.0	3.5	0.0	0.0		25.0	28.5	25.7
10	25.0	5.4	0.68	1.0	3.7	0.0	0.0		28.7	30.0	27.0

✓SMD is almost equal to AD on day 9, and therefore, irrigation amount of 25 mm would be given in the morning of day 10.

✓Similarly, irrigation amount of 17.8 mm would be required after a week on day 8th morning.

1. A crop grwn over an area of 50 ha can tolerate 5 decisiemens m^{-1} of electrical conductivity in the drainage water. The consumptive use of the crop is 1 m, 30% of which is obtained from the rainfall and the remainder is met from the irrigation water having electrical conductivity of 2 decisiemens m^{-1}. For efficient crop production, the leaching requirement and the quantity of water that must be drained from the area are ______ (Ans 40% and $0.23 Mm^3$) (GATE 2011)

2. A 100 ha reservoir receives 2500 mm of rainfall during a period of 2 years. During this period the mean inflow to the stream is 1.0 m^3s^{-1}, the mean outflow from the stream is 0.8 m^3s^{-1}, and the increase in the storage is 500 ha-m. Assuming that there is no seepage loss, the total evaporation during the period in m is _________(Ans. 10.11) (GATE 2011)

3. A 200 m long horizontal pipe carries a discharge of 50 L s-1. The center line of the pipe is 5 m above the datum. The diameter of the pipe tapers from 200 mm to 100 mm. Using g = 9.81 m s–2 and neglecting losses in the pipe, if the pressure at the larger end of the pipe is 100 kPa, the pressure at the other end of the pipe in kPa is __________(Ans. 80.2-81.5) GATE 2014

4. In a canal command, maize crop is grown in an area of 30 ha. The crop evapotranspiration (ET_c) of maize is 840 mm per season and the effective rainfall during growing season is 20 mm. It is irrigated with water having salinity of 1.1 dS m^{-1} by a surface irrigation method. If the leaching efficiency of the field soil is 0.8 and the average soil salinity tolerated by the maize crop for 100% yield is 1.7 dS m^{-1}, the depth of irrigation water in mm per season required to meet the seasonal ET_c and leaching requirement will be _______. (Ans. 1000-1013) (GATE 2015)