# SNS COLLEGE OF TECHNOLOGY
# AN AUTONOMOUS INSTITUTION

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## DEPARTMENT OF AGRICULTURAL ENGINEERING

**COURSE CODE & NAME**: 19AGB303 & Irrigation and Drainage Engineering

III YEAR / VI SEMESTER

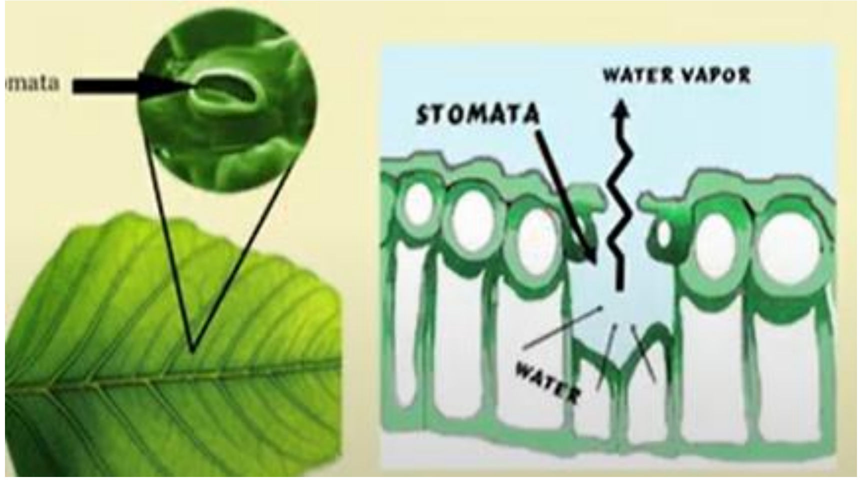
UNIT : II WATER RESOURCE AND IRRIGATION REQUIREMENT OF CROPS

**TOPIC 1 :** Evapotranspiration

# Terminologies

Evaporation – change of water from liquid to vapour
- occurs from all moist or wet surfaces including soil, water , plant and other surfaces.

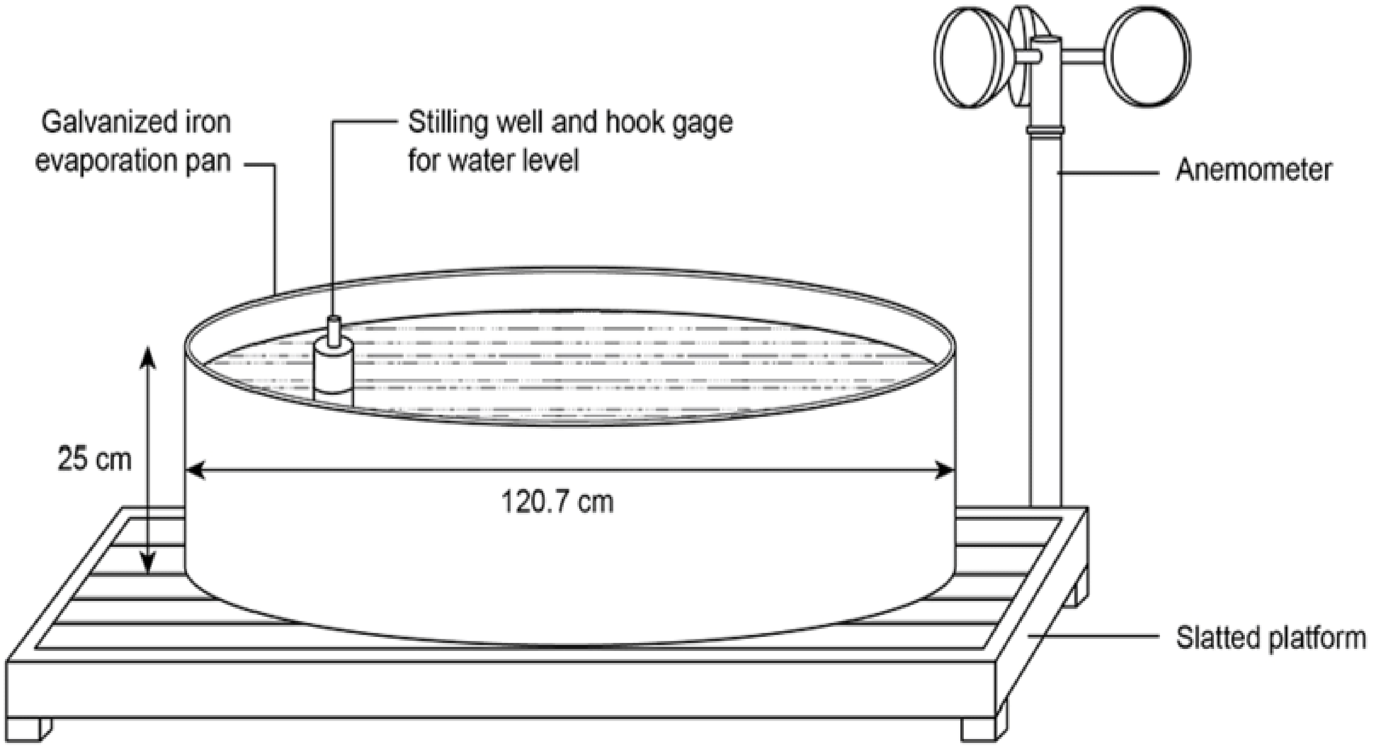
Evaporation from land surface is affected by degree of soil saturation, temperature of soil and air, humidity and wind velocity




Transpiration - loss of water from plant leaves through small openings in leaves called stomata

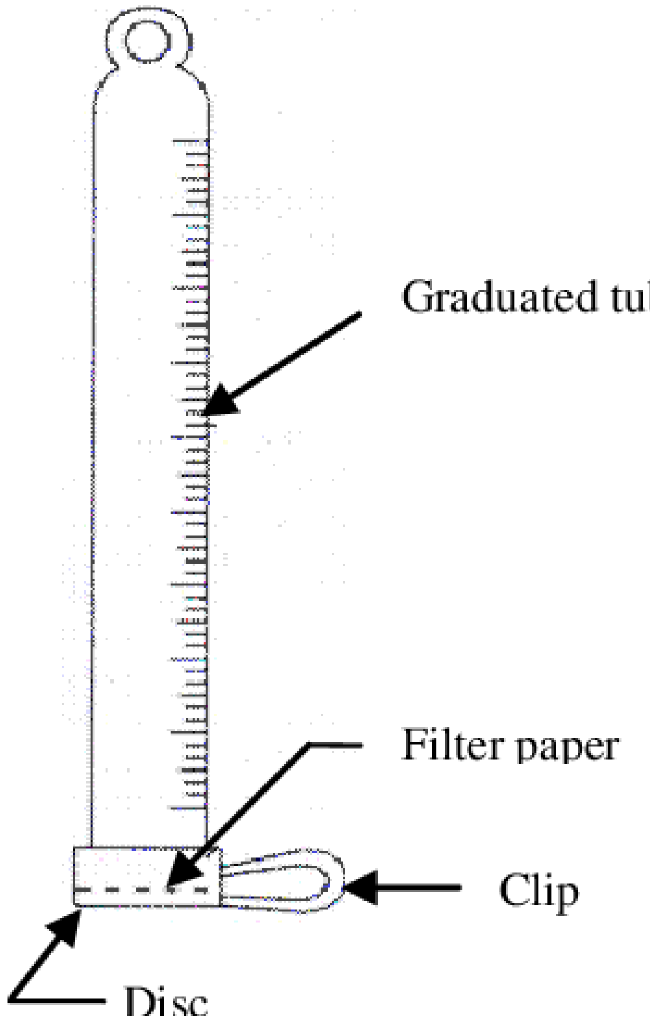
Both evaporation and transpiration occur in response to **climate demand**

# Measurement of Evaporation




**Class A Pan Evaporimeter**

**Pan coefficient** (usually around **0.7 - 0.8**) is used to convert pan evaporation to actual lake or reservoir evaporation.




**Piche Evaporimeter**

U.S. Weather Bureau

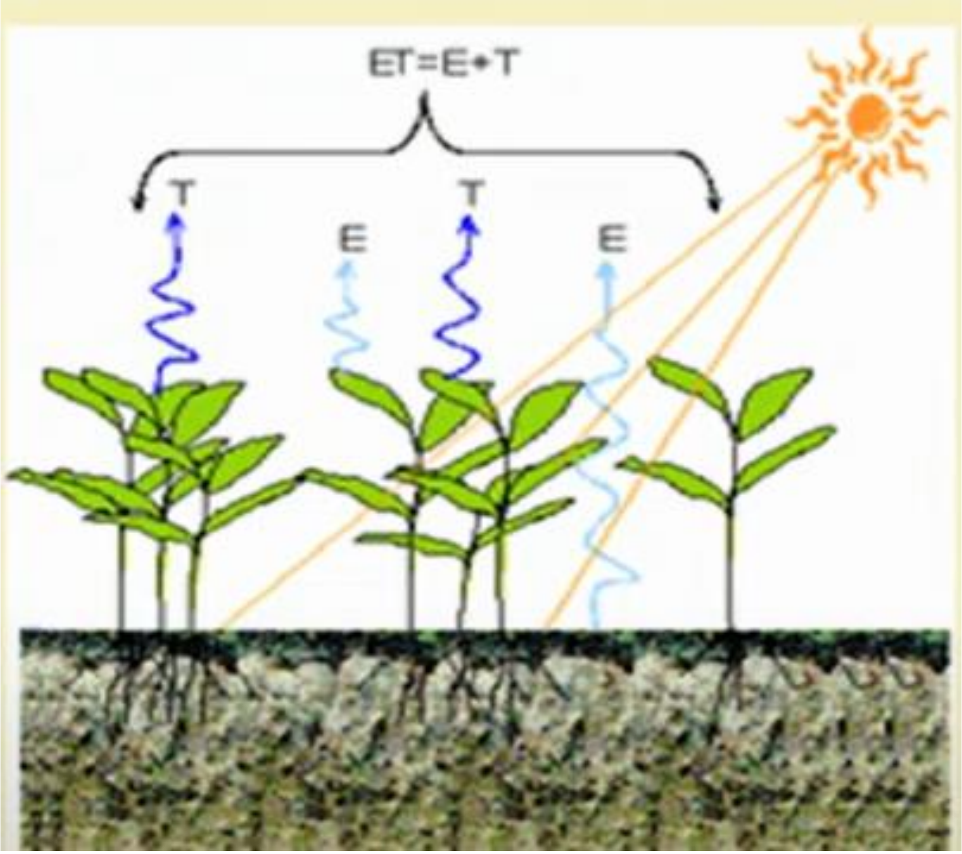
**World Meteorological Organization (WMO)**.

# What is Evapotranspiration?

In a crop field, evaporation (from soil surface –E ) and transpiration (through plants -T) occur simultaneously .

ET = E + T

Planning, designing and operation of irrigation and water management systems.



# Evapotranspiration per day

ET is measured in **millimeters per day (mm/day)**, representing the depth of water lost from a given area.

What does 1 mm ET/day mean?

- 1 mm ET/day means that 1 millimeter of water depth is lost from the soil and plants over a 24-hour period due to evapotranspiration.
- This is equivalent to 1 liter of water lost per square meter (1 $m^2$) of land per day.

As one hectare has a surface of 10000 $m^2$ and 1 mm is equal to 0.001 m, a loss of 1 mm of water corresponds to a loss of 10 $m^3$ of water per hectare. In other words, 1 mm $day^{-1}$ is equivalent to 10 $m^3$ $ha^{-1}$ $day^{-1}$

# Conversion Factors

| | depth | volume per unit area | | energy per unit area * |
|---|---|---|---|---|
| | mm $day^{-1}$ | $m^3$ $ha^{-1}$ $day^{-1}$ | l $s^{-1}$ $ha^{-1}$ | MJ $m^{-2}$ $day^{-1}$ |
| **1 mm $day^{-1}$** | 1 | 10 | 0.116 | 2.45 |
| **1 $m^3$ $ha^{-1}$ $day^{-1}$** | 0.1 | 1 | 0.012 | 0.245 |
| **1 l $s^{-1}$ $ha^{-1}$** | 8.640 | 86.40 | 1 | 21.17 |
| **1 MJ $m^{-2}$ $day^{-1}$** | 0.408 | 4.082 | 0.047 | 1 |

* For water with a density of 1000 kg $m^{-3}$ and at 20°C.

Water depths can also be expressed in terms of energy received per unit area.
The energy refers to the energy or heat required to vaporize free water. This energy, known as the latent heat of vaporization ($\lambda$), is a function of the water temperature. For example, at 20°C, $\lambda$ is about 2.45 MJ $kg^{-1}$.

**Hence, an energy input of 2.45 MJ per $m^2$ is able to vaporize 0.001 m or 1 mm of water, and therefore 1 mm of water is equivalent to 2.45 MJ $m^{-2}$.**

# Factors affecting ET

**A. weather/climatic parameters**

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

**B. Crop characteristics**

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

**C. Management and environment factors**

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

# Activity

On a summer day, net solar energy received at a lake reaches 15 MJ per square metre per day. If 80% of the energy is used to vaporize water, how large could the depth of evaporation be?

1 MJ $m^{-2}$ $day^{-1}$ =

Therefore

0.8 x 15 MJ $m^{-2}$ $day^{-1}$ = 0.8 x 15 x 0.408 mm $d^{-1}$ = 4.9 mm $day^{-1}$

Soln: The evaporation rate could be 4.9 mm/day

# Evapotranspiration and crop yield relationship

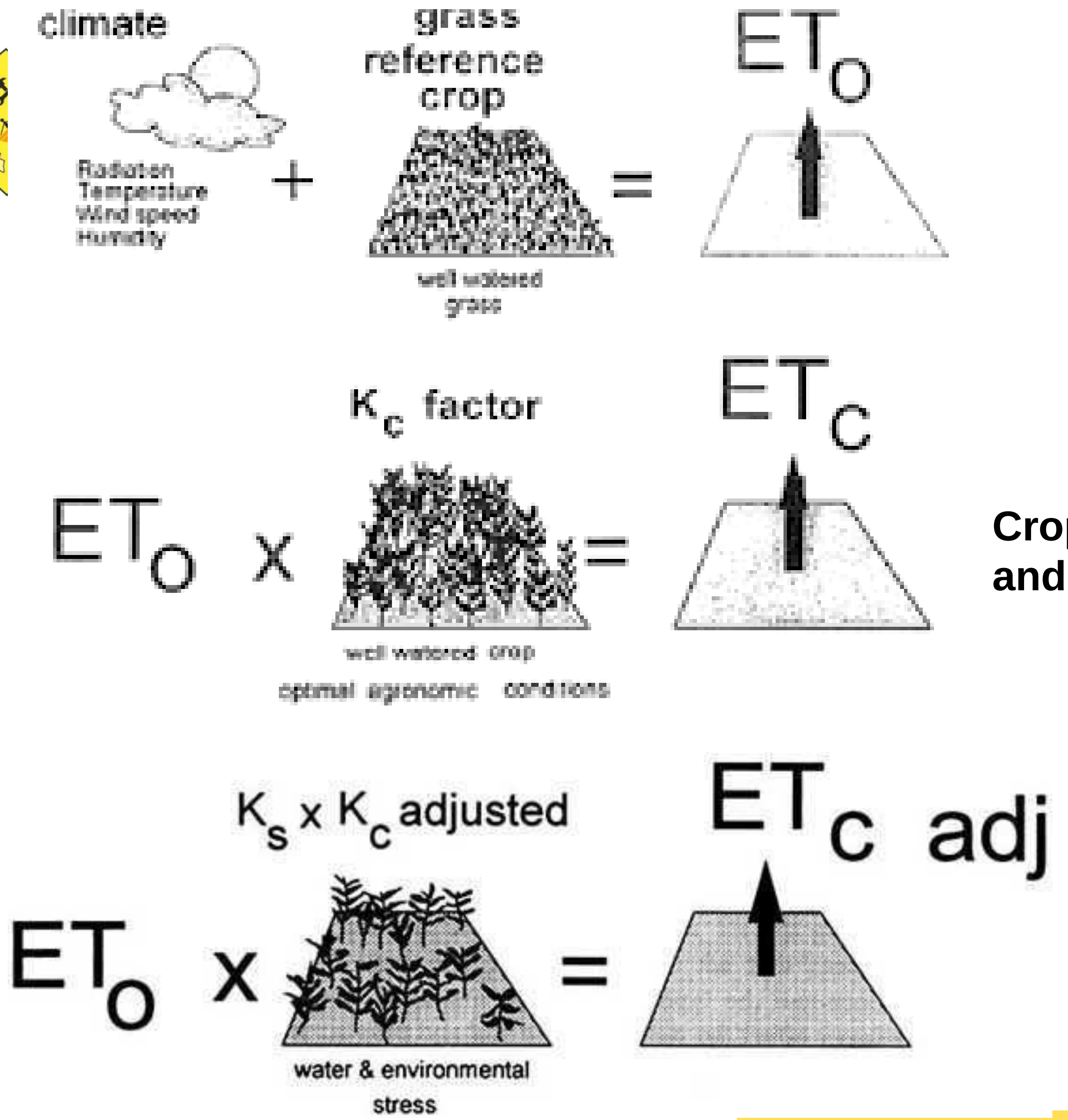
Relative Yield = 1- Ya/Ym (Ya –actual yield; Ym – maximum yield

Relative ET can be expressed as 1- Eta/ETm.

Thus, the relationship equation can be as-

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

Where ky is a constant which is the yield response factor




**Crop evapotranspiration under standard ($ET_c$) and non-standard conditions ($ET_{c\ adj}$)**

# ET concepts

## Potential ET

Potential Evapotranspiration (PET) is the highest rate of evapotranspiration by a short and actively growing crop.

## Actual ET

The rate of evapotranspiration by a particular crop in a given period under prevailing soil water and atmospheric conditions.

Crop evapotranspiration under standard condition is the evapotranspiration from a well maintained crop, grown in large fields, under optimum soil moisture condition and able to give maximum production under given climatic condition.

## Reference crop ET (($ET_0$)

Evapotranspiration rate from a reference surface, not short of water is called the reference crop evapo-transpiration.

Reference surface is a hypothetical grass reference crop with specific characteristics.

Hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 $sm^{-1}$ and the albedo of 0.23, - green grass of uniform height, actively growing and adequately watered.

# Average $ET_o$ for different agro-climatic regions in mm/day

| Regions | Mean daily temperature (°C) | | |
|---|---|---|---|
| | Cool ~10°C | Moderate 20°C | Warm > 30°C |
| Tropics and subtropics | | | |
| - humid and sub-humid | 2 - 3 | 3 - 5 | 5 - 7 |
| -arid and semi-arid | 2 - 4 | 4 - 6 | 6 - 8 |
| Temperate region | | | |
| - humid and sub-humid | 1 - 2 | 2 - 4 | 4 - 7 |
| -arid and semi-arid | 1 - 3 | 4 - 7 | 6 - 9 |

To find the ET crop the following relationship is used

$$ETc = ETo \times Kc$$

Kc = Crop coefficient

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

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

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

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

Etc adj = (Ks Kcb+Kc) ETo

# Consumptive Use (CU)

- Water used in all the plant process as well as direct evaporation from soil and plant surface

- CU exceeds ET by the amount of water used in metabolic process, photosynthesis, transport of minerals and photosynthates, structural support and growth.

- The difference between ET and CU is usually 1% ; Hence assumed as to be equal

So, **ET = CU**

# ET Determination

**1. Direct measurement**

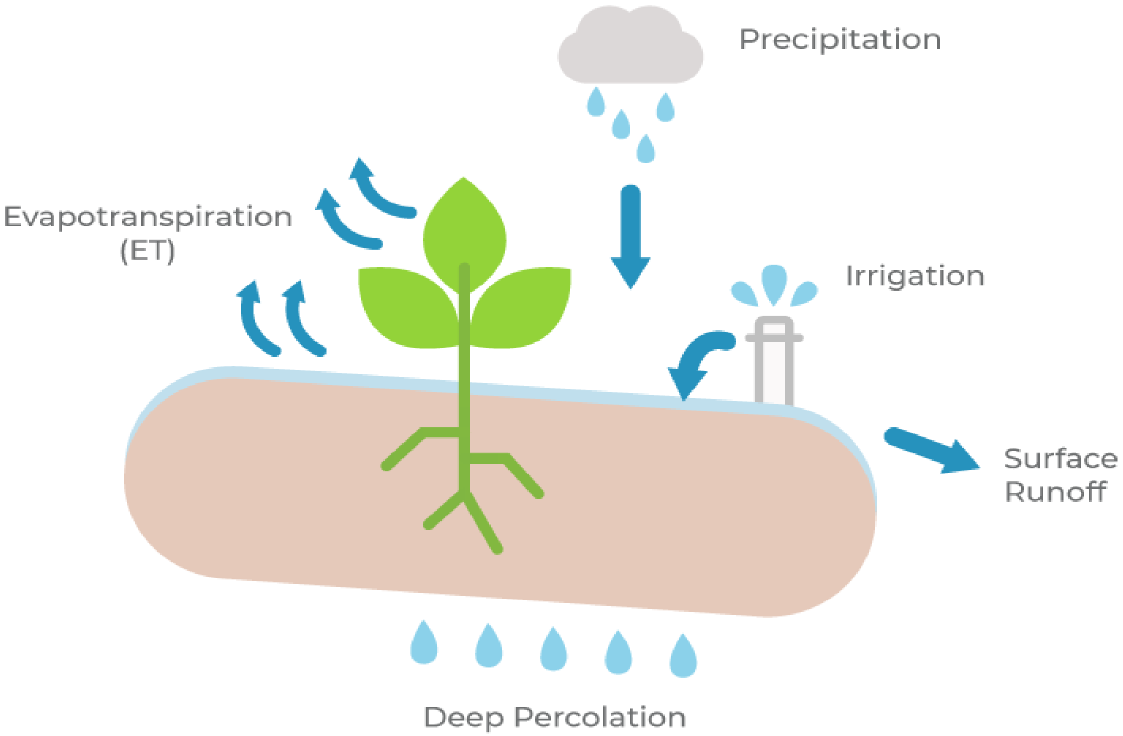
- Involves isolating a portion of the crop from its surroundings and determining ET by measurement.

**2. Indirect measurement**

- Calculated from crop and climate data
- Theoretical and empirical equations
- If measured ET are not available

# ET Measurement Methods

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



# 1. Energy balance and microclimatological methods

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

Rn - G - ƛ Et – H = O

Where Rn = net radiation, H = Sensible heat ; G = Soil heat flux, ƛ ET = Latent heat flux,

Latent heat flux (ƛET) representing the evapotranspiration fraction can be derived from the ‘energy balance equation’ if all other components are known.’Rn’ and ‘G’ can be estimated from climatic parameters.

Measurement of ‘H’ is complex and requires accurate temperature gradients above the surface.

# 2. Soil water balance

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

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

**Water Inputs =** P + I + C

Where, P = Precipitation, I = irrigation ; C = Contribution from ground wate

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

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

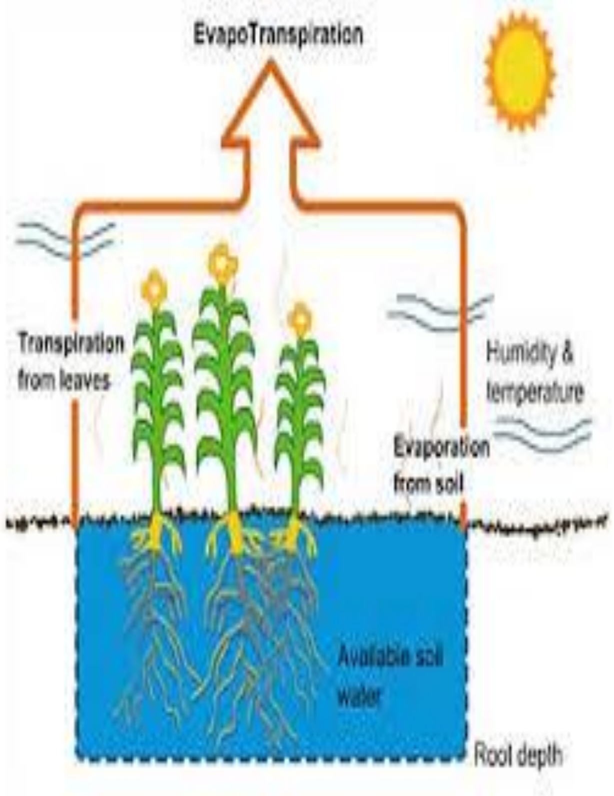
Thus, **Change in soil water** = (P + I + C) - (ET + D + RO) .

Suppose, the amount of water in root zone at the beginning is M1 and at tl end of period is M2 .

Then , M1 - M2 = P + I + C – ET - D – RO

Or M1 + P + I+ C = ET + D + RO + M2

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



# 3. Lysimeters

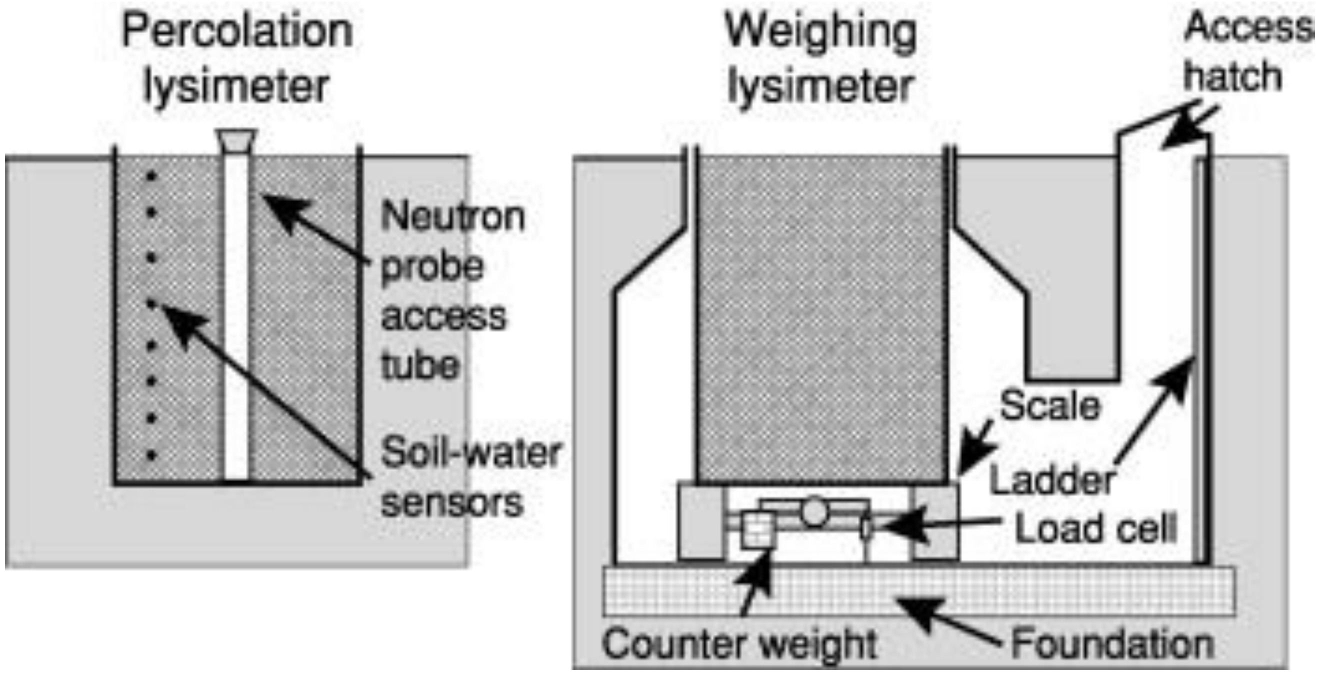
- Device used for estimating evapotranspiration.
- It consists of specially designed open-top tanks buried in the field that are filled with undisturbed soil, and planted with the same crop as the surrounding area.
- Rectangular units of 4.0 m2 are satisfactory for most crops.
- Total depth ranges between 100-150 cm as per 8root depth of crops.
- In general, 50% available soil moisture depletion in root zone should not be exceeded.
- The crop grown in lysimeter is the same as in surrounding area.

# Types of Lysimeter

In the drainage/percolation type, the inflows and drainage are measured, but changes in storage within soil are not measured.

In weighing type lysimeters each element i.e. rainfall, irrigation, runoff and ET can be determined by using water balance equation.

ET = Weight change + water added - percolation




Neutron probe a device that measures soil moisture content by detecting the backscattered flux of slow neutrons, which is proportional to the density of hydrogen atoms in the soil, and thus water content.

# Empirical Methods (based on climatological data and crop factors)

According to FAO,

- Temperature based (Thornwaite, SCS Blainey Criddle, FAO24 Blaney Criddle, Hargreaves)
- Radiation based (Turc, Preistly Taylor, Jensen-Haise, and FAO 24 Radiation)
- Pan evaporation based ( Pan evaporation, FAO 24 Pan)
- Combination (Penman, Penman Moneith, FAO 56 Penman Monteith)

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

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

Modified Penman and radiation methods offer best results for periods as short as 10 days followed by pan evaporation method.

Blaney-criddle method is ideal for periods of one month or more in many climates.

# Blaney-criddle Formula

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

$$U\ (CU) = \Sigma u = KF = \Sigma kf = \Sigma\ 100$$

Where,

U or CU = Seasonal consumptive use

u = monthly consumptive use

t = Mean monthly temperature ($^0$F)

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

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

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

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

f = p (0.46 t +8.13) , using t in $^o$C )

T = mean daily temperature for the month.

P = mean daily percentage of total annual daytime.

# Hargreaves Methods

Hargreaves method is a temperature based method and it was derived to overcome non availability of solar radiation data at many locations.

*Hargreaves and Samani (1985) recommended estimating solar radiation from extraterrestrial radiation and proposed the following equation for estimating $ET_o$ in mm/day*

$$ETo = 0.0023\ R_A \sqrt{TD}\ (T_{mean} + 17.8)$$

Where,
TD = difference between mean monthly maximum and minimum temperatures in °**C,**
$R_A$= extraterrestrial solar radiation in **MJ m$^{-2}$ d$^{-1}$,**
$T_{mean}$ = mean monthly air temperature **in °C**.

Extra terrestrial radiation is the theoretical amount of solar energy that would be available on a horizontal plane on the earth's surface if the earth were not surrounded by an atmosphere.

**Radiation method :** bright sunshine hours, general levels of humidity and wind velocity.

ET0 = C (W x Rs)

Where, **Rs** = Measured mean incoming shortwave radiation (mm day-1) – (by pyrenometer) or obtained from Rs = (0.25+0.50x n/N) Ra.

Where = Ra is extraterrestrial radiation (mm day-1), N = maximum possible sunshine duration (h $day^{-1}$), n = measured mean actual sunshine duration (h $day^{-1}$),

**W** = Temperature and altitude dependent weighing factor

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

# Pan evaporation method :

Evaporation from pans provides measurement of integrated effect of radiation, wind, temperature and humidity on evaporation from open water surface.

To relate pan evaporation to ET0, empirically derived Pan coefficients are suggested to account for climate, type of Pan and Pan environments

$$ETo = K\ pan \times E\ pan$$

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

K pan = Pan coefficient.

**Modified Penman method :** utilises almost all the meteorological Parameters associated with ET.

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

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

or Rn = 7.5 Rs – Rnl

Rs = Short wave radiation (given earlier)

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

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

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

W = Temperature and altitude dependent weighting factor.

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

## Crop co-efficients for estimating ET crop

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

**ETc = ETo x Kc**

While $ET_o$ accounts for variations in weather and is used as an indicator of atmospheric demand for water, $K_c$ values account for the difference between $ET_o$ and $ET_c$ and link them.

# FAO Kc curve

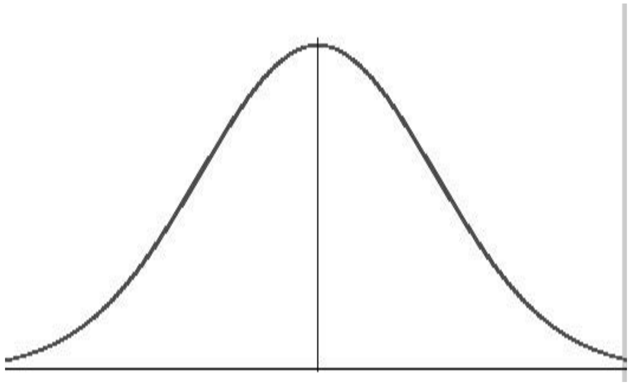
$K_c$ **is the crop coefficient** for a given crop and growth stage, and is usually determined experimentally. Each agronomic crop has a set of specific crop coefficients used to predict water use rates at different growth stages.

**There are four main crop growth stages: initial, crop development, mid-season, and late season:**

a) Initial period – planting to 10% ground cover

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

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



d) Late season – Start of maturity to harvest.

**Info bank :** In case of annual crops, Kc is typically low at seedling, emergence and establishment stage, increases with increase in ground cover and attains maximum value at mid-season stage and thereafter decreases towards ripening and maturity stage.


- ❖ Evapotranspiration
- ❖ Factors affecting ET
- ❖ Methods to measure ET
- ❖ Crop Coefficient Kc

THANK YOU...