SNS COLLEGE OF TECHNOLOGY
(An Autonomous Institution, Affiliated to Anna University)
Coimbatore – 641 035.

Unit II

Evapotranspiration

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

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

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

Datton's law of evaporation

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

Where es = Saturation vapour pressure of water

Ea = Actual vapour pressure of air above

f (u) = function of wind velocity

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

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

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

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

As one hectare = 10000 m^2

One mm = 0.001 m

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

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

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

MJ m^{-2} day^{-1} is represented by λ ET, the latent heat flux.

Conversion factors for ET

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

Factors affecting evapotranspiration

A. weather/climatic parameters

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

B. Crop characteristics

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

C. Management and environment factors

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

Evapotranspiration and crop yield relationship

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

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

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

Evapotranspiration and consumptive use:

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

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

Evapotranspiration concepts

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

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

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

To find the ET crop the following relationship is used

ETc = ETo x Kc

Kc = Crop coefficient

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

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

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

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

ETc adj = (Ks Kcb+Kc) ETo

Measurement of Evapotranspiration

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

1. Energy balance and microclimatological methods

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

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

Where Rn = net radiation, H = Sensible heat

G = Soil heat flux, $\lambda\, ET$ = Latent heat flux,

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

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

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

Water Inputs = $P + I + C$

Where, P = Precipitation, I = irrigation

C = Contribution from ground water.

Losses of water = $ET + D + RO$

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

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

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

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

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

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

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

ET = Weight change + water added - percolation

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

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

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

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

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

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

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

Where,

U or CU = Seasonal consumptive use

u = monthly consumptive use

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

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

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

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

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

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

Or

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

Thus, finally it become

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

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

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

T = mean daily temperature for the month.

P = mean daily percentage of total annual daytime.

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

$ET_0 = C (W x Rs)$

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 ET_0, empirically derived Pan coefficients are suggested to account for climate, type of Pan and Pan environments

ETo = K pan x E pan

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

K pan = Pan coefficient.

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

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

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

or Rn = 7.5 Rs – Rnl

Rs = Short wave radiation (given earlier)

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

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

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

W = Tempreature and altitude dependent weighting factor.

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

Crop coefficients for estimating ET crop

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

$$ETc = ETo \times Kc$$

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

CROPWAT : FAO IDP 46 and 49

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

Soil Plant and Meteorological factors determining Water needs of crops

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

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

WR= CU = ET

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

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

Where, IR = Irrigation requirement

EP = Effective precipitation

S = Soil profile moisture contribution

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

IR = WR - (EP + S)

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

NIR = (CU – EP) + AL

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

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

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

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

Determination of crop water requirements

A. Direct measurements

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

6. Water balance method

B – <u>From climatic data</u>

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

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

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

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

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

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

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

General sensitivity of crops to drought

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

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

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

Group IV – Highly Sensitive : Lowland rice, Maize

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

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

4. Crop management Practices

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

SCHEDULING IRRIGATION

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

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

Advantages

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

Factors influencing irrigation schedules

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

When to irrigate

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

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

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

Approaches for scheduling irrigation

1. Soil moisture monitoring

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

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

(iii) Feel and appearance method.

2. Atmospheric measurements and water balance technique

(i) Measurement of crop evapotranspiration (ETc)

(ii) IW/CPE approach

(iii) Lysimeter studies

(iv) Field water balance

3. Plant based monitoring

(i) Contact methods

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

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

(ii) Non contact method

a. Site specific crop management and irrigation

b. Plant spectral responses

c. Radiometric sensors

- Multispectral sensors
- Hyperspectral sensors
- Thermal sensing

Plant Indices

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

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

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

Water Resources

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

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

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

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

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

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

Water budget in its elementary form can be represented by the equation-

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

Principal annual components of India’s water budget:

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