ARBA MINCH UNIVERSITY
Water Technology Institute
Faculty of Meteorology and Hydrology

Course Name:-Irrigated Lands Hydrology
Course Code:- MHH1403

CHAPTER TWO

CROP WATER REQUIREMENTS

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2.1 Introduction

☞ **Crop water requirements:** is defined as "the depth of water needed to meet the water loss through evapotranspiration (ETcrop) of a disease free crop growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment".

☞ It is the quantity of water required by the crop in a given period of time to meet its normal growth under a given set of environmental & field conditions.

☞ The determination of water requirements is the main part of the design and planning of an irrigation system

Cont…

- The water requirement is the water required to meet the water losses through
  - Evapotranspiration (ET)
  - Unavoidable application losses
  - Other needs such as leaching & land preparation
- The water requirement of crops may be contributed from different sources such as irrigation, Effective rainfall, Soil moisture storage and ground water contributions.

Hence, WR = IR + ER + S + GW

Where, IR = Irrigation requirement

ER = Effective rainfall

S = carry over soil moisture in the crop root zone

GW = ground water contribution

Cont…

i. *Irrigation req't of Crops (Net Irrigation Req't)*

- The irrigation water requirement of crops is defined as the part of water requirement of crops that should be fulfilled by irrigation.

- In other words, it is the water requirement of crops excluding effective rain fall, carry over soil moisture and ground water contributions.

$$IR(NIR) = WR - (P_{eff} + S + GW)$$

ii. Effective Rainfall (P_{eff})

- Effective rainfall is the rainfall that is stored in the root zone and can be utilized by crops.
- All the rainfall that falls is not useful or effective.
- As the total amount of rainfall varies, so does the amount of useful or effective rainfall.

- Some of the seasonal rainfall that falls will be lost as unnecessary **deep percolation**; **surface runoff** and **some water may remain in the soil after the crop is harvested**.
- From the water requirement of crops point of view, this water, which is lost, is ineffective.

Cont…

- Methods for calculating the effective rainfall from entered monthly total rainfall data.

1. *Fixed Percentage Effective Rainfall*

- The effective rainfall is taken as a fixed percentage of the monthly rainfall;

Effective Rainfall = % of Total Rainfall

2. *Dependable Rain*

- An empirical formula developed by FAO/AGLW based on analysis for different *arid and sub-humid climates*.
- This formula is as follows:
  - *Effective Rainfall =0.6 * Total Rainfall – 10*
    - *For (Total Rainfall < 70 mm)*
  - *Effective Rainfall = 0.8 * Total Rainfall – 24*
    - *For (Total Rainfall > 70 mm)*

Cont…

3. Empirical Formula for Effective Rainfall

$$Effective\ Rainfall = a * Total\ Rainfall - b$$

For (Total Rainfall < z mm)

$$Effective\ Rainfall = c * Total\ Rainfall - d$$

For (Total Rainfall > z mm)

Where a, b, c, d and z are the variables to be defined by the user.

4. Method of USDA Soil Conservation Service (default)

❖The effective rainfall is calculated according to the formula developed by the USDA Soil Conservation Service which is as follows: (Total Rainfall < 250 mm)

$$Effective\,rain\,fall = \frac{Total\,rain\,fall}{125*(125-0.2*total\,rain\,fall)}$$

(Total Rainfall > 250 mm)

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$$Effective\ Rainfall = 125 + 0.1 * Total\ Rainfall$$

Cont…

iii. Ground water contribution (Gw):

- Some times there is a contribution from the groundwater reservoir for water requirement of crops.

- The actual contribution from the groundwater table is dependent on the depth of ground water table below the root zone & capillary characteristics of soil.

- For clay soils the rate of movement is low and distance of upward movement is high while for light textured soils the rate is high and the distance of movement is low.

- For practical purposes the GW contribution when the ground water table is below 3m is assumed to be nil.

iv. Carry over soil moisture(S):

- This is the moisture retained in the crop root zone b/n cropping seasons or before the crop is planted.
- The *source of this moisture is either from the rainfall that man occurs before sowing or it may be the moisture that remained in the soil from past irrigation.*
- This moisture also contributes to the consumptive use of water and should be deducted from the water requirement of crops in determining irrigation requirements.

2.2 Evapotranspiration Process

ET- The combination of two separate processes where by water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred to as evapotranspiration (ET).

Evaporation

- Is the process during which water is converted from liquid/solid state (vaporization) into vapour through transfer of heat energy.
- Energy is required to change the state of the molecules of water from liquid to vapour.
- This energy is mainly from solar radiation and, to a lesser extent, from the ambient temperature of the air.

Cont…

Class Activity

Discuss briefly

i. Evaporation process

ii. Climate/Meteorological factors that affect evaporation

iii. Physical factors that affect evaporation

iv. Evapotranspiration process

Cont…

There are three types of evaporation process:

A. Evaporation from free surface (reservoir, stream, pond…)

- The driving force to remove water vapour from the evaporating surface is the difference between the water vapour pressure at the evaporating surface and that of the surrounding atmosphere.
- As evaporation proceeds, the surrounding air becomes gradually saturated and the process will slow down and might stop if the wet air is not transferred to the atmosphere.
- The replacement of the saturated air with drier air depends greatly on wind speed.
- In short, the evaporation is a function of the difference between vapour pressure of the body of water and vapour pressure of the air above.

B. Evaporation from land

C. Evaporation from vegetation covers(Transpiration)

Cont…

Factors that affecting evaporation are:

1. ***Climate/Meteorological factor***
   i. Temperature
   ii. Wind:
   iii. Humidity :
   iv. Sunshine:

2. Physical factor

   i. Nature of evaporating surface(Vegetation, Soil surface, Snow/ice)
   ii. (Salinity, dissolved salt)

Cont…

Transpiration

☞ is the process by which plants loose water from their bodies.

☞ This loss of water includes the quantity of water transpired by the plant and that retained in the plant tissue.

☞That is, the water entering plant roots and used to build plant tissue or being passed through leaves of the plant into the atmosphere.

☞ Crops predominately lose their water through ***stomata***.

☞These are small openings on the plant leaf through which gases and water vapour pass.

Factors that affecting transpiration are:

1. Climate factor (T^{o}, vapour pressure, Sunshine, wind…)
2. Soil factor(ability of soil that supply water to the roots)
3. Crop/Plant factor(extent & efficiency of root systems in moisture absorption)

Cont…

Evapotranspiration (ET)

☞Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes.

☞Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface.

☞This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area.

☞When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process

☞At sowing nearly 100% of ET comes from evaporation, while at full crop cover more than 90% of ET comes from transpiration

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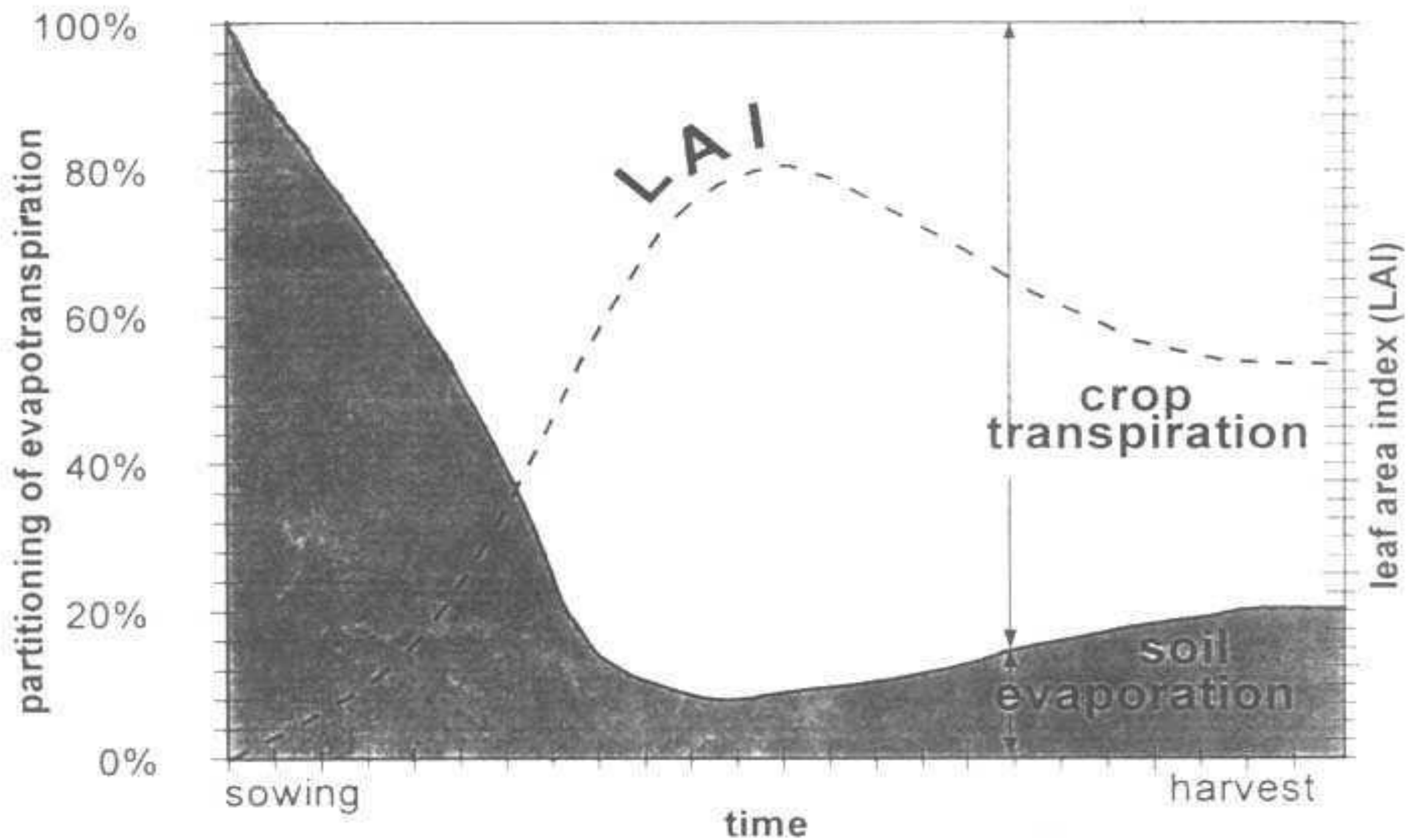

Figure 2.1 The partitioning of evapotranspiration into evaporation and transpiration over the growing period for an annual field crop

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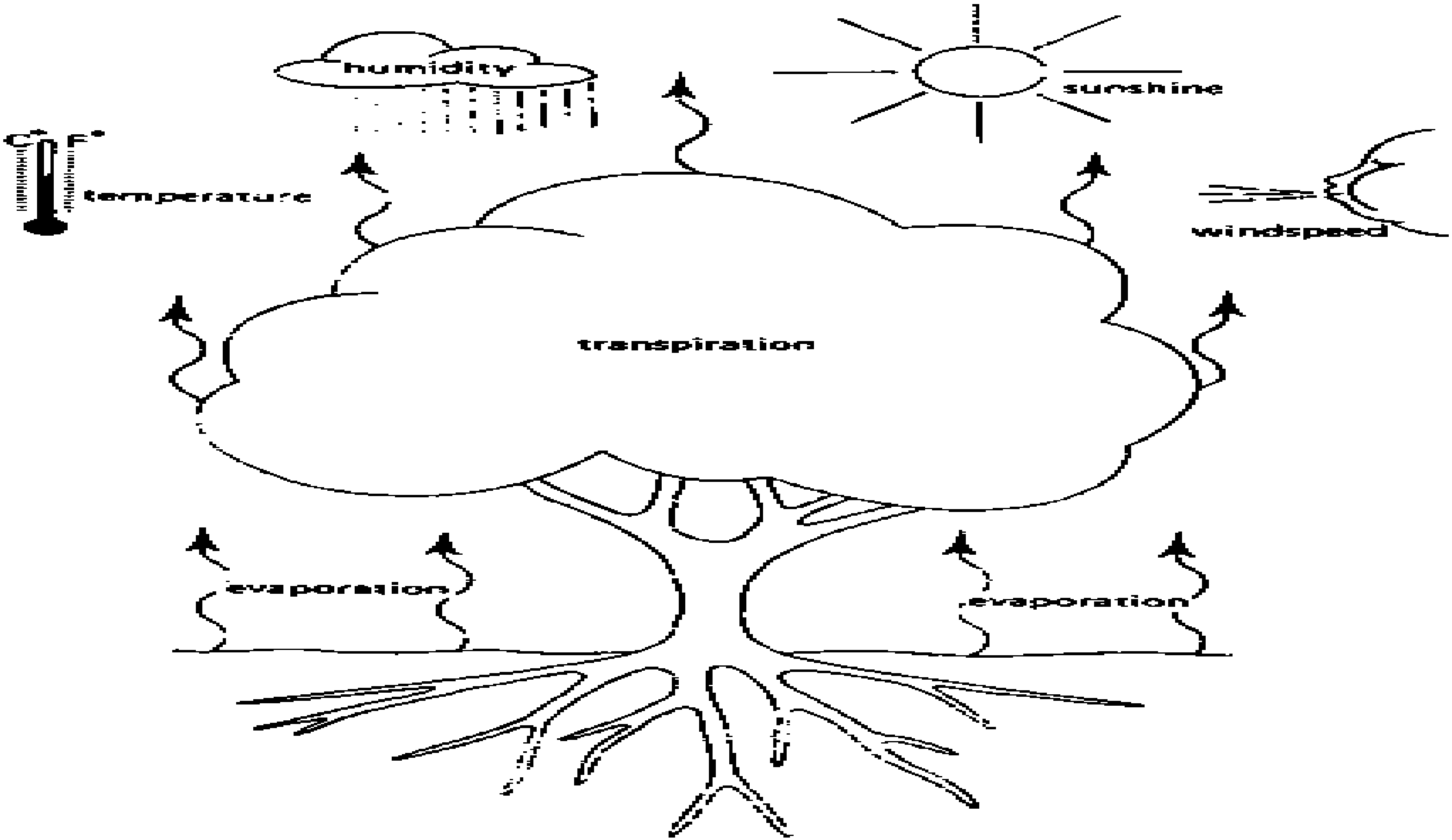

Fig. 2. 2 Major factors influencing crop water needs

2.3 Potential Evapotranspiration (PET)

- This is also called reference crop evapotranspiration it is the rate of evapotranspiration from an extensive surface 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water".

- The only factors affecting ETo are climatic parameters.
- Consequently, ETo is a climatic parameter and can be computed from weather data.
- ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors.
- The ETo is usually expressed in millimetres per unit of time

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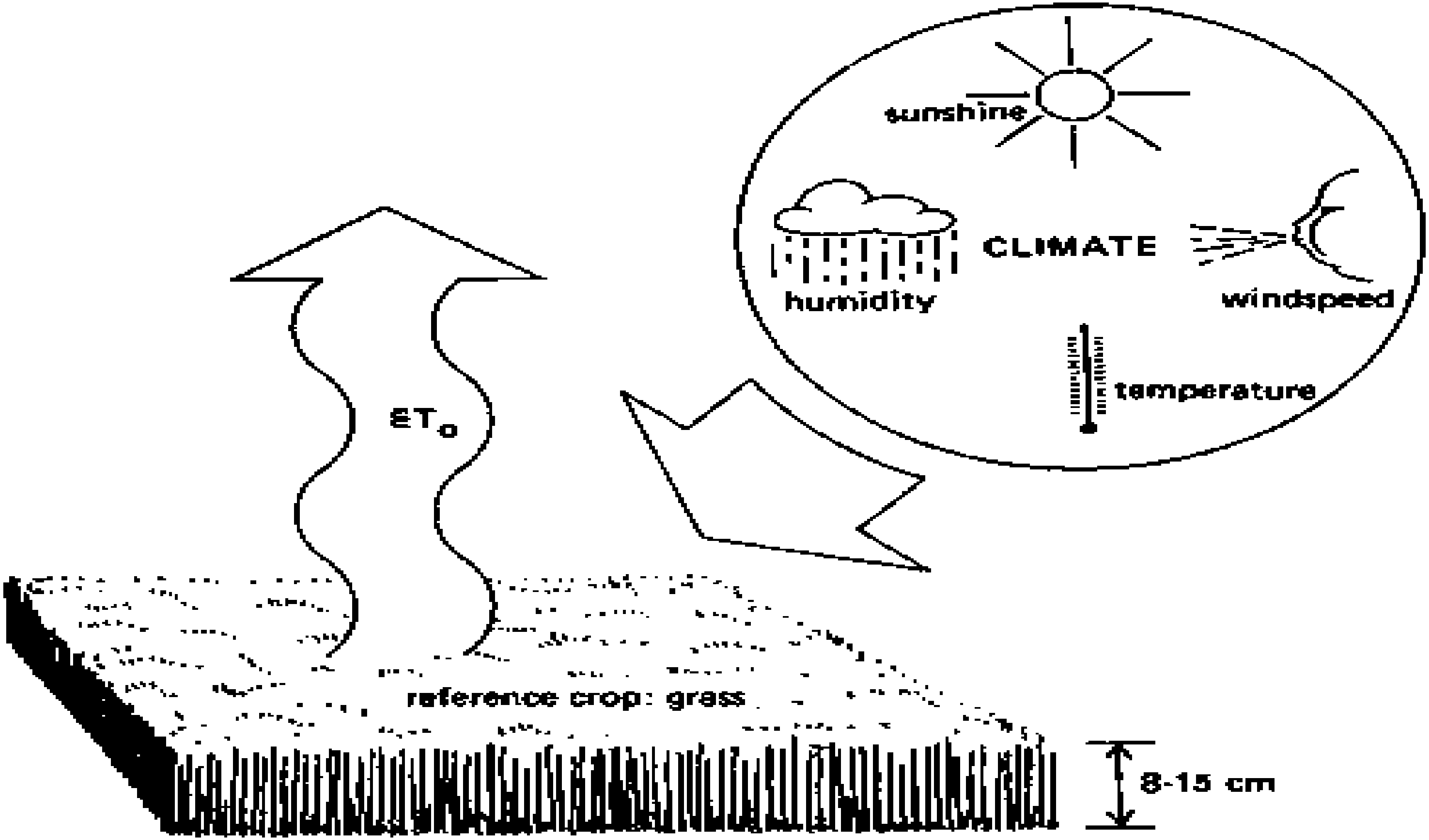

Fig. 2.3 Reference crop evapotranspiration

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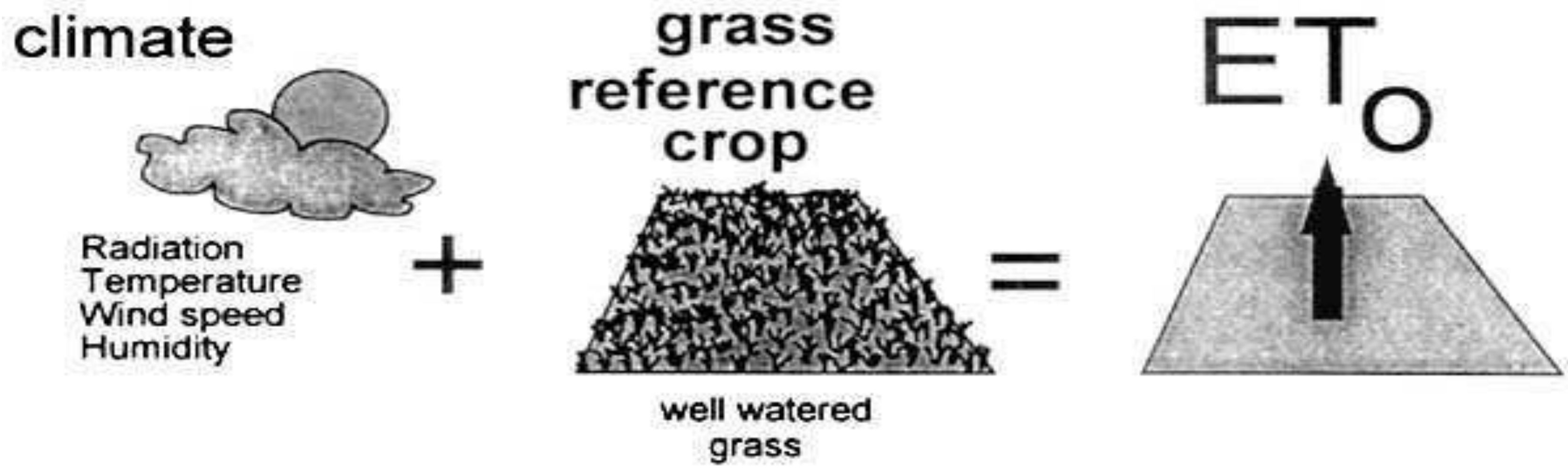
The major climatic factors which influence the crop water needs are:-

- ✓ Sunshine
- ✓ Temperature
- ✓ Humidity and
- ✓ Wind speed



Eto = Grass reference crop*climate

2.4 Consumptive use (CU) of water and methods of estimation

2.4.1 Consumptive use (CU) of water

- Consumptive use (CU) is synonymous to Crop evapotranspiration (ETcrop).
- Consumptive use:- is the depth (quantity) of water required by the crop to meet its evapotranspiration losses and the water used for metabolic processes.
- But the water used for metabolic processes is very small & accounts only less than 1 % of evapotranspiration.
- Hence the consumptive use is taken to be the same as the loss of water through evapotranspiration.
- Note: CU= ET + water used by the plants in their metabolic process for building plant tissues (insignificant)

Cont…

❖It deals with the influence of the crop type and growth stage on crop water needs, in other words, the relationship between the reference grass crop and the crop actually grown in the field.

❖Crop evapotranspiration is calculated by multiplying ETo by Kc, coefficient expressing the difference in evapotranspiration between the cropped and reference grass surface.

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

Where:

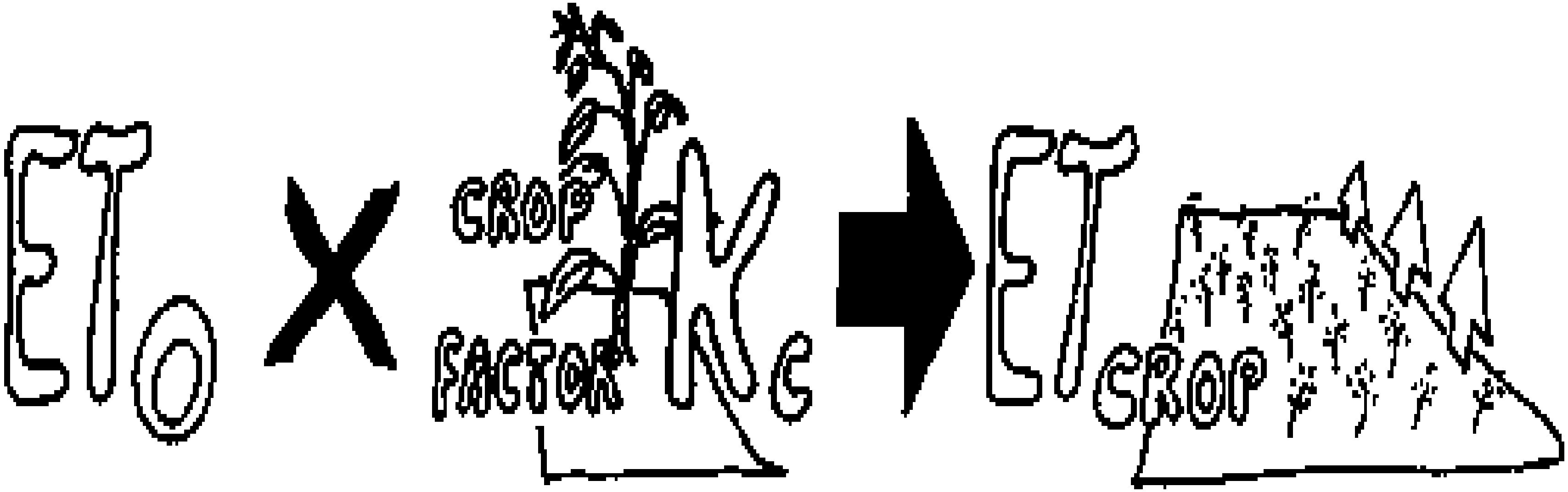
ET crop =crop evapotranspiration or crop water need (mm/day)

Kc =crop factor

ETo=reference evapotranspiration (mm/day)

Cont…

- Both ET crop and ETo are expressed in the same unit: usually



The crop factor, Kc, mainly depends on:-

- ☞ The climate
- ☞The type of crop
- ☞The growth stage of the crop
- ☞Cultivation practice

Cont…

A. Influence of Climatic factors on the crop water needs

i. **Temperature:** As the temperature increases, the saturation vapor pressure also increases and results in increase of evaporation and thus consumptive use of water.

ii. **Wind Speed:** The more the speed of wind, the more will be the rate of evaporation, because the saturated film of air containing the water will be removed easily.

iii. **Humidity: -** The more the air humidity, the less will be the rate of consumptive use of water. This is because water vapor moves from the point of high moisture content to the point of low moisture content. So if the humidity is high water vapor cannot be removed easily.

iv. **Sunshine hours: -** The longer the duration of the sunshine hour the larger will be the total amount of energy received from the sun. This increases the rate of evaporation and thus the rate of consumptive use of crops.

Cont…

Table 2.1 Effect of major climatic factors on crop water needs

Climatic Factor	Crop water need	
	High	**Low**
Temperature	hot	cool
Humidity	low (dry)	high (humid)
Wind speed	windy	little wind
Sunshine	sunny (no clouds)	cloudy (no sun)

► The highest crop water needs are thus found in areas which are hot, dry, windy and sunny. The lowest values are found when it is cool, humid and cloudy with little or no wind.

Cont…

B. Influence of the crop type on the crop water needs(Kc)

- The agronomic feature of the crops is variable, some crops completely shade the ground while others shade only some part of the ground.
- To account these variations in the nature of the crop suitable values of crop coefficient are used to convert the PET to actual evapotranspiration.
- So for the same climatic conditions different crops have different rates of consumptive uses

❖ *The influence of the crop type on the crop water need is important in two ways:*

1. **The crop type has an influence *on the daily water needs of a fully grown crop*; i.e. the peak daily water needs:**

➢ a fully grown *maize* crop - with its large leaf area - will use more water per day than a fully grown crop of *onions*; that is when the two crops are grown in the same area.

Cont…

- When determining the influence of the crop type on the daily crop water needs, reference is always made to a fully grown crop; the plants have reached their maximum height; they optimally cover the ground; they possibly have started flowering or started grain setting.
- When the crops are fully grown their water need is the highest. It is the so-called "peak period" of their water needs.

2. The crop type has an influence on *the duration of the total growing season of the crop.*

- There are short duration crops, e.g. *peas*, with a duration of the total growing season of 90-100 days and longer duration crops, e.g. melons, with a duration of the total growing season of 120-160 days.
- The daily water need of m*elons* may be less than the daily water need of peas, the seasonal water need of melons will be higher than that of beans because the duration of the total growing season of melons is much longer.

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C. Influence of growth stage of the crop water needs(Kc)

- The total growing period (in days) is the period from sowing or transplanting to the last day of the harvest.
- When the plants are very small the evaporation will be more important than the transpiration. When the plants are fully grown the transpiration is more important than the evaporation.
- For example:- A fully grown maize crop will need more water than a maize crop which has just been planted.

The total growing period is divided into 4 growth stages:

1. **The initial stage**: this is the period from sowing or transplanting until the crop covers about 10% of the ground.
2. **The crop development stage**: this period starts at the end of the initial stage and lasts until the full ground cover has been reached (ground cover 70%); it does not necessarily mean that the crop is at its maximum height.

Cont…

3. **The mid - season stage**: this period starts at the end of the crop development stage and lasts until maturity; it includes flowering and grain-setting.

4. **The late season stage**: this period starts at the end of the mid season stage and lasts until the last day of the harvest; it includes ripening.

- Thus, to approximate duration of growth stages for various field crops are taken from table.
  - ***For example : take Sorgum***
    - *Initial stage: 25 days*
    - *Crop development stage: 35 days*
    - *Mid-season stage: 40 days*
    - *Late season stage: 20 days*

Total = 120 days

Cont…

- To determine the crop factor Kc, it is necessary, to know the total length of the growing season and the lengths of the various growth stages.
- *The determination of the Kc values for the various growth stages of the crops involves several steps*:

Step 1: Determination of the total growing period of each crop

Step 2: Determination of the various growth stages of each crop

Step 3: Determination of the Kc values for each crop for each of the growth stages

Step 4: Calculating ETc as the product of ETo and Kc.

- Values of the crop factor (kc) for various crops also can be taken from table.

For example : take Sorghum

- Kc initial stage = 0.35
- Crop dev. stage = 0.75
- Mid-season stage = 1.10
- Late season stage = 0.65

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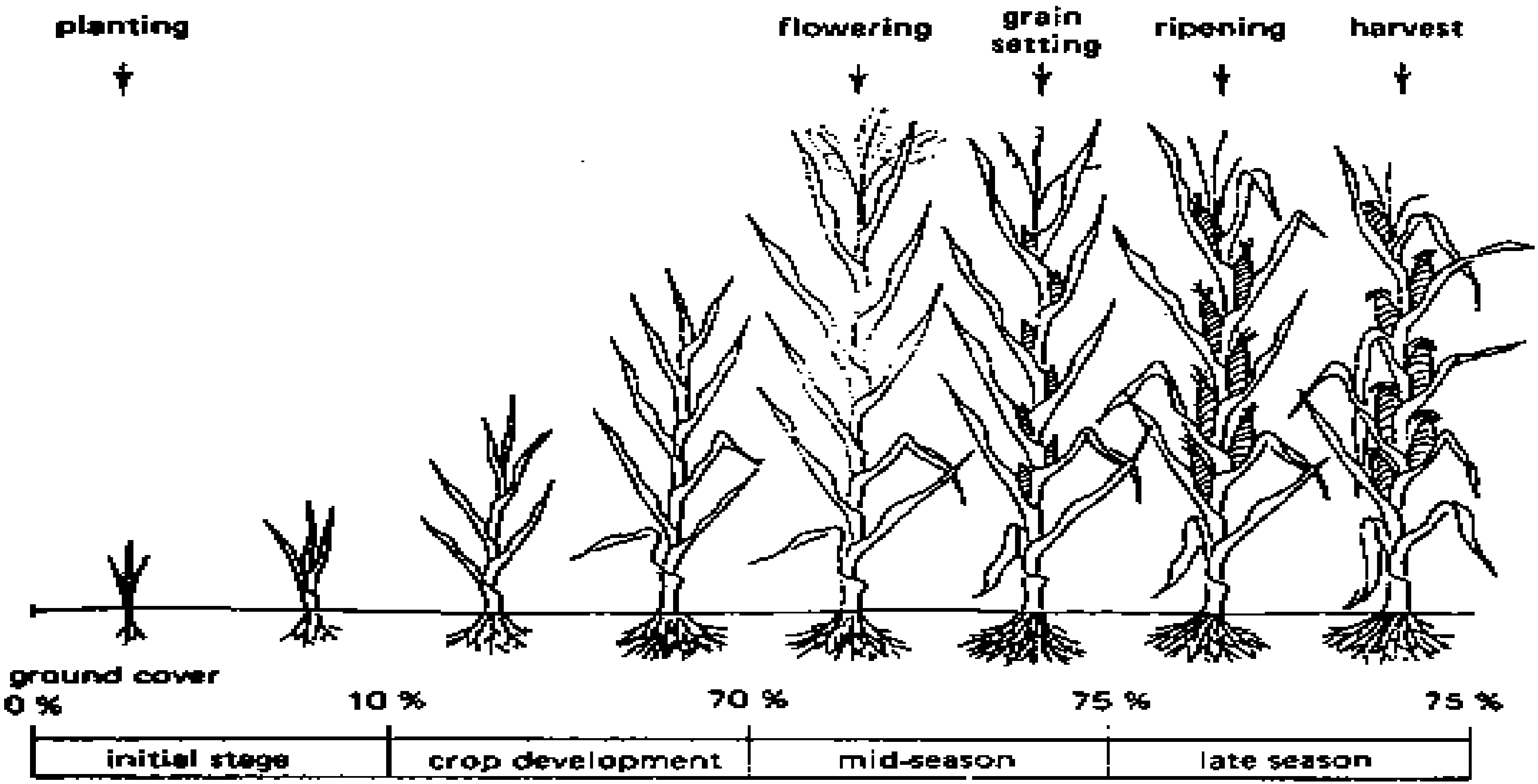

Fig. 2.6 Growth stages of a crop

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D. Influence of local conditions and agricultural practices

This includes:

- ☞The variation in climate over time
- ☞Size of field
- ☞Distance and altitude
- ☞Soil water availability
- ☞ Irrigation and cultivation methods and practices.

2.4.2 Determination of Consumptive Use of water

- Under normal field conditions PET (ETo) will not occur and thus consumptive use (ETcrop) can be determined by determining the ETo and multiplying with suitable crop coefficients (Kc).

1. Direct Measurement of Consumptive Use

a. Lysimeter-Experiment

- Lysimeters are large containers having pervious bottom.
- This experiment involves growing crops in lysimeters there by measuring the water added to it and the water loss (water draining) through the pervious bottom.
- Consumptive use is determined by subtracting the water draining through the bottom from the total amount of water needed to maintain proper growth.
- ETc = IR + Eff.P + –soil moisture- Drainage

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b. Field experimental plots

- This is most suitable for determination of seasonal water requirements.
- Water is added to selected field plots, yield obtained from different fields are plotted against the total amount of water used.
- The yield increases as the water used increases for some limit and then decreases with further increase in water.
- The break in the curve indicates the amount of consumptive use of water.

c. Soil moisture studies

- Soil moisture measurements are done before and after each irrigation application.

Cont…

- Knowing the time gap b/n the two consecutive irrigations, the quantity of water extracted per day can be computed by dividing the total moisture depletion b/n the two successive irrigations by the interval of irrigation.
- Then a curve is drawn by plotting the rate of use of water against the time from this curve, seasonal water use of crops is determined.

d. Water Balance method

- The method consists of assessing the incoming and outgoing water flux into the crop root zone over some time period.

Cont…

- Irrigation (I) and rainfall (P) add water to the root zone.
- Part of I and P might be lost by surface runoff (RO) and by deep percolation (DP) that will eventually recharge the water table.
- Water might also be transported upward by capillary rise (CR) from a shallow water table towards the root zone or even transferred horizontally by subsurface flow in (SF_{in}) or out of (SF_{out}) the root zone.

Based on inflow – outflow – storage principle.

$$ET = I + P - RO - DP + CR \pm \Delta SF \pm \Delta SW$$

where: I - Irrigation

P – rainfall

RO - Runoff

CR – capillary rise

DP – Deep percolation

SF – subsurface flow & SW – soil water content

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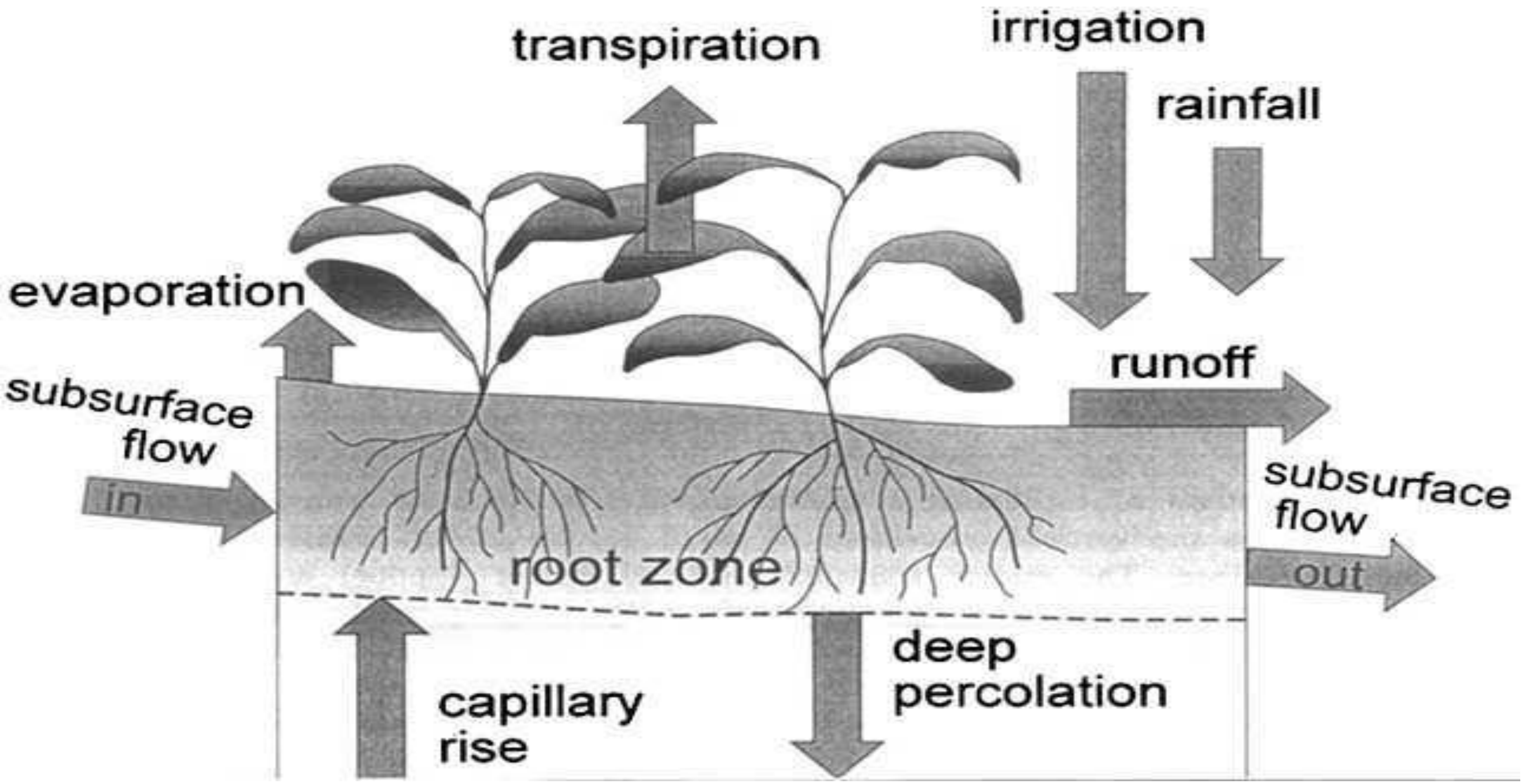

[Figure 2.7 Soil water balance of the root zone](#)

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2. Determination of Evapotranspiration using Empirical equations

❖ Owing to difficulty in accuracy field measurments, ETo is generally determine by experiment, theoretical, on the basis of climatological data.

❖ Most of the emperical formula are:

1. Balney-Criddle Method
2. Thornthwaite Method
3. Hargreaves class A pan Evaporation
4. Hargreave's Method
5. FAO Penman Method
6. Modified Penman Method

The choice of the method must be based on:-

☞ the type of climatic data available and

☞ on the accuracy required in determining water needs.

Cont…

1. Blanney- Criddle method

- This method is suggested where only temperature data are available.
- $ETo = \sum C[\, P\, (0.46T_m + 8)]$ mm/day

Where

ETo= reference crop evapotranspiration in mm/day for the month considered.

T_m= mean daily temperature in ^{o}c over the month

P = mean daily percentage of total annual day time hours obtained from table for a given month and latitude.

C = adjustment factor which depends on minimum relative humidity, sunshine hours and daytime wind estimates

- **Limitation:** This method is an approximate method , since it doesn't consider a number of important factors such as humidity , wind velocity and altitude

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Table 2.2: Monthly day time percentage hours (P) to be used by Blaney-Criddle

Lat. ºN	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
0	8.50	7.66	8.49	8.21	8.50	8.22	8.50	8.49	8.21	8.50	8.22	8.50
10	8.13	7.47	8.45	8.37	8.81	8.60	8.86	8.71	8.25	8.34	7.91	8.10
15	7.94	7.36	8.43	8.44	8.98	8.80	9.05	8.83	8.28	8.26	7.75	7.88
20	7.74	7.25	8.41	8.52	9.15	9.00	9.25	8.96	8.30	8.18	7.58	7.66
25	7.53	7.14	8.39	8.61	9.33	9.23	9.45	9.09	8.32	8.09	7.40	7.42
30	7.30	7.03	8.38	8.72	9.53	9.49	9.67	9.22	8.33	7.99	7.19	7.15
35	7.05	6.88	8.35	8.83	9.76	9.77	9.93	9.37	8.36	7.87	6.97	6.86
40	6.76	6.72	8.33	8.95	10.02	10.08	10.22	9.54	8.39	7.75	6.72	6.52
42	6.63	6.65	8.31	9.00	10.14	10.22	10.35	9.62	8.40	7.69	6.62	6.37
44	6.49	6.58	8.30	9.06	10.26	10.38	10.49	9.70	8.41	7.63	6.49	6.21
46	6.34	6.50	8.29	9.12	10.39	10.54	10.64	9.79	8.42	7.57	6.36	6.04
48	6.17	6.41	8.27	9.18	10.53	10.71	10.80	9.89	8.44	7.51	6.23	5.86
50	5.98	6.30	8.24	9.24	10.68	10.91	10.99	10.00	8.46	7.45	6.100	5.65

Cont…

- **Example 2.1**: Determine for the month April the mean ETo in mm/day using the Blaney-Criddle method with given Latitude of 35° North, T max in April = 29.5°C, T min in April = 19.4°C.

Answer

Step 1: determine T mean= $\frac{T_{max}+T_{min}}{2}=\frac{29.5+19.4}{2}=24.5$

Step 2: determine p at Latitude=35°North, Month: April From Table : p = 8.83

Step 3: calculate ETo = p (0.46 T mean + 8)

ETo = 8.83 (0.46 × 24.5 + 8)=170 mm/day.

➢ Thus the mean reference crop evapotranspiration ETo =170 mm/day during the whole month of April.

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- **Example 2.2**: Use Blaney-Criddle method to calculate consumptive use (PET) for rice crop grown from January to March (Dalua Rabi crop) in Orissa at a latitude 22^0 N from the following data taken from a nearby observatory. Find the net irrigation demand for rice using the given rainfall during crop period.

Month	*January*	*February*	*March*
Mean temperature ^0C	*12*	*16*	*24*
Rainfall (mm)	*8*	*20*	*16*

- For rice crop, monthly crop coefficient K of may be taken as 1.10.

2. Thornthwaite method

- Thornthwaite (1948) developed an exponential relationship between mean monthly temperature and mean monthly consumptive, given as

$$ET_o = 1.62\,R_f\left(\frac{10T_m}{I}\right)^a$$

Where R_f is the reduction factor which can be get from Table
T_m the mean monthly temperature in ^{0}C,
a is a constant can be computed from the relation

$$a = 675*10^{-8}I^3 - 771*10^{-6}I^2 + 0.01792I + 0.492$$

Where I is the annual heat index calculated monthly heat index(i).

$$i = \left(\frac{T_m}{5}\right)^{1.514} \qquad I = \sum_{n=l}^{12} i = \sum_{n=1}^{12}\left(\frac{T_m}{5}\right)^{1.514}$$

Cont…

Table 2.3: Reduction Factor R_f for PET to be used in Thornthwiate's equation

	Month											
Latitude	J	F	M	A	M	J	J	A	S	O	N	D
0^0N	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
10^0N	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
20^0N	0.95	0.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
30^0N	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
40^0N	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81
50^0N	0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.00	0.92	0.76	0.70

- **Example 2.3:** Using ***Thornthwaite*** formulas calculate the consumptive use of rice for the month of February. Take the following data

1. Latitude = 22^0N
2. Mean monthly temperature = 16^0C
3. Assume Rf=0.89

Solution

$$I = i = \left(\frac{T_m}{5}\right)^{1.514} = \left(\frac{16}{5}\right)^{1.514} = 5.818$$

a =0.493 + 0.01792 x 5.818 –0.0000771 x 5.818^2 + $6.75*10^{-8}*$ 5.818^3 =0.493 + 0.1043 – 0.0026 = 0.594

$$ET_o = 1.62 R_f \left(\frac{10T_m}{I}\right)^a = 1.62*0.895*\left(\frac{10*16}{5.818}\right)^{0.594}$$

Eto = 10.38269mm/month

3. Hargreaves class A pan Evaporation

Hargreaves Class A pan evaporation method. In this method, evapotranspiration (consumptive use) is related to pan evaporation by a constant K, called *consumptive use coefficient.* The formula can be written as

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

or

$$\boxed{E_t \text{ or } C_u = K \cdot E_p}$$

Consumptive use coefficient (K) is different for different crops and is different for the same crop at different places. It also varies with the crop growth, and is different at different crop stages for the same crop. The above relationship is now available for various crops from many countries such as Israel, Philippines, U.S.A. and India. Research stations constantly go on reporting more and more data. Where specific data are not available, average values can be used as recommended by Hargreaves, and given in Table The crops have been divided into 8 groups and the coefficients have been suggested for average conditions of soil, etc.

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

(*i*) *Group A*. The important crops include :

Sugar, Beats, Maize, Cotton, Jowar, Bean, Peas, Potatoes, etc.

(*ii*) *Group B*. This group consists of deciduous fruits and some field crops. Important crops are :

Tomatoes, Hybrid Walnuts, Plumes, Olives, and some group *A* crops that fail to produce maximum vegetative cover and maximum growth ratios.

(*iii*) *Group C*. $\frac{E_t}{E_p}$ ratios are of the order of 0.6. It includes crops like Melons, Onions, Carrots, Hops, Grapes, etc.

(*iv*) *Group D*. The maximum $\frac{E_t}{E_p}$ ratio is about 0.90 and usually occurs at about 75 to 80% completion of crop vegetative cycle. The important crops are :

Wheat, Barley, Celery, Flax and other small grains, etc.

(*v*) *Group E*. Ratios of $\frac{E_t}{E_p}$ vary from 0.7 to 1.10. The model value being 0.90. The important crops are :

Pastures, Orchard with cover crop, Plantain, etc.

(*vi*) *Group F*. It includes citrus crops such as Oranges, Grape fruit, etc. The $\frac{E_t}{E_p}$ ratios are fairly constant throughout the year and average to a value of about 0.60.

(*vi*) *Group G*. $\frac{E_t}{E_p}$ values generally increase with crop and vary from 0.66 to 1.00. It includes *Sugarcane and Alfalfa*.

(*viii*) *Paddy or Rice*. $\frac{E_t}{E_p}$ increases from 0.80 to 1.30, with crop growth and then falls down, reaching its maximum value somewhere near 50% growth, as shown in Table

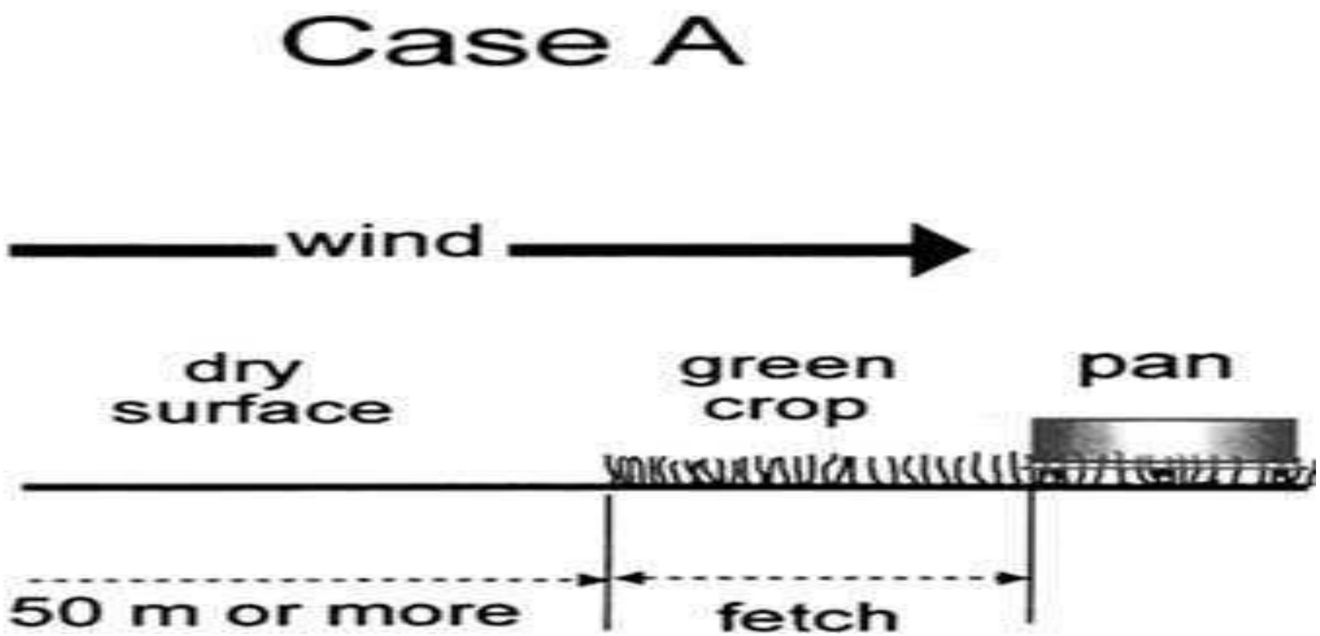
Cont…

Determination of Ep

- ✓ E_{pan} can be experimental determined by directly measuring the quantity of water evaporated from standard class pan A.
- ✓ This pan is 1.2m in diameter, 25cm in deep & bottom is raised 15cm above the ground surface. The depth of water is kept in fixed range (5 to7.5cm) below the top of the pan.

❖In selecting the appropriate pan coefficient, not only the pan type, but also the ground cover in the station, its surroundings as well as the general wind and humidity conditions, should be checked.

❖Case A where the pan is sat on a short green (grass) cover and surrounded by fallow soil



❖It can be determined by:

a. Experimentally

b. Christiansen formula

$E_p = 0.459R * C_t*C_w*C_h*C_s*C_e$, Where,

R= Etra-territsterial radiation in cm or mm(from Table)

Ct = Coefficient for temperature

$Ct = 0.393 + 0.02796T_m + 0.0001189\ T_m^2$

T_m= mean temperature, °c

Cw = Coefficient for wind velocity

$Cw = 0.708 + 0.0034\ v - 0.0000038\ v^2$

v=mean wind velocity at 0.5ms above the ground, km/day.

Ch= Coefficient for relative humidity.

$Ch = 1.250 - 0.0087H - 0.75*10\text{-}4H^2 - 0.85*10\text{-}8H^4$

H= mean percentage relative humidity at noon

Cs= Coefficient for percent of possible sunshine

$Cs = 0.542 + 0.008\ S - 0.78*10\text{-}4\ S^2 + 0.62*10\text{-}6S^3$

S= mean sunshine percentage

Ce= Coefficient of elevation

$Ce = 0.97 + 0.00984E$

E= elevation in 100 meters

Cont…

Table 2.12. Mean Monthly Values of Extra-terrestrial Radiation R in cm.

Latitudes in degrees	*Jan.*	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
North												
45	15.621	19.990	31.953	41.072	50.317	52.146	52.426	46.101	35.204	25.730	16.891	13.843
40	19.609	23.393	35.027	42.926	50.003	52.146	52.730	47.498	37.770	29.312	20.701	17.831
35	23.546	26.670	37.871	44.450	51.384	51.918	52.730	48.565	40.056	32.664	24.460	21.819
30	27.407	29.794	40.411	45.669	51.460	51.384	52.451	49.276	42.037	35.814	28.092	25.781
25	31.140	32.690	42.647	46.558	51.206	50.571	51.841	49.682	43.688	38.710	31.572	29.642
20	34.722	35.382	44.552	47.117	50.597	49.428	50.902	49.708	45.009	41.300	34.900	33.376
15	38.100	37.821	46.126	47.320	49.657	47.980	49.657	49.403	45.989	43.612	37.973	36.906
10	41.250	40.005	47.346	47.168	48.388	46.253	48.082	48.717	46.609	45.593	40.818	40.259
5	44.120	41.885	48.209	46.660	46.787	44.221	46.178	47.701	46.888	47.244	43.409	43.358
0	46.736	43.485	48.692	45.822	44.882	41.910	43.993	46.335	46.812	48.539	45.695	46.177

Example 2 *Determine the pan evaporation from the following data for the month of April, using Christiansen method.*

Latitude 15° 19′ N, Elevation + 449 metres

Month : April.

Mean Temperature 31.8°C.

Mean wind velocity at 0.5 m above the ground = 183 kilometres per day.

Mean relative humidity = 40%

Mean sunshine per cent = 89%

Use tables for extra-terrestrial radiation (Table 2.12). (b) What is the consumptive use for April in this country for a crop having a consumptive use coefficient equal to 0.80.

Solution. Find the value of *R* from Table 2.12 for the month of April and for a latitude of 15° 19′ N. It comes out to be about **47.3 cm.** Now, using eqs. (2.10) to (2.14), we get

$$C_t = 0.393 + 0.02796 \times 31.8 + 0.0001189\,(31.8)^2 = 1.403$$

$$C_w = 0.708 + 0.0034 \times 183 - 0.0000038\,(183)^2 = 1.200.$$

$$C_h = 1.250 - 0.0087 \times 40 + 0.75 \times 10^{4}\,(40)^2 - 0.85 \times 10^{-8}\,(40)^4 = 1.000$$

$$C_s = 0.542 + 0.008 \times 89 - 0.78 \times 10^{-4}(89)^2 + 0.62 \times 10^{-6}(89)^3 = 1.073.$$

$$C_e = 0.97 + 0.00984 \times 4.49 = 1.014.$$

(*a*) Pan evaporation E_p is given by eq. (2.9) as :

$$\mathbf{E_p = 0.459\, R \cdot C_t \cdot C_w \cdot C_h \cdot C_s \cdot C_e}$$

$$= 0.459\,(47.3)\,(1.403)\,(1.200)\,(1.000)\,(1.073)\,(1.014)$$

$$= 39.8 \text{ cm.} \quad \textbf{Ans.}$$

(*b*) $E_t = K \cdot E_p = 0.8 \times 39.8 = 31.84$ cm

Hence, the required value of consumptive use = 31.84 cm. **Ans.**

4. Hargreaves Method

- Potential evapotranspiration (PET) describes the amount of water transpired by a short green crop with a height between 30 and 50 cm (Jensen *et a*l., 1990).
- In a situation where solar radiation, wind speed, relative humidity and other data are completely absent, reference evapotranspiration can also be estimated using the equation stated by Hargreaves and Samani (1982).
- This method has produced good results, because at least 80 percent of ETo can be explained by temperature and solar radiation cited by Samani (2000)
- ΔT is related to humidity and cloudiness (Samani and Pessarakli, 1986).

Cont…

- Thus, although this equation only needs a daily measurement of maximum and minimum temperatures, and is presented here as a temperature-based method, it effectively incorporates measurement of radiation, albeit indirectly.
- For limited meteorological data available area, the Hargreaves PET method, which requires only temperatures was best.
- The Hargreaves method is based on the following equation:

$$ET_O = 0.0023 * R_a * (T_{mean} + 17.8) * \sqrt{(T_{max} - T_{MIN})}$$

Where:

- ***ETO*** is the Reference evapotranspiration (mmd^{-1})
- $\boldsymbol{T_{mean}}$ is the Mean temperature
- **Ra** Extraterrestrial radiation (calculated from latitude and time of year);

Cont…

$$R_a = \frac{24(60)}{\pi} G_{sc} dr \left[\omega_s \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin\omega_s\right]$$

- The corresponding equivalent evaporation in mm day^{-1} is obtained by multiplying Ra by 0.408
  - » i.e. $1MJm^{-2}day^{-1}=0.408mmday^{-1}$
- G_{sc} is the solar constant=$0.082MJ/m^2min$;
- dr is the inverse relative distance (Earth-Sun)

$$dr = 1 + 0.033\cos\left(\frac{2\pi J}{365}\right)$$

- J is the Julian day (i.e. the number of the day in the year between 1(1 January) and 365 or 366 (31 December)
- ωs is the sunset hour angle and is given by:

Cont…

$$\omega_s = \arccos\left[-\tan\varphi \tan\delta\right]$$

- δ is the solar declination, given by:

$$\delta = 0.409 \sin\left(\frac{2\pi J}{365 - 1.39}\right)$$

- φ is the latitude (radians)
- Latitude, φ is positive in the northern hemisphere and negative in the southern hemisphere.

Cont…

5. Penman Method

- Penman developed a theoretical formula based on the principles of both energy budget and mass-transfer approaches to calculate potential evapotranspiration.
- A simple energy budget neglecting all minor losses can be written as:

$$ET = \frac{(\Delta \times H + \gamma \times E_a)}{(\Delta + \gamma)}$$

- Where
- ET the daily evaporation from free water surface in mm/day
- Δ the slope of the saturated vapor pressure vs. temperature curve at mean air temperature given from table ,
- H is the heat budget of an area with crops which is the net radiation in mm of evaporable water per day is & estimated form the relation:

$$H = H_a(1-r)(0.29\cos\phi + 0.55n/N) - \sigma T_a^4(0.56 - 0.092\sqrt{e_a})(0.10 + 0.9n/N)$$

Cont…

- Ha is the extraterrestrial solar radiation received on a horizontal surface in mm of evaporable water per day (whose value for different latitudes are given in **Table**),
- r is the reflection coefficient whose values for close crops may be taken as 0.15-0.25, for barren land 0.05-0.45 and for water surface 0.05,

ϕ the latitude of the place where ETo is to be computed,

- n is the actual duration of bright sunshine which is a function of latitude and is an observed data at a place,
- N is the maximum possible hours of bright sunshine available at different location (**given in Table**),

σ is the Stefan-Boltzman constant = 2.01×10^{-9} mm/day, T

- T_a is the mean air temperature in $^oK = (273 + ^0C)$

γ is a constant (called psychometric constant whose value is 0.49 mmHg/^{0}C or 0.66 mb/^{0}C,

Cont…

- Ea is the drying power of air which includes wind velocity and saturation deficit and is estimated form the relation:

$$E_a = 0.35\left(1 + \frac{V_2}{160}\right)(e_s - e_a)\ \text{mm/day}$$

- u_2 is the mean wind speed in km/day measured 2 m above the ground,
- e_s is saturation vapor pressure at mean air temperature in mm Hg (**given in Table**)
- e_a is actual vapor pressure in the air in mm of mercury

$$e_a = RH^* e_s$$

and

- ➢ The relation that can reduce the wind speed measured at any other height z to 2 m height is given by:

$$u2 = u\left(\frac{2}{z}\right)^{0.143}$$

Table 2.4: Saturation vapour pressure of water

Temperature (°C)	Saturation vapour pressure e_s mmHg)	mbar	Slope of plot between (1) and (2)
(1)	(2)	(3)	(4)
0.0	4.58	6.11	0.30
5.0	6.54	8.72	0.45
7.5	7.78	10.37	0.54
10.0	9.21	12.28	0.60
12.5	10.87	14.49	0.71
15.0	12.79	17.05	0.80
17.5	15.00	20.00	0.95
20.0	17.54	23.38	1.05
22.5	20.44	27.95	1.24
25.0	23.76	31.67	1.40
27.5	27.54	36.71	1.61
30.0	31.81	42.42	1.85
32.5	36.68	48.89	2.07
35.0	42.81	57.07	2.35
37.5	48.36	64.46	2.62
40.0	55.32	73.14	2.95
42.5	62.18	84.23	3.25
45.0	71.20	94.91	3.66

Table 2.5: Mean daily maximum duration of bright sunshine hour N for different month and latitudes (Doorenbos & Pruitt, 1977)

N Lat S Lat	Jan July	Feb Aug	March Sept	April Oct	May Nov	June Dec	July Jan	Aug Feb	Sept March	Oct April	Nov May	Dec June
50	8.5	10.1	11.8	13.6	15.4	16.3	15.9	14.5	12.7	10.8	9.1	8.1
48	8.8	10.2	11.8	13.8	15.2	16.0	15.6	14.3	12.6	10.9	9.3	8.3
46	9.1	10.4	11.9	13.5	14.9	15.7	15.4	14.2	12.6	10.9	9.5	8.7
44	9.3	10.5	11.9	13.4	14.7	15.4	15.2	14.0	12.6	11.0	9.7	8.9
42	9.4	10.6	11.9	13.4	14.6	15.2	14.9	13.9	12.9	11.1	9.8	9.1
40	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.3
35	10.1	11.0	11.9	13.1	14.0	14.5	14.3	13.5	12.4	11.3	10.3	9.8
30	10.4	11.1	12.0	12.9	13.6	14.0	13.9	13.2	12.4	11.5	10.6	10.2
25	10.7	11.3	12.0	12.7	13.3	13.7	13.5	13.0	12.3	11.6	10.9	10.6
20	10.0	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
15	11.3	11.6	12.0	12.5	12.8	13.0	12.9	12.6	12.2	11.8	11.4	11.2
10	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
5	11.8	11.9	12.0	12.2	12.3	12.4	12.3	12.3	12.1	12.0	11.9	11.8
0	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1

Table 2.6: Mean Monthly Solar Radiation Incident on Earth's Outer Space (Extra Terrestrial Radiation) in mm of Evaporable Water per day

	North Latitude in Degrees									
Month	0^{o}	10^{0}	20^{0}	30^{0}	40^{0}	50^{0}	60^{o}	70^{o}	80^{0}	90^{o}
Jan.	14.5	12.8	10.8	8.5	6.0	3.6	1.3	-	-	-
Feb.	15.0	13.9	12.3	10.5	8.3	5.9	3.5	1.1	-	-
Mar.	15.2	14.8	13.9	12.7	11.0	9.1	6.8	4.3	1.8	-
Apr.	14.7	15.2	15.2	14.8	13.9	12.7	11.1	9.1	7.8	7.9
May	13.9	15.0	15.7	16.0	15.9	15.4	14.6	13.6	14.6	14.9
Jun.	13.4	14.8	15.8	16.5	16.7	16.7	16.5	17.0	17.8	18.1
Jul.	13.5	14.8	15.7	16.2	16.3	16.1	15.7	15.8	16.5	16.8
Aug.	14.2	15.0	15.3	15.3	14.8	13.9	12.7	11.4	10.6	11.2
Sep.	14.9	14.9	14.4	13.5	12.2	10.5	8.5	6.8	4.0	2.6
Oct.	15.0	14.1	12.9	11.3	9.3	7.1	4.7	2.4	0.2	-
Nov.	14.6	13.1	11.2	9.1	6.7	4.3	1.9	0.1	-	-
Dec.	14.3	12.4	10.3	7.9	5.5	3.0	0.9	-	-	-

Cont…

Example 2.4: Using Penman's formulas compute the consumptive use(Cu) from a drainage basin located Gurgaon(Haryana) during month of April of rice. ***The following data is given:***

- Latitude of the place = 28^0N
- Elevation of the area = 220 m

Metrological observed data during April

- Mean Relative humidity for April = 35%
- Mean monthly temperature = 40^0C
- Mean observed sunshine hour per day =13hr
- Mean Wind velocity measured at 2 m height = 72 km/day

Solution

- **Data available and obtained from table**
- *S*aturated vapour pressure @ 40^0C, e_s = 55.32 mm of Hg
- Slope of e_s vs.T^o curve @ 40^0C (Δ = 2.95 mm of HG/^{0}C
- *Mean monthly solar radiation at the top of atmosphere during April @* 28^0N = *14.9 mm of evaporable water per day*

Cont…

- *Mean monthly possible sunshine hour during April* @28^0N=12.9hr Albedo/ Reflection for the area(r=0.25)

$$E_t = C_u = \frac{A\,H_n + E_a \cdot \gamma}{A+\gamma}$$

where $A = 2.95$ mm of Hg/°C

H_n = to be computed by eq.

E_a = given by

$$= 0.35\left(1+\frac{V_2}{160}\right)(e_s - e_a)\ \text{mm/day}$$

$$= 0.35\left(1+\frac{72}{160}\right)\times(55.32-19.36)$$

$(\because\ e_a = (\text{R.H.})\, e_s$

$= 35\% \times 55.32 = 19.36$ mm Hg

$= 18.07$ mm/day

$\gamma = 0.49$ mm of Hg/°C

Cont…

H_n is given by eqn. (2.16) as :

$$H_n = H_c(1-r)\left(a + b\cdot\frac{n}{N}\right) - \sigma\cdot T_a^4\,(0.56 - 0.092\sqrt{e_a}) \times \left(0.10 + 0.90\,\frac{n}{N}\right)$$

where H_c = mean monthly incident solar radiation at top of atmosphere

$= 14.9$ mm of evaporable water/day

$r = 0.25$

$a = 0.29\cos\phi = 0.29\cos 28° = 0.256$

$b = 0.52$

$n = 13$ h

$N = 12.9$ h

$\sigma = 2.01\times10^{-9}$ mm/day

$T_a = (40°C + 273) = 313°K$

$e_a = (R.H.)\,e_s = 35\% \times 55.32$

$= 19.36$ mm of Hg

Prepared by: Tegegn T.

Cont…

Substituting values, we get

$$H_n = 14.9\,(1 - 0.25)\left[0.256 + 0.52 \times \frac{13}{12.9}\right] -$$

$$\left[\{2.01 \times 10^{-9} \times (313)^4\} \times \{0.56 - 0.092\sqrt{19.36}\} \times \left\{0.10 + 0.90 \times \frac{13}{12.9}\right\}\right]$$

$$= 14.9\,(0.75)\,(0.78) - (19.292)\,(0.155)\,(1.007)$$

$$= 8.716 - 3.011$$

$= \mathbf{5.705}$ mm of evaporative water/day

Now, $C_u = \dfrac{AH_n + E_a\gamma}{A + \gamma}$

$$= \frac{2.95 \times 5.705 + 18.07 \times 0.49}{2.95 + 0.49}$$

$$= \frac{49.648 + 8.854}{3.44} = \mathbf{17.01\ mm/day.}$$ **Ans.**

Cont…

6. Modified Penman Method

- ❖ A slightly modified penman equation from the original (1948) is suggested here to determine ETo involving a revised wind function term.
- ❖ The method uses mean daily climatic data, since day and night time weather conditions considerably affect level of ET; an adjustment for this is included.
- The modified penman equation is ,
  - ETo = c (W*Rn + (1 – W) * F(u).* (ea – ed))

Where:

- ETo = reference crop evapotranspiration ,mm/day
- W = temperature – related weighting factor
- Rn = net radiation in equivalent evaporation in , mm/day
- F(u) = Wind – related function

Cont…

- (ea-ed) = difference between the saturation vapor pressure at mean air temp. and the actual mean vapor pressure of the air in mm bar.
- C = adjustment factor to compensate for the effect of day and night weather conditions.

❖ For areas where measured data on temperature, humidity, wind and sunshine duration or radiation are available, the penman method is suggested.

2.5 Duty-Delta Relationship

Crop period and Base period

- ***Crop period is*** the time period that elapses from the instant of its *sowing to the instant of its harvesting.*

- ***Base period*** is the time between the *first watering of a crop* at the time of its sowing to its *last watering before harvesting*.

- Crop period is slightly more than the base period, but for all practical purposes, they are taken as one and the same thing and both are expressed in days.

- ***Frequency of irrigation*** is the time interval between *two consecutive watering.*

Cont…

Duty and Delta of Crops

- **Duty (D):** is defined as the area of the land which can be irrigated if one cumec (m^3/sec) of water was applied to the land continuously for the entire base period of the crop.

❖ It is expressed in hectares / cumecs

- **Delta (Δ):** is the total depth of water required by a crop during the entire base period.

❖ Delta included not only consumptive use of water for a crop but also the water lost by evapotranspiration and seepage from canals, and deep percolation in the field.

$$\text{Delta } (\Delta) = \frac{\text{Total quantity of water (ha-m)}}{\text{Total area of land (ha)}}$$

Cont…

- The relation between duty, base period and delta, can be obtained as follows:-
- Considering the area of land of D-hectares, base period of B days

  *Quantity of water= 1*B*24*60*60, m³* .... (1)

  $$Quantity\ of\ water = 1*B*24*60*60,\ m^3 \quad \ldots (1)$$

- If Delta (Δ) is the total depth of water in meters supplied to the land of D- hectares, the quantity of water is also given by:

  $$Quantity\ of\ water = (D*10^4)*\Delta,\ m3 \quad \ldots (2)$$

- Equating the volumes of water given in eqn-s 1 and 2:

  $$1*B*24*60*60* = (D*10^4)*\Delta$$

$$D = \frac{8.64B}{\Delta} \quad \text{or} \quad \Delta = \frac{8.64B}{D}$$

Where D = in ha/cumec
Δ = in m &
B = in days

Cont…

Different forms of Duty

***1.Flow duty*:**

☞In the case of irrigation from irrigation canals, the duty is expressed as the total area of the land which can be irrigated per unit cumec of water was supplied to the land.

☞ If duty and the area of land to be irrigated are known, the required discharge in the canal can be determined.

$$Discharge(m^3/s) = \frac{Area(ha)}{Duty(ha/cumec)}$$

2. *Quantity Duty*

☞For Tank /pond irrigation, the duty is usually expressed as the total area of land which can be irrigated per million m^3 of water stored in the tank. If the duty and the area to be irrigated are known, the volume of water to be stored in the tank can be determined.

$$Volume(Mm^3)\frac{Area(ha)}{Duty(ha/Mm^3)}$$

Cont…

3. *Delta Duty:*

☞It can be expressed in terms of the total depth (i.e. delta) of water required for a crop.

☞It is another form of the quantity duty because the total depth is equal to the volume divided by the area of land.

$$Delta(m) = \frac{Volume(ha - m)}{Area(ha)}$$

Cont…

Factors affecting Duty

- **Type of crop**

☞ Different crops require different amount of water, hence, the duties for them are different.

☞ Duty will be less for a crop requiring more water and vice versa.

- **Climate and season**

☞ Duty varies from season to season and also from time to time and same season.

☞ When the temperature of the command area is high the evaporation loss is more and the duty becomes low and vice versa.

- **Slope of ground**

☞ If the slope is steep duty is less and if the slope is flat duty will be more.

Cont…

- **Type of soil**

☞ If the permeability of the soil is high, more water lost due to percolation and hence duty of water will be less.

☞ For a sandy soil, permeability is more, the duty of water is less.

- **Useful rainfall**

☞ If the amount of RF is more in the base period of a crop the amount of irrigation water is required will be less and duty will be high. B/s the amount of rain fall fulfils part of the total requirement of the crop.

- **Efficiency of cultivation**

☞ If cultivation method is faulty and less efficient, resulting in the wastage of water and hence duty will be less.

- **Condition, type and location of canal**

☞ If the canal is in good condition and properly maintained the duty is more compared to that in different condition and poorly maintained.

Cont…

- **<u>Example 2.5</u>:** 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.
- Solutions: Water is required at an interval of 10 days for a period of 120 days. It evidently means that 12 no. of watering are required and each time, 10 cm depth of water is required. Therefore total depth of water required

$$\Delta = 12 \times 10 \text{ cm} = 120 \text{ cm}$$

Hence Δ for rice = 120 cm

- **<u>Example 2.6</u>:** If wheat requires about 7.5 cm of water after every 28 days, and the base period for wheat is 140days, find out the value of delta for wheat.
- Solutions : Assuming the base period to be representing the crop period as per usual practice, we can easily infer that the water is required at an average interval of 28 days up to a total period of 140 days.

- This means that $\frac{140}{28}$ =5 no. of watering are required.
  - The depth of water required each time = 7.5 cm
  - Total depth of water required in 140 days = 5x7.5 cm = 37.5 cm
  - Hence, Δ for wheat = 37.5 cm

Cont…

•**Example 2.7 :** A discharge of 15 cumecs is released at the head of the canal. If the duty at the field is 1800 ha/cumecs, and the losses in the transit are 30%, determine the area that can be irrigated.

Solution:

Discharge at field= 0.7*15=10.5 cumecs

Irrigated area(A)=D*Q=1800 * 10.5= 18,900ha

- **Example 2.8:** 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

- Δ (cm) = $\frac{864B}{D}$ where B is in days and D is in hectares/ cumec
- In this question, B = 120 days and D = 864 hectares/cumec

$$\Delta = \frac{864x120}{864} = 120\ cm$$

2.6 Irrigation Efficiencies

- **Not all water** taken from a source (river, well) reaches the root zone of the plants.
- Part of the water is lost during transport through the canals and in the fields.
- The remaining part is stored in the root zone and eventually used by the plants.
- In other words, only part of the water is used efficiently, the rest of the water is lost for the crops on the fields that were to be irrigated.
- Efficiency is the ratio of the water output to water input.

Cont…

1. Water Conveyance efficiency (Ec)

- Is the ratio of the water delivered into field from the out let point of the channel to the water entering into the channel at its starting point.
- This term is used to measure the efficiency of water conveyance system associated with the canal network, water courses and field channels.
- It is expressed as follows:

$$E_c = \frac{W_f}{W_d} * 100$$

Where E_c = water conveyance efficiency , %

W_f = Water delivered to the irrigated plot (At the field supply channel)

W_d = Water diverted from the source

Cont…

2. Water application Efficiency (Ea)

❖Is the ratio of the quantity of water stored in the root zone of the crops to the quantity of water actually delivered into the field.

❖After the water reaches the field supply Channel, it is important to apply the water as efficiently as possible.

❖A measure of how efficiently this is done is the water application efficiency.

$$E_a = \frac{W_s}{W_f} * 100$$

Where E_a = application efficiency, %

W_s = water stored in the rot zone of the plants.

W_f = Water delivered to the irrigated plot (At the field supply channel)

Cont…

- Water application efficiency below 100 percent are due to seepage looses from the field distribution channels, deep percolation below the crop root zone and runoff loses from the tail end of borders and furrows (in very long fields).

3. Water storage efficiency (E_s)

➢Is the ratio of water stored in the plant root zone during irrigation to the water needed in the root zone prior to irrigation,(field capacity-existing moisture content.)

$$E_s = \frac{W_s}{W_n} * 100$$

Where E_s = Water storage efficiency, %

W_s= Water stored in the root zone of the plants

W_n = Water needed in the root zone prior to irrigation

Cont…

4. Field Canal Efficiency (E_f)

❖Is the ratio between water received at the field inlet and that received at the inlet of the block of fields.

$$E_f = \frac{W_p}{W_f}$$

where E_f = Field canal efficiency
W_p = water received at the field inlet
W_f = water delivered to the field channel

5. Water distribution efficiency(Ed)

➢This shows how uniformly water is applied to the field along the irrigation run.

$$E_d = (1 - \frac{d}{D}) * 100$$

Where E_d = water distribution efficiency, %
D = average depth of water penetration.
d= average deviation from d.

6. Consumptive use Efficiency (E_{Cu})

❖ Is the ratio of consumptive water use by crop of irrigated farm to water stored in the root zone of soil on the farm or project area.

$$E_{CU} = \frac{W_{cu}}{W_S} * 100$$

Where E_{cu} = Consumptive efficiency

W_{cu} = water consumed by crop during its growth in an Irrigation project

W_s = Water stored in the root zone of the plants

Cont…

7. Project Efficiency (E_i)

- It shows the percentage of the total water consumed by the crops of farm, field or project to the water delivered from source of supply.
- It indicates the overall efficiency of the systems from the head work to the final use by plants for Cu.
- The Overall project efficiency must be considered in order to fix the amount of water required at the Diversion head work.

$$E_i = \frac{W_c}{W_d} * 100$$

Where E_i = Irrigation or project efficiency

W_c = water consumed by crop during its growth in an Irrigation

W_d = water delivered to the field during the growth stage period of crops

Example 2.9

- The base period, duty of water and area under irrigation for various crops under a canal system are given in the table below. If the losses in the reservoir and canals are respectively 15% & 25%, determine the reservoir capacity.

Crop	Wheat	Sugar cane	Cotton	Rice	V. table
Base period B (days)	120	320	180	120	120
Duty,D (ha/cumec)	1800	1600	1500	800	700
Area irrigated (ha)	15000	10,000	5000	7500	5000

Cont…

Exercise 2.1

- A stream of 130 lit /sec was diverted from the diversion headwork and 100lit/sec are delivered to the field. An area of 1.6 ha was irrigated in 8 hrs. The effective root zone depth is 1.70m. The runoff loss in the field was 420m3.The depth of water penetration was 1.70m and 1.10m at the head and tail of the run respectively. The available moisture holding capacity of the soil is 20cm per meter depth of soil. Irrigation was started at a moisture extraction level of 50% of the available moisture. It is required to determine the Ec, Ea, Es and Ed.

Exercise 2.2

- Workout irrigation(project) efficiency if water conveyance and deliver loss=40%, deep percolation and surface runoff in farm=30%, and water storage in the soil lost by evaporation=20%.

2.7 Estimating depth & Scheduling of Irrigation on the basis of soil moisture

2.7.1 Soil Moisture Irrigation relation ship

1. Saturation Capacity

- ❖ When all macro and micro pore spaces are filled with water, the soil is said to have reached its Saturation Capacity.
- ❖ It is maximum moisture holding capacity of soil/upper limit of possible moisture contents.

2. Field Capacity

- ➢ After irrigation is stopped, part of water held in the larger pores moves downward.
- ➢ At field capacity, the macro pores are field with air & water whereas smaller pores are stilled full with water.
- ➢ Field capacity is the upper limit of the available soil moisture.

Cont…

- The water and air content of the soil at filed capacity are highly conductive for the crop growth.

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

3. Permanent Wilting Point:

➢Is the moisture content beyond which plants can no longer extract enough moisture and remain wilted unless water is added to the soil.

➢At PWP the plant starts wilting and if no water is given to the plant, and then it will die.

4. *Available Water*

❖Is amount of water in the soil at any time in excess of wilting point.

❖It is a measure of availability of maximum quantity of water for use by plant without replenishment.

Prepared by: Tegegn T.

Cont…

5. ***Readily available moisture:*** - is the portion of available moisture that is most easily extracted by plants.

- It varies from 70 to 80%nof available moisture.

***6. Optimum moisture content*: -**

7. Root zone depth: **-** is the depth below the ground surface in which the crops develop root system to drive water for growth.

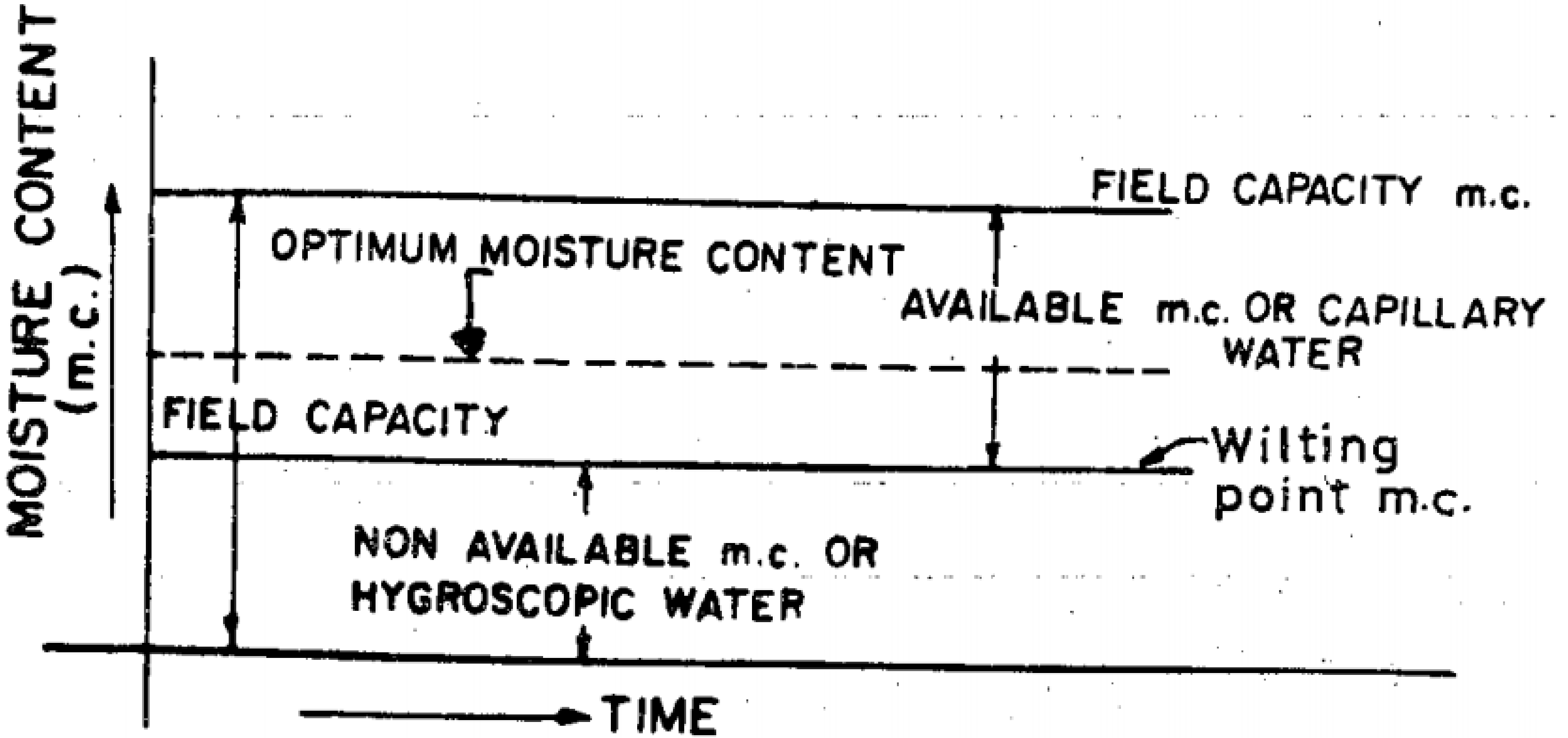
8. Depth of water stored in root zone: **-** is the depth of water stored in root zone of soil containing water up to field capacity.

$$F = \frac{Weight of\ water retained in unit area of\ soil}{Weight of\ soil of\ unit area}$$

Cont…

$$F = \frac{Weight\ of\ water\ retained\ in\ unit\ area\ of\ soil}{\gamma_s * 1 * d}$$

$$Depth\ of\ water\ stored\ in\ unit\ area = \frac{F * \gamma_s * d}{\gamma_w}$$



Cont…

2.7.2 Estimating depth & Scheduling of Irrigation

- Water is not applied randomly at any time and in any quantity.
- Irrigation scheduling is the schedule in which water is applied to the field.
- It is an important aspect of an efficient operation of an irrigation system.
- The two scheduling parameters of irrigation scheduling are the *depth of irrigation* and *interval of irrigation.*

Depth of irrigation (d):

➢ This is the depth of irrigation water that is to be applied at one irrigation.

➢ It is the depth of water that can be retained in the crop root zone b/n the field capacity and the given depletion of the available moisture content.

Cont…

- All the water retained in the soil b/n FC and PWP is not readily available to crops.
- The readily available moisture is only some percentage of the total available moisture.
- The depth of water to be stored in the root zone during each irrigation is to replenish the soil moisture to field capacity.

The depth of irrigation (d) is given by :

$$d(net) = \frac{d * \gamma_s * (FC - Mo)}{\gamma_w} \text{ , } m$$

Where γ_s = Apparent specific gravity of soil

d = Effective root zone depth in m

FC = water content of soil at FC

MO = Optimum moisture content

γ_w = Apparent specific gravity of water

Cont…

- Because of application losses such as deep percolation and runoff losses, the total depth of water to be applied will be greater than the net depth of water.

$$d\,(gross) = \frac{d(net), m}{Ea}$$

- Where Ea = Field application efficiency and other parameters as defined above

Interval of irrigation (i):

- The interval of irrigation is the *time gap* in days between two successive irrigation applications.
- It depends on the type of the crop, soil type and climate conditions.
- Thus interval of irrigation depends on the consumptive use rate of the crop and the amount of readily available moisture (RAM) in the crop root zone.

Cont…

❖The consumptive use rate of the crop varies from crop to crop and also during different stages of the crop.

❖The RAM moisture also varies from soil to soil depending on soil water constants.

- *The interval (frequency) of irrigation is given by i (days)*

$$i(days) = \frac{d(net)}{ET_{crop(peak)}}$$

Where: $ET_{crop\ (peak)}$ is the peak rate of crop evapotranspiration in m/day.

❖For the same crop and soil type the $ET_{crop\ (peak)}$ goes on increasing from the initial stage to the development and mid season stage the interval of irrigation will go on decreasing and increasing during late season stage

Cont…

Example 2.10

- ✓ Irrigation is required for a certain crop if root zone depth=100cm, field capacity=22%, wilting point=12%, apparent specific gravity of soil=1.5gm/cm^3. Assume 50% depletion of available moisture before application of irrigation water at field capacity. Determine Depth of water which is stored in the root zone.

Solution

i. Available moisture=Field capacity-PWP=22-12=10%

ii. Readily available moisture at 50% depletion of available moisture=10*50/100=5%

iii. Optimum moisture= Field capacity - Readily available moisture =22-5=17%

Iv Depth of water stored in the root zone

$$= \frac{(F - M_o) * \gamma_s * d}{\gamma_w} = \frac{(0.22 - 0.17) * 1.5 * 100}{1.0} = 6.25\text{cm}$$

Example 2.11

Water was applied to the field having clay loam as soil type. Find out field capacity FC of the soil with the following data:

Depth of root zone = 1.5m

Existing water content = 3%

Dry density of soil = 1.5g/cm^3

Quantity of water applied to the field = 600m^3

Water loss in evaporation = 10%

Area of the field plot = 1000m^2

Assume that no water is lost due to deep percolation.

Cont…

Solution:

i. Weight of water retained in soil=

$$V_W = 600 - \frac{10}{100} * 600 = 540m^3$$

$$\Rightarrow M_W = 540 * \rho_W = 540 * 1g/cm^3 = 540 * 10^6 g$$

ii. Total dry weight of the soil in the root zone

=Area*depth of root zone*Dry density of soil

$=1000m^2*1.5m*1.5*10^6\ g/m^3$

$= 2250*10^6\ g$

$$iii. Weight of\ water\ as \%\ of\ soil\ weight = \frac{540*10^6 g}{2250*10^6 g} * 10 = 24\%$$

iv. Field capacity = Existing water content + % of water retained

= 3% + 24%

=27%

Cont…

Example 2.13

- After how many days you will supply water to soil in order to ensure sufficient irrigation of the given crop, if field capacity of the soil=30%, permanent wilting point=12%, apparent specific gravity of soil=1.25gm/cc, effective root zone =100cm and daily consumptive use of water for given crop = 12.5mm . Assume 50% depletion of available moisture before application of irrigation water at field capacity.

Exercise 2.3

- ✓ Wheat is to be grown in a having field capacity equal to 27% and the permanent wilting point is 13%. Find the storage capacity in 80cm depth of soil, if the dry unit weight of a soil is 14.72kN/m^3. If irrigation water is to be supplied when the average soil moisture fall to 18%, find the water depth required to be supplied water if the field application efficiency is 80%. What is the amount of water needed at canal outlet if the water lost in the water-courses and the field channels is 15% of the outlet discharge? use

Use: $\left[\because \ \gamma_w = 9.81 \text{ kN/m}^3\right]$

2.8 Estimating Crop Water and Irrigation Requirements Using Computer Program

The FAO CROPWAT model

- CROPWAT is a computer programme that can calculate crop water and irrigation requirements from climatic and crop data.
- The programme is interactive in nature.
- In addition, the programme allows the development of irrigation schedules for different management conditions and the estimation of scheme water supply for varying cropping patterns.
- The CROPWAT model is based on a water balance model where the soil moisture status is determined on a daily basis from calculated evapotranspiration and inputs of rainfall and irrigation.

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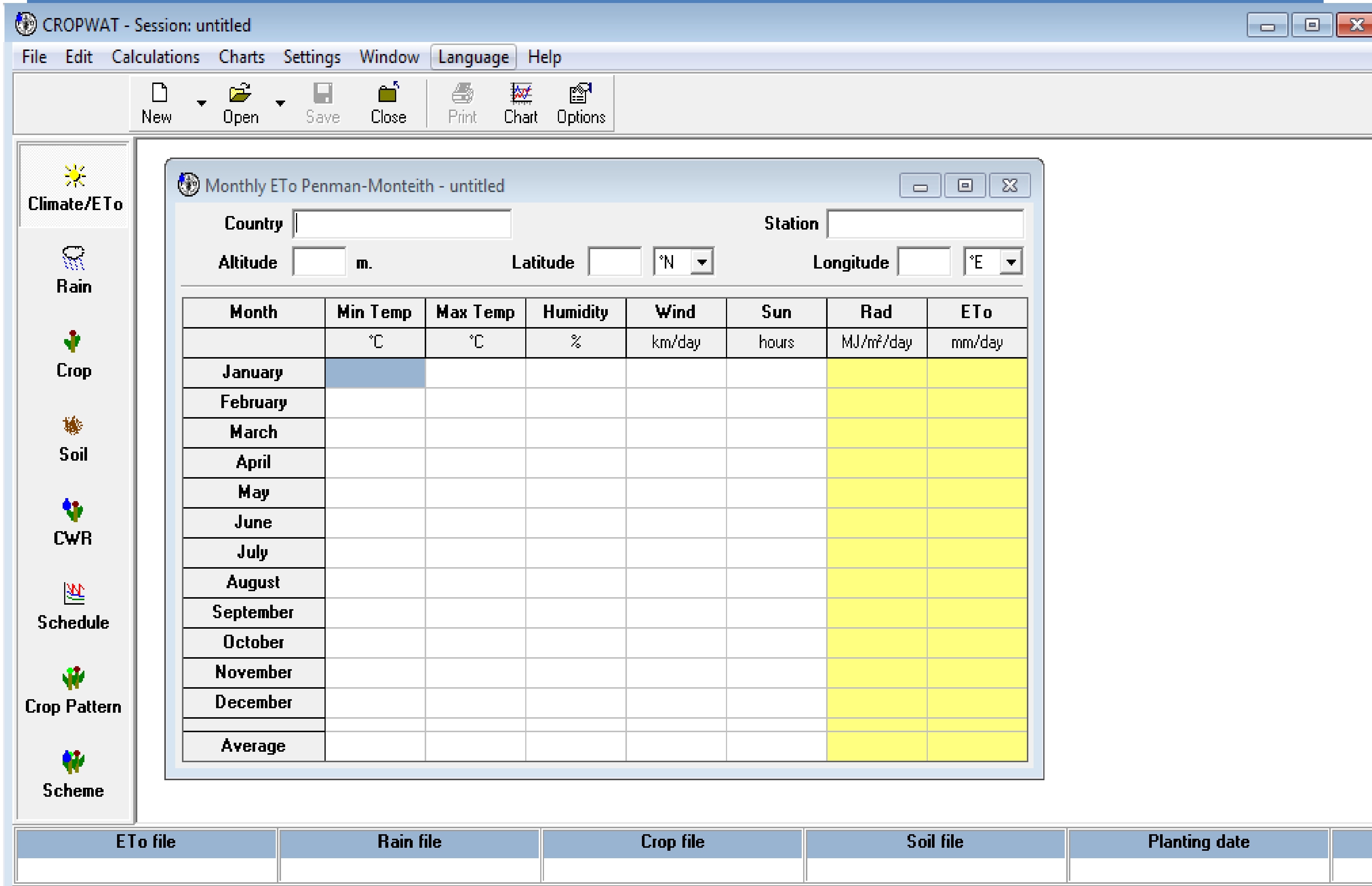
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THANK YOU!!!